Bed Bug Management in Low-Income, Multi-Unit Housing: An Evaluation of Resident Education, and Cost-Effective, Minimally Toxic Suppression Methods

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ABSTRACT

In the United States, we have been battling the bed bug (*Cimex lectularius* L.) resurgence for over ten years. Current treatment methods are labor intensive, time consuming, and very expensive. Many studies have evaluated the efficacy of treatment methods, but few have focused on bed bug suppression in multi-unit housing. Low income, multi-unit housing residents lack basic bed bug knowledge and are particulary vulnerable to bed bug infestations because they are unable to afford conventional treatment. In this study, diatomaceous earth (D.E.), an inexpensive desiccant dust labeled for bed bug control, was evaluated for its efficacy in killing bed bugs, and determined to be successful. A proactive bed bug suppression program that included D.E. was implemented in a low-income housing facility in Harrisonburg, VA. The program consisted of inexpensive, low toxicity, integrated bed bug management methods, including a novel strategy for applying a perimeter barrier of D.E. in apartment units ($n = 121$). Over the course of one year, both the number of initial infestations and the costs associated with bed bug treatments were reduced. Low-income, multi-unit housing residents ($n = 479$) from three cities (Harrisonburg and Richmond, VA; New Orleans, LA) were surveyed before and after an educational seminar to assess their bed bug. After attending the seminar, residents ($n = 112$) significantly improved ($P < 0.0001$) their bed bug knowledge, and were able to correctly answer more bed bug-related questions than they had before the educational seminar.

Dedication

To my family and friends, who have supported me throughout my education.

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Chapter 1. Introduction

Bed bugs (*Cimex lectularius* L.: Hemiptera: Cimicidae) have invaded the United States. In 2010, bed bug infestations were found in movie theaters in both Times Square and Harlem in New York City, as well as in the Elle Magazine headquarters in Manhattan (Paddock 2010). Also in New York City, retail stores, including Victoria's Secret, Macy's, and Bloomingdales, have all dealt with well-publicized bed bug infestations (Chung 2010, Siff 2010). At the University of Cleveland Preparatory School (Cleveland, Ohio), when bed bugs were found in classrooms on two consecutive days, the school shut down and the entire building was fumigated (Reid 2012). In 2013, the National Pest Management Association's (NPMA) annual survey of pest management professionals (PMPs) in the United States reported that PMPs had treated for bed bug infestations in hotels, college dormitories, nursing homes, schools and day care centers, office buildings, hospitals, taxis, trains, buses, airplanes, movie theaters, summer camps, and many other locations (Haiken 2013, Potter et al. 2013).

Due to the bed bug spread, public facilities have had to take action, and many have implemented prevention procedures for when bed bugs arrive. In the public library system of Denver, Colorado, bed bugs are found in returned books so often that the administration has published a return protocol and quarantine process for library materials that may have come in contact with bed bugs (Denver Public Library 2013). The Johns Hopkins Hospital Bed Bug Procedure includes a description of bed bug characteristics, photographs for identification, and a list of required actions if bed bugs are suspected or found, which includes "[confining] the patient to one area, preferably an area with no fabric furniture or carpet," and double-bagging all of the patient's belongings and valuables, and any potentially contaminated linens in separate tightly sealed plastic bags (Johns Hopkins Safety Manual 2013). These prevention programs are our future in the U. S., but prevention programs are rare because so few people and organizations understand bed bugs.

A focused effort must be made to educate the public about bed bugs. Those who are currently suffering from bed bug infestation,s and those at high risk need accurate information regarding bed bug identification, biology, insecticide resistance, and minimally toxic management methods. Greater educational efforts, and proactive bed bug prevention programs will help our society to accept bed bugs as part of our lives from this point forward. The overall hypothesis of this study is that if people are educated and aware of bed bugs, they can use minimally toxic, cost-effective methods to proactively suppress and manage bed bug infestations in low-income multi-unit housing facilities.

Therefore, the objectives of this research study were:

1. To determine the bed bug response to diatomaceous earth applications in laboratory evaluations.
2. To develop and evaluate a proactive bed bug suppression program, using minimally toxic and cost-effective methods, for use in multi-unit housing facilities.
3. To assess and improve the bed bug knowledge base of low-income, multi-unit housing residents.

Chapter 2. Literature Review

Bed Bug Biology and Behavior

Like most members of the order Hemiptera, bed bugs have piercing-sucking mouthparts and an incomplete life cycle (Schaefer and Panizzi 2000). Bed bugs belong to the insect family Cimicidae and the genus *Cimex* (Usinger 1966). Cimicids of all life stages require a blood meal from a warm-blooded mammalian or avian host in order to molt to the next life stage and to reproduce. Different cimicid species are specialized to feed on the blood of different animals (Johnson 1941). One species, the bat bug (*Cimex pilosellus*, Hemiptera: Cimicidae) lives in colonies of roosting bats and must have a bat host in order to reproduce (Cranshaw et al. 2013). The swallow bug (*Oeciacus vicarius*, Hemiptera: Cimicidae) is a parasite of cliff swallows and barn swallows. The poultry bug (*Haematosiphon inodorus*, Hemiptera: Cimicidae) is a parasite of chickens and other poultry (Cranshaw et al. 2013). Another species, *Hesperocimex coloradensis* (Hemiptera: Cimicidae), preys on other bird species including purple martins, woodpeckers, and owls (Cranshaw et al. 2013).

There are two human-specific species of bed bugs, the common bed bug, *Cimex lectularius* L., and the tropical bed bug, *Cimex hemipterus* Fabricius. *C. hemipterus* is adapted to the high humidity and temperatures of semitropical to tropical climates, and can be found in the tropical regions of Africa, Asia, North America, and South America. In the United States, the tropical bed bug can be found in Florida (Jones 2004). While the common bed bug is more tolerant of temperate climates, *C. lectularius* has a worldwide distribution and is frequently found throughout North America, Europe, and Central Asia (Jones 2004). While the occurrence both species is increasing worldwide, it is the common bed bug that has made a spectacular resurgence in the United States.

Description

The common bed bug is a small wingless insect in the order Hemiptera and the family Cimicidae. Bed bugs of all life stages are dorso-ventrally flattened and have piercing-sucking mouthparts. Adult bed bugs are 5-7 mm long, oval-shaped, and reddish brown in color. Like all hemipterans, bed bugs undergo incomplete metamorphosis. After hatching from an egg, immature bed bugs go through five nymphal stages and are morphologically similar to the adults but differ in that they range in size from 1 mm (1st instar) to 5-7 mm (5th instar) and are lightly brown and yellow in color (Johnson 1941, Usinger 1966).

The common bed bug, *Cimex lectularius* L*.,* is a blood-feeding temporary ectoparasite of humans (Schaefer and Panizzi 2000, Johnson 1941). After hatching, first instar bed bugs, and each successive instar, must take a complete blood meal in order to molt to the next life stage (Johnson 1941). Once a fifth instar has molted to adult, additional blood meals are required for reproduction and, in females, prior to egg-laying. In order to feed, bed bugs must first locate a host. Carbon dioxide stimulates a bed bug to search for a host. When in close proximity to the host, the bed bug uses the host's body heat to orient their movement (thermotaxis). Once the host is located, the bed bug will probe the skin (several times) with its proboscis in order to find a capillary space. The host's capillary action will allow the blood to be pumped directly into the bed bug. Bed bugs will feed to capacity if uninterrupted, ingesting approximately 130% of its unfed body weight (Johnson 1941, Usinger 1966, Lehane 2005).

After feeding, bed bugs will leave the host to digest their blood meal, often returning to an aggregation of conspecifics (Pfeister et al. 2009). Several studies have determined that bed bugs can benefit from being in an aggregation. Saenz et al. (2014) evaluated the development rates of grouped and solitary bed bug nymphs. It was determined that nymphs housed in groups developed 2.2 days faster than solitary-housed nymphs, which represents a 7.3% decrease in overall development time (Saenz et al. 2014). Benoit et al. (2007) determined that bed bugs in an aggregation were also more resistant to dehydration and desiccation in dry environments. In order to learn more about bed bug dispersal in an environment, Pfeister et al. (2009) evaluated the effect of population structure and size on bed bug aggregation behavior. Pfeister et al. (2009) observed that bed bug nymphs had the highest tendency towards aggregating after feeding, and adult female bed bugs were found away from an aggregation more often than any other life stage.

Reproduction and Egg Production

The bed bug mating process is called traumatic insemination, because a male bed bug inseminates a female by stabbing her in the abdomen with his paramere, or copulatory organ (Carayon 1966). This process is metabolically taxing to female bed bugs and can result in both a reduction in life-span and a 24% reduction in reproductive capacity (Stutt and Siva-Jothy 2001). Polanco et al. (2011a) reported that female bed bugs exposed to a single mating event, produced 27% more eggs than females exposed to multiple matings. Pfiester et al. (2009) suggested that females would leave an aggregation to escape the repeated mating attempts of males, causing eggs to be laid away from bed bug aggregations. Pfiester et al. (2009) also determined that when an aggregation contained a higher percentage of adult bed bugs (particularly males), adult female bed bugs were more likely to leave an aggregation. While bed bugs are likely to be found in aggregations, the dispersal behavior of adult female bed bugs due to unwanted copulation has the potential to cause control efforts to fail (Pfeister et al. 2009).

After a female bed bug has ingested a blood meal and has been mated, she will begin to lay eggs within approximately 2-3 days (Usinger 1966). On average, a female bed bug can lay approximately 20-25 eggs over the course of about 10 days after a blood meal (Johnson 1941, Polanco et al. 2011a). With access to weekly blood meals, an adult female bed bug under laboratory conditions may produce 1 egg per day and approximately 147 eggs in her lifetime (Polanco et al. 2011a).

Life-Span

Without feeding (absence of a host), bed bugs can live for several weeks or months (Harlan 2007). Usinger (1966) determined that when starved, adult male bed bugs had a mean survival time of 142.6 days and adult females lived 130.6 days. In a more recent study, Polanco et al. (2011b) determined that at room temperature, starved pyrethroid-resistant adult male bed bugs had a mean survival time of 42.9 days and adult female bed bugs lived for 43.7 days. However, starved pyrethroid-resistant first instar bed bugs only had a mean survival time of 13.8 days (Polanco et al. 2011b). When bed bugs received regular weekly blood meals, Polanco et al. (2011c) determined that the average life span of a bed bug, starting as an egg, developing through all nymphal life stages, and dying as an adult, was approximately 143 days.

In *The Monograph of Cimicidae*, Usinger presented a comprehensive review of the bed bug knowledge available at the time (1966). As a result of the current bed bug resurgence, many of the topics and studies presented by Usinger have been reexamined and more current studies have produced different results (Harlan 2006, Polanco et al. 2011c). It is important to continue to research the biological characteristics of bed bugs so that new control strategies and prevention measures can be developed to effectively inhibit bed bug proliferation and slow the rapid spread of infestations.

Bed Bug Resurgence

Bed Bugs in History

As members of the family Cimicidae, bed bugs are very closely related to bat bugs (Schaefer 2000). Usinger suggested that over 35,000 years ago, bed bugs evolved from an ancestral form of bat bugs that fed on bats in caves located in what is now the Middle East, Europe, and India (1966). When proto-humans moved into these caves, the bats moved out, leaving the proto-humans with their bat bug infestations (Harlan 2006). It is speculated that the bat bugs found these human ancestors to be an easier host to parasitize because of their large mass and relatively hairless bodies (Usinger 1966). As the early humans moved from solitary caves, into huts and villages, the cimicid ectoparasites went with them (Sailer 1952).

Bed bugs appear in historical records many times: in Greece in 400 B.C., Italy in 77 A.D., China in 600 A.D., Germany in the 11th century, France in the 13th century, and England in the 16th century (Usinger 1966). From these records, we can assume that bed bugs were a common pest in many cultures and societies in the old world.

Bed bugs first arrived in what is now the United States aboard ships with the early colonists in the 1700s (Potter 2011). As the new world expanded with more colonies along the Atlantic coast, and later to the west, with the advent of the railroads, bed bugs infestations became more prevalent in highly populated areas, such as seaports and large cities (Marlatt 1916). As human and bed bug populations grew, people were warned that bed bugs could enter a home on stored furniture that had been infested, in the travelers' luggage, and on the clothes of people who were exposed to bed bugs in other homes or public places (Usinger 1966).

In 1730, John Southall published the first scientific work on the topic of bed bugs. Southall's publication promoted his "Non-pariel Liquor", a concoction that he created while traveling abroad in Jamaica. Southall stated, "I set about destroying of Buggs, and found to my Satisfaction, that wherever I apply'd it, it brought out and kill'd 'em all." However, Southall did not recommend using it on furniture due to strength and odor (Southall 1730). Since this original publication in 1730, there has been a long recorded history of people using many methods of bed bug control including traps, heat, oil sprays, chemical mixtures, and fumigation (Usinger 1966).

Insecticides and Bed Bug Eradication in the 20th Century

While prevention was stressed as a first defense against bed bugs, bed bug control in the early 1900s focused on eliminating infestations using synthesized insecticides (Usinger 1966). Possibly the most important compound ever synthesized in the western world was dichloro-diphenyl-trichloroethane (DDT), in 1874 (Howard 1931, Perkins 1982). The insecticidal properties of DDT, particularly with regard to mosquito and fly control, were discovered in 1939 (EPA 1975). During World War II, DDT was primarily used by the military for controlling mosquitoes and other indoor pests, such as cockroaches and later bed bugs (Usinger 1966). In the 1940s, people all over the world were successfully using liberal amounts of DDT for bed bug control. Bed bug resistance to DDT was first documented in U. S. military barracks at Pearl Harbor in 1947 (Johnson and Hill 1948). In 1959, the National Pest Control Association began to recommend the organophosphate insecticide, malathion, for control of DDT-resistant bed bug populations (Usinger 1966, EPA 1975, EPA 2006).

While many resistant bed bug infestations were controlled, malathion had short-lived success. By 1975, bed bugs all over the world were exhibiting resistance to malathion and, in 1988, its label registration was restricted from indoor use (Feroz 1971, 1974, Shetty 1975, EPA 2006). Other insecticides used during the 1950s to 1970s to control bed bugs included diazinon, lindane, chlordane, dichlorvos (Potter 2011). From the 1940s through the 1980s, virtually no non-chemical methods of control were used because chemical control of bed bugs was extremely effective. When the synthetic pyrethroids (i.e. permethrin, cypermethrin, and deltamethrin) became common indoor pest control products in the 1980s, the incidence of bed bug infestations had already declined precipitously within the United States (Potter 2011). Therefore, in spite of the rapid development of resistance, bed bugs were essentially eradicated within the United States and were no longer considered a significant pest (Ebeling 1975, Usinger 1966).

Resurgence in the 1990s

Since the 1990s, bed bugs have been making a resurgence in the United States (Harlan 2006, Krueger 2000). As of 2006, bed bug infestations had been reported in all of the 50 states, occurring in single-family homes, apartments, hotels, health care facilities, theaters, college dormitories, and on public transportation (Hwang et al. 2005, Gangloff-Kaufmann et al. 2006). In January 2013, Orkin Pest Control announced a list of the top 50 most bed bug-infested cities of 2012 based on the number of treatments performed between January and December 2012. Topping the list were Chicago, Detroit, and Los Angeles, respectively. Orkin's parent company, Rollins Inc., reported a 33% increase in bed bug business in 2012 when compared with 2011 (Orkin 2013).

In 2010, 2011, and 2013, the National Pest Management Association and the University of Kentucky conducted national surveys of pest management companies to assess the impact of the bed bug resurgence on the pest management industry (Potter et al. 2010a, Potter et al. 2011, Potter et al. 2013). When respondents were asked whether their company had encountered bed bugs in the past year, the number of positive responses increased from 95% in 2010 to 99.6% in 2013. When asked their opinions as to why bed bug incidence was increasing in the United States, respondents indicated many factors including: international travel, immigration, the unregulated transfer of second-hand clothing, and furniture, a higher turnover of occupants in apartments and public housing, an overall lack of societal awareness or precautions worldwide, and bed bug resistance to insecticides (Potter et al. 2010a, Potter at al 2011).

Insecticide Resistance

Insecticide resistance in insect pests has been widely studied since DDT-resistant house flies were first discovered in northern Sweden (Brown 1968). Many groups of insects, including agricultural pests, urban pests, and insects of medical and veterinary importance, have developed resistance to different insecticide chemistries (Mamidala et al. 2011).

Bed bug resistance to DDT was first reported in 1947 (Johnson and Hill 1948). Busvine (1958) reported bed bug resistance to DDT, BHC, and dieldrin in a bed bug population from Israel. In recent years, insecticide resistance within different bed bug populations has been widely documented. Boase (2001) documented resistance to pyrethroids and carbamates in a field-collected bed bug strain from the United Kingdom. Moore and Miller (2006) reported a 300-fold resistance ratio (Cochran 1995) to deltamethrin in a field strain of bed bugs collected from Arlington, VA. Romero et al. (2007) reported resistance to the synthetic pyrethroids, deltamethrin, and λ-cyhalothrin, in seven out of eight field-collected bed bug populations collected from around the United States.

There are four major types of resistance mechanisms in insects: target site insensitivity, metabolic resistance, reduced cuticular penetration, and behavioral resistance (Lemon 1994, Hemingway et al. 2002, Zhu et al. 2013). In an insect, target site insensitivity involves a conformational change at the receptor site for a particular toxin. This physical change in the receptor site inhibits the toxin from binding where it would normally and renders the toxin ineffective to the insect. Metabolic resistance is the result of the enhanced detoxification activity of particular enzymes within an insect, such as mixed function oxidases and esterases. These enzymes are able to degrade the toxins before they reach the target sites, reducing or eliminating the toxic effect on the insect. Another resistance mechanism is reduced cuticular penetration, where an insect's cuticle has evolved to be thicker, more dense, or more sclerotized, so that insecticides are unable to penetrate the exoskeleton and get into the insect's body. The fourth type of insecticide resistance is behavioral, specifically where populations have been selected for those individuals that avoid insecticide treated surfaces or food sources (Lemon 1994). All four mechanisms of insecticide resistance have been reported in bed bugs (Romero et al. 2009b, Zhu et al. 2013).

Further studies have characterized the types of resistance present in field populations of bed bugs. Knockdown resistance (*kdr*) to pyrethroid insecticides was first documented in a population of bed bugs collected in New York (Yoon et al. 2008). Subsequently, *kdr*-type resistance was found to be widespread among bed bug populations within the United States (Zhu et al. 2010). Knockdown resistance is caused by a point mutation in the alpha-subunit of a voltage-sensitive sodium channel of the insect nerve, thus reducing target site binding of pyrethroid insecticides.

Metabolic resistance cause by enhanced enzyme detoxification activity has been documented in bed bug strains from Virginia, Ohio, and Massachusetts, where studies have reported the enzyme activity contributing to the bed bugs' overall ability to reduce their pesticide load (Adelman et al. 2011, Romero et al. 2007, Bai et al. 2011). Studies have also determined that field-collected bed bug populations exhibit multiple types of insecticide resistance mechanisms.

Koganemaru et al. (2013) evaluated field-collected bed bugs with documented metabolic and *kdr* resistance to determine if they also exhibited reduced cuticular penetration-type resistance. To test this hypothesis, pyrethroid-susceptible bed bugs and pyrethroid-resistant bed bugs were exposed to a topical insecticide application and an injected insecticide application. The LD_{50} (lethal dose required for 50% of the test population) value of the topically treated bed bugs was divided by the LD_{50} value of the bed bugs of the same strain that were injected with insecticide to calculate a cuticle penetration ratio. The penetration ratios were compared between pyrethroid-resistant and susceptible bed bug strains. Koganemaru et al. (2013) found that pyrethroid-resistant bed bugs exposed to topical applications of deltamethrin were more than 200,000 times more resistant as compared with bed bugs of the same strain that were injected with deltamethrin, suggesting that the bed bug's cuticle played a strong role in its resistance to pyrethroid insecticides.

Very little research has been conducted on behavioral resistance in bed bugs. Only Romero et al. (2009a) suggested that when bed bugs avoid contacting an insecticide-treated filter paper, they were exhibiting a type of behavioral resistance. However, more studies are needed to characterize resistance behaviors in bed bugs.

Common Treatment Methods and Costs

Chemical Control Methods

In spite of widespread resistance, chemical insecticide treatments are still the most commonly used method of bed bug control in the U. S. A survey of pest management companies in the United States reported that 99% of pest management professionals apply chemical insecticides as part of their bed bug treatment protocols (Potter et al. 2010a). The survey also reported that although pyrethroid-resistance is widespread in bed bug field populations, pyrethroid insecticides are still the most commonly used insecticide for bed bug control (Potter et al. 2013). Pyrethroids make up the majority of the insecticides registered by the EPA for indoor-use (Potter et al. 2013). Because all pyrethroids have the same mode of action, pest management professionals are left with few insecticides with differing modes of action.

Chlorfenapyr is a slow-acting contact and stomach poison in the pyrrole class of insecticides and one of the few non-pyrethroid products labeled for indoor use (Zhu 2008, Potter et al. 2012). While Potter et al. (2012) suggest that chlorpenafyr does offer a longer residual activity (up to 4 months) than pyrethroids, its slow-acting mode of action makes this insecticide less practical for use in the field (Haynes and Potter 2013, Romero 2011). Phantom® (0.5% chlorfenapyr, BASF Corp., St. Louis, MO), the only chlorfenapyr product registered in the United States, is the single most widely used (51%) product by pest management professionals because it is often used in combination with faster-acting pyrethroids (Potter et al. 2011).

Another type of slow-acting insecticide labeled for bed bug control is hydroprene, which is an insect growth regulator (IGR) that acts as a juvenile hormone mimic. While hydroprene is the fourth most used bed bug control insecticide in the United States, a laboratory evaluation of the bed bug response to Gentrol® (hydroprene 9%; ZOECON, Schaumber, IL) showed no developmental delay in nymphs (Todd 2006). Additionally, all of the surviving nymphs molted successfully to adults, and some were even able to produce viable progeny. Goodman et al. (2013) reported that after being exposed to elevated concentrations (3x-10x label application rate) of Gentrol®, pyrethroid resistant bed bugs produced fewer eggs, but those eggs and subsequent nymphs were able to develop. Moore and Miller (2009) evaluated the bed bug response to applications of Gentrol® combined with either a pyrethroid or chlorfenapyr in a low-income apartment facility in Arlington, VA. Although the combination treatment applied made it impossible to identify specific effects of hydroprene on the bed bugs, the slow activity of hydroprene led the researchers to suggest that IGRs were ineffective for bed bug control. For these reasons, IGRs are rarely used alone, and are often combined with faster-acting insecticides, like pyrethroids.

A recent trend among insecticide manufacturers is the development and production of dual-action insecticide products. Insecticides formulated with both pyrethroid and neonicotinoid active ingredients have been evaluated in the laboratory and field, producing successful results. Potter at al. (2012) evaluated the response of pyrethroid resistant bed bugs to two dual-action products: Temprid™ (imidacloprid 21.0%, beta-cyfluthrin 10.5%; Bayer Environmental Science, Research Triangle Park, NC), and Transport® (bifenthrin 27.27%, acetamaprid 22.73%; FMC Corporation, Philadelphia, PA). Both insecticide formulations were found to produce greater and more rapid bed bug mortality than either of their pyrethroid or neonicotinoid ingredients alone. A recent study, in the Dodson Urban Pest Management Laboratory (Virginia Tech, Blacksburg, VA), found similar results when evaluating another dual-action product, Tandem® (thiamethoxam 11.6%, lambda-cyhalothrin 3.5%; Syngenta Crop Protection, LLC, Greensboro, NC). While these combination pyrethroid/neonicotinoid products are both effective and popular, bed bug resistance still has the potential to develop, particularly because of the already widespread resistance to pyrethroids.

In the United States, carbamates and organophosphates are not registered for use indoors (households) with the exception of the organophosphate, dichlorvos (2, 2-dichlorovinyl dimethyl phosphate; DDVP), which is registered in the United States for bed bug control. The dichlorvos product is formulated into resin strips (DDVP 18.6%, Nuvan Prostrips®; Amvac Chemical Corp., Los Angeles, CA), which vaporize to produce the toxin. A laboratory study by Potter et al. (2010b) found that dichlorvos vapors killed bed bugs and their eggs when confined in small (~0.16 m^3) cages. Lehnert et al. (2011) determined that the use of heat and air circulation could increase dichlorvos resin strip vaporization, making dichlorvos applications more practical for bed bug control in larger areas (i.e. an unoccupied double-occupancy dormitory room). Miller et al. (2011) evaluated the bed bug response to dichlorvos resin strip applications in plastic garbage bags (at least 3 mil. thick) containing either cloth items or electronics. In this study, complete mortality of adult and nymph bed bugs was not observed within 7 days (the time interval suggested by the pesticide label) or 14 days. While still registered by the EPA for bed bug control, dichlorvos resin strip applications do not always kill bed bugs of all life stages.

Fumigation. Chemical fumigation is an extremely effective method of treating structural pests but has not been widely used to control bed bugs because it is expensive and does not offer any residual activity (Miller and Fisher 2008, Yu 2008). Containerized fumigation is useful for treating personal items such as large furniture, electronics, musical instruments, and various other personal and valuable items (Walker et al 2008, Miller and Fisher 2008). For those who can afford it, whole-building fumigation is practical for eradicating bed bugs where there are multiple units with heavy infestations and high levels of clutter, because it is a one time expense.

Fumigation with sulfuryl fluoride gas has been commonly used for drywood termite control (Matsumura 1985). Miller and Fisher (2008) evaluated the bed bug response to Vikane® (sulfuryl fluoride 99.8%; Vikane®, Dow Agrosciences, Indianapolis, IN) in an apartment complex in Reading, PA. This study determined that sufluryl fluoride fumigation was 100% effective at treating all bed bug life stages in high density multi-story structures.

Fumigation with high concentrations of carbon dioxide (CO_2) can also be used to control bed bugs. CO_2 fumigation has been used to control stored product pests (Navarro et al. 2012) and also works for bed bugs. Herrmann et al. (1999) reported that 60% CO_2 caused 100% mortality in all life stages of bed bugs within 24 hours. Wang et al. (2012) evaluated the bed bug response to container fumigation at different concentrations of CO_2 (50-100%) over time and reported 100% mortality in adult and nymph bed bugs within 7 and 18 hours at 50% and 100% CO_2 concentration, respectively. Wang et al. (2012) determined that CO_2 fumigation was an effective, affordable, and rapid method of treating bed bug infested household items.

Non-chemical Treatment

Because bed bugs have proven their ability to develop resistance to a wide range of insecticide classes, effective non-chemical methods are needed to kill bed bugs and potentially inhibit the development of resistance (Romero 2011). In addition, there has been a trend toward the use of non-chemical control methods because of environmental concerns and potential human health risks. Integrated bed bug control programs (chemical and non-chemical methods) are often offered by major pest management companies. These programs can include many non-chemical and mechanical bed bug management tools such as heat treatments, steam treatments, carbon dioxide snow applications, and diatomaceous earth applications (Kells 2006, Cooper 2011). Common non-chemical bed bug management tools include:

Mattress Encasements. An important non-chemical bed bug management strategy is the installation of mattress and box spring encasements. Bed bugs are most commonly found near beds and sleeping furniture because these areas provide bed bug harborage near the host (Cooper 2011). Mattress and box spring encasements are used to prevent bed bugs from infesting a bed so that the mattress and box spring do not have to be discarded. The purpose of an encasement is to trap any bed bugs already on the mattress and prevent new bed bugs from aggregating within the box spring (Cooper 2007). If mattresses and box springs are encased prior to being infested, bed bugs would not be able to harbor inside and the mattresses and box springs; thus, the bed itself would not have to be treated. If installed after an infestation has been discovered, an encasement would seal bed bugs inside, preventing them from biting the host, and causing them to eventually starve to death.

Mattress encasements are used by 86% of pest management professionals in the United States (Potter et al. 2011). Many mattress encasements are available to consumers but not all are effective (Cooper 2011). An appropriate mattress encasement will prevent even the smallest first instar bed bug from escaping. The most important features of a "bed bug-proof" encasement are a zipper with tightly interlocking teeth and a secure closure at the zipper's ends (Cooper 2007, Protect-a-Bed 2013). Mattress encasements must be made of durable (tear-resistant) material that will prevent bed bugs from feeding through the encasement (bite-proof) (Miller 2009b). The encasement should be the appropriate size for the mattress or box spring so that it fits tightly and does not have any folds or loosely hanging areas that could provide harborage for bed bugs (Miller 2009b).

Monitoring Devices. Passive bed bug monitoring devices, such as the Climb-Up Interceptor© (Susan McKnight Inc., Memphis, TN) or The Bed Moat® (The Bed Moat, Inc., Toronto, Canada), are important products for use in an integrated bed bug management program. Monitoring devices are intended to intercept and trap bed bugs that may be using bed or furniture legs as routes to access a sleeping host. Today's passive monitoring products are based on technology used at the beginning of the 20th century when people would place cans or jars containing oil or kerosene under furniture legs to intercept bed bugs searching for a host (Potter 2008). Monitors can be installed under the legs of all beds, sleeping furniture, couches, and chairs. However, they can also just be placed near sleeping areas when mattresses sit directly on the floor (Wang et al. 2009a). Many of today's monitors have at least two interior wells. These interior wells have slick plastic walls that prevent bed bugs from climbing them, and are intended to trap bed bug until the monitor is inspected. At inspection, bed bugs in the outer well of the monitor are assumed to have come from the room to the furniture leg, while bed bugs in the inner well are assumed to have been leaving the furniture.

Monitoring devices are important for many reasons: the early detection of low-level infestations; to detect bed bug reintroductions; and to determine if bed bugs are still present after a treatment (Cooper 2011). Ideally, monitors are most effective if there are few means for bed bugs to access a host. Bed frames should be pulled away from walls, and excess bedding (i.e. bed skirts, extra pillows, etc.) should be removed so that nothing touches the floor, so that the only route for a bed bug to access the host is through the monitor (Cooper 2011, Wang and Cooper 2011).

Several studies have evaluated the use and success of monitoring devices. Wang et al. (2010) used passive monitoring devices to characterize the infestation level and dispersal of bed bugs in a high-rise apartment building. Wang et al. (2009a) determined that interception devices are effective tools for detecting low-level bed bug infestations. In another study, Wang et al. (2009b) documented the effectiveness of a bed bug management program by using interception devices (and subsequent bed bug catch data) to monitor the reduction of the bed bug populations in apartment units over time.

Freezing Temperatures. Extreme cold temperatures will kill bed bugs. Studies have found that bed bugs of all life stages die within an hour of exposure to -18º C conditions (Johnson 1941). However, bed bugs have been shown to survive for several days when exposed to temperatures below freezing (0º C) (Cooper 2011). Usinger (1966) found that a bed bug's metabolism began to slow down at temperatures approximately 13-15º C, and that a bed bug could survive overnight at temperatures as low as -15º C. Further reports have shown that bed bugs exposed to -5º C required at least five days to reach mortality (Kells 2006). Kells (2006) recommends flash-freezing at -26º C to ensure death of all bed bugs and eggs.

Because of the variability in mortality, freezing is not typically recommended as a bed bug treatment method. However, one method of effectively freezing bed bugs to death is to use the Cryonite® system (Silvandersson Sweden AB, Knäred, Sweden). The Cryonite® system releases a dry carbon dioxide snow at -60º C to instantly kill bed bugs and their eggs after direct contact (Cooper 2011). The Cryonite® snow can only be used to treat bed bugs in locations where direct contact is possible, such as cracks and crevices, furniture, and walls. Because the snow is a dry and non-toxic product, the Cryonite® system can also be used on surfaces in direct contact with food, as well as in electronics, electric outlets, and motors (Brown and Loughlin 2012). Brown and Loughlin (2012) used the Cryonite® system to successfully treat an apartment complex, a single family home, and a homeless shelter with only two treatments. As with other bed bug control methods that require direct contact in order to kill bed bugs, the Cryonite® system should not be used alone but should be employed as a component of an integrated bed bug management program.

Heat. Heat exposure is a very effective way of eradicating bed bug infestations. The recognized thermal death point (full mortality in one minute) for all life stages of bed bugs and eggs is 50º C (122º F) (Kells and Goblirsch 2011). In 1941, a study reported that bed bugs could live for only 15 minutes or an hour when exposed to 43º C and 45º C, respectively (Johnson 1941). More recent research has demonstrated that bed bugs exposed to a temperature of 41º C for one hour will experience 75-80% mortality; however, 100% of bed bugs will die when exposed to 48º C for the same amount of time (Benoit 2009a).

The bed bug's susceptibility to heat has allowed us to use common household dryers to kill bed bugs in infested cloth items (Miller 2009a). The high heat setting on most household dryers easily reaches the thermal death point for bed bugs and will kill all life stages as long as the dryer is loosely packed with room for air flow (Potter et al. 2007, Naylor and Boase 2010). In 2010, 86% of pest management professionals were recommending the use of household dryers to treat infested items (Potter et al. 2011). While simple and inexpensive, this method of bed bug control may not be successful if a dryer has an automatic temperature shutoff or if the upper temperature limit is set below the bed bug thermal death point (Haynes and Potter 2013).

Heat chambers and portable heating units can be used to treat infested furniture, electronics, and other household items unsuited for laundering. Pereira et al. (2009) developed an inexpensive "Do-it-Yourself" heat chamber constructed with common materials that can be purchased at hardware stores. Using thermocouples, Pereira et al. (2009) monitored the temperature within the heat chamber, and were able to record temperatures above the thermal death point for bed bugs within six hours. While heat chambers require more time to reach lethal temperatures than dryers, more and larger items can be treated at the same time (Miller 2009c).

Heat can also be used to treat whole rooms or entire structures (Cooper 2011). After completely sealing specific rooms or apartments, whole-unit heat treatment technicians set up heaters (electric or propane) and fans (to circulate the heat) in the treatment area. The temperature in the treatment area is raised above 57.2º C and monitored for several additional hours (Miller 2009c). While whole-unit heat treatments have been proven effective, they must be performed by a reputable company with technicians trained to monitor the temperatures in the treatment area so that the bed bugs are killed. Experienced technicians are also trained to avoid malfunctions (i.e. fires, electrical outages, and damage to items).

Diatomaceous Earth. An important bed bug control strategy is the use of mechanical insecticides and desiccant dusts, like diatomaceous earth (Romero 2009b). Diatomaceous earth (DE) is amorphous silicon dioxide, composed of the fossilized skeletons of *Diatomaceae*, a species of aquatic unicellular algae (Calvert 1930). Over 20 million years ago, different species of diatoms would remove silicon from water, reinforcing their skeletons with hydrated amorphous silica (Korunic 1998). After they died, their skeletons sank to the bottom of the water bodies, where they were fossilized and compressed into soft, chalky rock masses of diatomaceous earth (Ross 1981, Quarles and Winn 1996). Today, these deposits are mined, dried, and pulverized into a fine talc-like powder that can be used for many purposes (Quarles 1992, Calvert 1930).

Different deposits of diatomaceous earth are mined from different locations. Thus, they can have different properties that lend themselves to a variety of uses (Korunic 1998). Some types of diatomaceous earth are used for water purification, the clarification of liquors and juices, filtration of commercial fluids, or the separation of various oils and chemicals (Calvert 1930). Because some types of diatomaceous earth can absorb up to 89% of their own weight in liquids, they can be used as a pesticide carrier or for the safe storage and transportation of hazardous liquids (Ebeling 1971). Diatomaceous earth can also be used in commercial products such as a mild abrasive in detergents, for absorption in deodorants, as filtration agents for swimming pool filter systems, as anti-caking agents, and as a digestive additive in animal feed (Snetsinger 1988). Another use for diatomaceous earth is as an inert desiccant dust for the control of insects (Quarles 1992).

Insecticide-grade Diatomaceous Earth. There are two types of diatomaceous earth available to consumers: an insecticide grade, and a filtration grade that is used in swimming pool filters. The filtration grade has been calcined (heated at temperatures greater than 800º C), or glassified at high temperatures in its processing, which causes the fossilized diatoms to change from amorphous hydrated silica to a crystalline form, making it an inhalation hazard (Quarles 1992, Calvert 1930, Katz 1991). The insecticide grade diatomaceous earth, however, comes only from fresh water diatom deposits, which are mined from the benthic zone of fresh water bodies like lakes, streams, and rivers (Calvert 1930). These diatom deposits are not heat treated in their processing and are therefore not an inhalation hazard (Korunic 1998).

Long-term health effects are possible if an individual is exposed to chronic inhalation of amorphous silica (the main component in diatomaceous earth) in the atmosphere (Omura 1981). The opportunity for long-term exposure to air-borne amorphous silica is typically associated with people employed in the mining and production of diatomaceous earth (Merget et al. 2002). Often, the employees are exposed to amorphous silica that has been calcined, and has contaminated the workplace atmosphere (Swensson 1971). Prolonged inhalation of crystalline silica can lead to a variety of respiratory problems, including emphysema, pneumoconiosis, silicosis, tuberculosis, chronic bronchitis, chronic obstructive pulmonary disease (COPD), and lung cancer (Korunic 1998, Omura 1981, Abrams 1954, Merget et al. 2002).

Insecticide grade diatomaceous earth is labeled for both indoor and outdoor use and for the control of a broad range of insect pests (EPA 1991). In the United States, the Environmental Protection Agency (EPA) classifies diatomaceous earth as Generally Recognized as Safe (GRAS), which means it does not produce toxic chemical residues and will not react with other substances in the environment (EPA 1991, 2013, Korunic 1998). In order to be registered by the EPA, insecticide grade diatomaceous earth must be mined from freshwater deposits of diatomite. Diatomaceous earth deposits must have a large oil absorption capacity, little clay composition, a small particle size (less than 12 μm), and contain less than 1% crystalline silica (Quarles 1992, Katz 1991, Capinera 2004).

Insecticide grade diatomaceous earth is non-toxic to mammals, if ingested (Quarles 1992, Allen 1972). Bertke (1964) determined that a daily diet containing 5% diatomaceous earth (freshwater) caused no health defects in rats that consumed it for 90 days. Feed containing 1 to 2% diatomaceous earth is often used to control internal parasites in dairy cattle (Allen 1972). In addition, Cummins (1975) reported that diatomaceous earth could be safely added to baking flour intended for human consumption. Both the U.S. EPA and Food and Drug Administration (FDA) allow diatomaceous earth to be used for control of insect pests (stored product pests, etc.) in food storage and processing areas (Federal Register 1961, 1981).

While non-toxic to mammals, diatomaceous earth can cause a mild irritation of the eyes, lungs, and skin. For this reason, the pesticide labels associated with different brands of insecticide-grade diatomaceous earth caution applicators to avoid contact with eyes or clothing, to use adequate ventilation, to avoid inhaling dust, and to wash thoroughly with soap and water after handling (BASF Corporation 2008). In cases of prolonged exposure to diatomaceous earth during the application process, specimen labels also recommend the use of a suitable dust mask that has been approved by the National Institute for Occupational Safety and Health (NIOSH) and U. S. Mine Safety and Health Administration (MSHA). While these recommendations must be regarded for the safe application of diatomaceous earth, it should be noted that there are no requirements for the use of personal protection equipment on the product label.

Mode of Action. Insecticidal diatomaceous earth acts as a desiccant by absorbing the waterproofing components of the insect epicuticle (Appel et al. 1999). As an insect walks through a diatomaceous earth application, damage occurs to the epicuticle by sorption and abrasion. Sorption is the primary mode of action because diatom particles have the capacity to absorb 89% of their total volume in oils and lipids (Calvert 1930). This sorption of waxes from the cuticle results in the loss of moisture from an insect's body through desiccation and causes death (Ebeling 1971). The abrasive properties of diatomaceous earth cause insect death when its particles come in contact with an insect body, become imbedded in the cuticle, and can rub against other surfaces (Ebeling 1971). An additional, less significant mode of action is as a repellent. Insects will often avoid applications of diatomaceous earth where they can see the piles of dust (White et al. 1966, Romero et al. 2009b).

Several physical traits can increase an insect's susceptibility to diatomaceous earth. Insects with a large surface area to volume ratio are more vulnerable to desiccation by DE because the exposed waterproofing components of the epicuticle make up a larger percentage of the insect's body. Bartlett (1951) was able to determine that insects with thinner cuticles were more susceptible to desiccation by DE than those with thicker cuticles. Finally, insects that have setaeceous body coverings are more susceptible to diatomaceous earth than insects with smooth bodies because the body hairs pick up more DE particles (Carlson and Ball 1962).

Control of Insect Pests. Insecticide grade diatomaceous earth is most commonly used to manage insect pests in bulk-stored agricultural products, but it can also be used as a structural treatment in food storage facilities (Duke 2010, Korunic 1998). The EPA product label indicates that diatomaceous earth is intended for indoor and outdoor control of ants, cockroaches, earwigs, fleas, mites, bed bugs, and other crawling insect pests.

Numerous studies have been conducted to evaluate insect response to diatomaceous earth. On plants, diatomaceous earth has been proven to effectively manage several species of aphid including the green peach aphid and the cowpea aphid (Ulrichs 2001, El-Wakeil 2009). The effect of diatomaceous earth on stored product pests has been extensively studied for many species including the confused flour beetle, the red flour beetle, mealworms, the sawtoothed grain beetle, spider beetles, the Indian meal moth, and the Mediterranean flour moth (Alexander et al. 1944, Mewis and Ulrichs 2001, Nikpay 2006, Vayais et al. 2006). Carlson and Ball (1962) determined that diatomaceous earth was also effective for controlling several beetle pests of grain, including several dermestid larvae, the rusty grain beetle, the flat grain beetle, the wheat weevil, the rice weevil, the lesser grain borer, and many others.

In stored product facilities, diatomaceous earth is used as a surface treatment targeting grain pests (Wright 1990, Bridgeman 1994). Collins and Cook (2006a,b) determined that diatomaceous earth applications on glass, plastic, and wooden surfaces were effective when attempting to kill several beetle, mite, and moth larvae. When diatomaceous earth was applied directly to the grain itself, researchers were able to reduce field populations of red flour beetle, lesser grain borer, and rice weevil by 98 to 100% (Korunic and Macklay 1999).

The efficacy of diatomaceous earth has also been evaluated for urban insect pests. Faulde et al. (2006) evaluated an insecticide grade diatomaceous earth that had been modified with a highly hydrophobic silane, 1,1,1-trimethyl-N-trimethylsilane, which increased the hydrophobicity of the particle surface and oil-binding capacity while also reducing water vapor adsorption. Faulde et al. (2006) determined that this modified DE could control infestations of German and American cockroaches, as well as silverfish. Other studies have proven that diatomaceous earth effectively kills ants (Brinkman and Gardner 2001), crickets (Thompson and Brandenburg 2006), termites (Grace and Yamamoto 1993), earwigs (Jesiolowski-Cebenko 1997), fleas (Dawson 2004), June beetles, textile pests, pest caterpillars, potato beetles, and bed bugs (Korunic 1998, Fagerlund 2009).

Bed Bug Control. Many sources recommend insecticide-grade diatomaceous earth as a desiccant dust for bed bug control (Martin 2009). Doggett et al. (2008) reported that diatomaceous earth had many advantages over available registered insecticides, including a longer shelf life, residual activity, low-risk of developing resistance, and low mammalian toxicity. Diatomaceous earth is effective for bed bug control because it can be applied in areas where bed bugs naturally congregate.

Several studies have evaluated bed bug response to diatomaceous earth in the laboratory. Romero et al. (2009) showed that bed bugs from three different laboratory strains all died within 10 days when continuously exposed to diatomaceous earth. Researchers have also evaluated the efficacy of diatomaceous earth at varying rates and relative humidities, and determined that while these factors could lengthen the total time to mortality, 100% mortality was still achieved in all studies (Doggett et al. 2008). Benoit et al. (2009b) determined that label rate applications of diatomaceous earth successfully killed first instar and adult female bed bugs in approximately four days. A study by Akhtar and Isman (2013) determined that bed bugs were also able to disseminate diatomaceous earth by horizontal transfer. This means that when a bed bug comes into contact with a diatomaceous earth application, it will pick up the DE on its body and is able to transfer it to additional bed bugs in harborages and aggregations.

Relatively few studies have been conducted to evaluate the efficacy of diatomaceous earth applications in field settings. Potter et al. (2013) conducted a study to evaluate the practicality of "real world" diatomaceous earth applications. This study determined that diatomaceous earth would be too difficult for the general public to apply correctly because they would not have access to professional dusting equipment (Potter et al. 2013). However, although Potter et al. (2013) described his application tools as simple, inexpensive, and a way to reduce air-suspended DE particles, the tools used were make-up brushes, paintbrushes, feather dusters, and polishing pads, which would not be considered acceptable or effective by industry standards. While Potter et al. (2013) reported that diatomaceous earth was impractical as a stand-alone treatment, many researchers and pest management professionals use diatomaceous earth as a component of a multi-step integrated pest management program. Wang et al. (2009) evaluated a diatomaceous earth-based integrated pest management program for bed bug management. This study determined that a DE-based IPM program was able to reduce the bed bug populations equally as well as an insecticide spray-based program, and was less expensive (Wang et al. 2009). A more recent study by Wang et al. (2012) evaluated the efficacy of three bed bug management programs which used either non-chemical methods only, insecticides only, or IPM methods, which included diatomaceous earth. While this study was marred by a lack of resident cooperation, researchers still determined that the IPM methods employed were better able to reduce bed bug infestation levels than the insecticidal methods (Wang et al. 2012).

Bed Bug Regulations in the United States

State Laws Regarding Bed Bugs

The highly transmittable and blood-feeding nature of bed bugs differentiates them from other urban pests with regards to the law. As of 2006, bed bugs have been reported in each of the fifty states in the United States (Gangloff-Kaufmann et al. 2006). At least 22 of these states now have specific statutes addressing bed bug infestations in rental properties, hotels, institutional facilities, schools, rail cars, and migrant labor camps.

In the United States, individual state legislatures approach bed bug regulations in different ways. In Arizona, bed bugs are classified as a public nuisance that endangers public health. Under the Arizona Revised Code for landlord and tenant obligations, it is illegal for landlords to enter into a lease with a tenant for a property in which the landlord knows to have a current bed bug infestation. Also, landlords are required to provide bed bug educational materials to all existing and new tenants. In Illinois, owners and operators of railroad cars that are used for passenger transport must be regularly inspected and, if necessary, fumigated for cockroaches, body lice, and bed bugs. In Iowa, to operate a migrant labor camp under the Iowa Administrative Rule, effective measures must be taken to control urban pests (including bed bugs) on camp premises. In Kansas, a hotel room may not be rented if it is infested with any type of insect. According to Kansas Administrative Rule, a bed bug infestation is defined as the presence of live bed bugs, bed bug exuvia, eggs or egg casings, or the "typical brownish or blood spotting on linens, mattresses, or furniture." In the state of Maine, there are extensive regulations concerning bed bug infestations in rental properties. Of particular note, under civil court procedures, both landlords and tenants are responsible for the prompt and honest disclosure of bed bug incidence. In New York, the bed bug infestation history (for the previous year) of a multi-unit rental property must be disclosed to new tenants prior to signing a lease agreement.

Bed Bug Litigation

Bed bug litigation primarily began in the United States on the east coast and in the Chicago area, but has since spread throughout the country (Cassidy et al. 2011). As of 2013, legal claims originate from the emotional, psychological, physical, and financial damages associated with encountering bed bugs. Attempting to determine who is to blame for a bed bug encounter is difficult because bed bugs can be picked up in may different locations, not just hotels, motels, hospitals, etc., but also from visiting friends and family, being near infested apartments, or placing personal belongings on infested furniture.

Different types of bed bug-related cases have been litigated. A common type of bed bug lawsuit deals with punitive damages for hotel guests. In *Mathias v. Accor Economy Lodging* (2003), a Chicago hotel owner, who feigned ignorance when customers complained about their rooms being infested, was ordered to pay $5,000 in actual damages and $186,000 per person in punitive damage awards, because of “conduct that [was] willful and wanton…and so egregious…” (Cassidy et al. 2011). Litigation can also arise between landlords and tenants. Because bed bug infestations in an apartment constitutes a breach of the warranty of habitability, lawsuits often arise from a landlord’s actions against a tenant who is withholding rent payments because an apartment was infested with bed bugs (Cassidy et al. 2011). In 2013, an Annapolis, MD, woman was awarded a $800,000 in a lawsuit she filed against her landlord after claiming breach of the warranty of habitability, because the landlord was found to have not efficiently dealt with bed bug infestation (Dicker 2013). Bed bug-related landlord-tenant cases can also be filed as class-action lawsuits, where groups of tenants can claim that a landlord failed to appropriately handle reported bed bug infestations and concerns. Under the Consumer Rights Act (2009) of Iowa’s landlord-tenant law, 300 residents of two apartment buildings in Des Moines, IA, filed a class-action lawsuit against their landlords, and claimed financial loss (pest control products and treatments, discarded furniture and personal items, etc.) due to the alleged deception (by the landlords) regarding building-wide bed bug infestations (Rood 2014). Most often, rulings favor the ‘victim,’ or the person who became infested with bed bugs.

Another type of bed bug lawsuit being filed in the United States arises from the sale of “as is” bed bug infested buildings. In 2010, the purchaser of a bed bug-infested apartment building in New York City sued the building’s seller, in an attempt to void the sale because of the uninhabitable state of the building. In this case, the New York Supreme Court ruled that bed bugs are considered a latent defect and that buyers do not have the right to rescind the purchase after discovering a bed bug infestation. In such cases, where buyers are unknowingly purchasing bed bug infested (and uninhabitable) buildings, these large-scale bed bug infestations typically tend to grow because there are no remediation attempts.

Bed Bugs in Public Housing

While bed bug infestations occur across all social and economic classes, the most severe infestations have been reported among the socially disadvantaged, including low-income minorities, the elderly, the disabled, and particularly public housing residents (Wang et al. 2012, Eddy and Jones 2011a, 2011b, Kells 2006). Arguably, the multi-unit housing industry has been the most financially vulnerable to bed bug infestations. Several states have passed specific legislation identifying apartment owners and managers as being physically and financially responsible for bed bug eradication.

In 2011, the U.S. Department of Housing and Urban Development (HUD) published their Bed Bug Notices which listed guidelines for the management and control of bed bugs in all HUD-assisted facilities. It was specifically stated that multi-family housing owner and managing agents (O/As) were 100% responsible for bed bug eradication in their properties. These guidelines were revised in 2012 at the request of the National Apartment Association (NAA), the National Multifamily Housing Council (NMHC), Representative Robert Dold (R-IL, past C.E.O. of Rose Pest Solutions, Chicago, IL), and Representative Steve Stivers (R-OH, serves on the Financial Services Committee, which oversees HUD). Revisions to the original guidelines were necessary because these stakeholders claimed that they created confusion about best management practices, inhibited the efforts of owners and property managers to prevent infestations, and failed to meaningfully address the financial issues between the owner and resident related to recurrent bed bug infestations (NMHC 2012).

The intention of the revision was to ensure that the guidelines recognized the shared responsibilities between property management staff and residents to prevent and eliminate bed bug infestations. The revised guidelines (HUD Notice H 2012-5) apply to all properties receiving HUD assistance, including Section 8 Project Based Rental Assistance, Rent Supplement or Rental Assistance Payment (RAP) contracts; properties with active Section 202 Direct Loans, Section 202/162, Section 202 and 811 Capital Advances, and Section 202 Senior Preservation Rental Assistance Contracts or Section 811 Project Rental Assistance demonstration funding; and properties with active Federal Housing Administration (FHA) insured mortgages. The only exception is that, under the revised guidelines, properties with Section 8, Rent Supplement, or RAP contracts may charge the cost of bed bug treatment to a tenant if they are deemed responsible for the bed bug infestation due to noncompliance. This exception is appropriate and supported by stakeholders because properties with Section 8, Rent Supplement, or RAP contracts are privately managed and the financial support is provided for individual residents, not the property as a whole.

The revised HUD guidelines suggest, but do not require, that O/As adopt an integrated pest management plan that focuses on preventing bed bug infestations. Citing the EPA's principles of bed bug IPM, these guidelines suggest that O/As raise resident and staff awareness through bed bug education and prevention. The IPM principles listed include: (a) inspecting infested areas, plus surrounding living spaces; checking for infestations on luggage and clothes when returning home from a trip; (b) reducing the number of secondhand items brought into units; (c) looking for bed bugs or signs of infestation on secondhand items before bringing the items home; (d) learning to correctly identify the pest; (e) keeping records that include dates and locations where bed bugs were found; (f) cleaning all items within a bed bug infested living area;

(g) reducing clutter where bed bugs can hide; (h) eliminating bed bug habitats; (i) physically removing bed bugs through cleaning; (j) using pesticides carefully according to the label directions; and, (k) following up on inspections and possible treatments. These guidelines go on to suggest that O/As provide training and education to their staff and residents on bed bug identification and IPM methods.

The HUD guidelines require that O/As must provide housing that is "decent, safe, sanitary and in good repair" and "must have no evidence of infestation." For this reason, O/As are financially responsible for bed bug control on their properties (note the previously mentioned exception for Section 8, Rent Supplement, and RAP properties). The guidelines require that O/As must "respond with urgency to any tenant report of bed bugs," but no longer require the inspection of the unit and surrounding units within 3 days or that treatments are scheduled within 24 hours. If a bed bug treatment requires that a resident be temporarily relocated, the relocation must be funded by the O/A, although reimbursement from HUD project funds may be available. In spite of the frequency or duration of bed bug remediation attempts in a single unit, O/As must ensure the right of return for residents that had to be relocated due to their bed bug treatments. However, O/As may deny tenancy to or evict residents with bed bugs, but only after complete adherence to all HUD, federal, state, and local landlord/tenant laws. This option is most likely to be the result of tenant noncompliance.

Bed bug management is a very time-consuming process and requires pest management professionals to implement thorough and tedious treatment strategies to get infestations under control. A highly infested apartment complex can take several months to treat, with new bed bug introductions occurring throughout the treatment process. Because many properties are faced with these recurring infestations, the HUD guidelines state that O/As are allowed to offer "protective tools" to residents to "help safeguard [their] properties from recurrences" and prevent bed bug introductions. Specifically, O/As may volunteer to inspect tenants' furniture before move-in, and may require the subsequent treatment of the furniture if necessary.

In Virginia, apartment management companies have paid anywhere from $8,000 to more than $500,000 in a single year for bed bug treatment. As a result, we have witnessed apartment complexes being sold (disclosure of bed bug infestations is not required in VA) or going into foreclosure as landlords attempt to abandon their infested properties. Consequently, apartment managers are desperate to find a way to keep bed bug costs down. One way to reduce costs is to educate apartment staff and residents about bed bugs, and encourage them to report introductions early before they become infestations. Another way to manage costs is to put preventative measures in place to reduce bed bug introductions or limit their potential spread within a building.

Bed Bug Education Efforts and Resources

Learning about bed bug biology, behavior, and prevention is imperative to their control. While misinformation is readily available on the Internet, there are many reputable sources that that provide accurate bed bug information. Many states, cities, and communities have formed bed bug task forces and resource centers in order to organize area-wide bed bug resources and control efforts. The Central Ohio Bed Bug Task Force, formed in 2008, is a model organization and is comprised of volunteer members from local social services agencies, health departments, fire departments, schools, pest management professionals and government and university representatives. The organization's mission is to provide bed bug resources to the community and to educate central Ohio residents about bed bugs, bed bug prevention, and control methods.

Universities and extension organizations have produced many bed bug resources for the public. The University of Minnesota (St. Paul, MN), with assistance from the Minnesota Department of Health, offers the "Let's Beat the Bug!" program which features a website (www.bedbugs.umn.edu), a direct email address, and a telephone hotline. The intent of this program is to provide information on bed bugs; suggest ways to reduce the number of bed bugs in your home; provide advice on selecting an appropriate pest control company; and give advice on how to avoid bed bugs while traveling, and in everyday life. Oregon State University, in conjunction with the EPA, hosts the National Pesticide Information Center (NIPC), which offers information on understanding and controlling bed bugs (http://npic.orst.edu/pest/bedbug.html). Other universities (The Ohio State University, the University of Kentucky, the University of California at Davis, Rutgers University, etc.) have published bed bug fact sheets aimed at bed bug identification and basic control methods.

In Virginia, the Department of Agriculture and Consumer Services (VDACS) Office of Pesticide Services (OPS) and Dr. Dini Miller (Virginia Tech) have created a bed bug outreach and education program. On the associated website (www.vdacs.virginia.gov/pesticides/bedbugs.shtml), there are thirteen fact sheets that cover basic bed bug information ("How to Identify a Bed Bug Infestation," and "Bed Bug Biology and Behavior"), control methods ("Bed Bug Treatment Using Insecticides," "Using Heat to Kill Bed Bugs," "Non-chemical Bed Bug Management," "Bed Bug Prevention Methods," and "Bed Bug Treatment: What You Should Expect"), and detailed action plans for specific environments (schools, hotels, shelters, apartments, home health care and social workers, migrant worker housing, and emergency facilities and patient transport). All fact sheets are currently available to download in both English and Spanish, and will soon be offered in Mandarin, Nepalese, Hindi, and Arabic. This bed bug resource also offers a full-color picture book entitled “Bed Bugs: How to Protect Yourself and Your Home,” which is intended to help residents prevent bed bug infestations or becoming infested.

Several U.S. authorities have created nationwide bed bug information directories for the general public. The EPA has produced the Bed Bug Information Clearinghouse, which is a searchable web database that compiles bed bug information from federal agencies, state and local governments, extension services, and universities. The main intention of the clearinghouse is to provide a nationwide resource for accurate bed bug and pesticide-related information. The Centers for Disease Control and Prevention (CDC) also hosts a bed bug information website, which includes links to recent scientific publications and resources for health professionals. The National Pest Management Association (NPMA) hosts a website which it describes as “Your One-Stop Shop for All Things Bed Bugs,” and provides pest management professionals and the general public with basic bed bug information, a best practices guideline for handling infestations, current bed bug news, and frequently updated social correspondence (blogs, Twitter feeds, Facebook pages).

To summarize, there are large numbers of past and ongoing studies regarding bed bugs in the United States. Many sources have made bed bug information available to the general public. However, some citizens, particularly those who are suffering from bed bug infestations and those at high risk for bed bug infestations, require bed bug information that is focused on basic bed bug identification, prevention, and control. Greater educational efforts and proactive bed bug control will help, not only those most vulnerable to bed bugs, but our entire society to accept bed bugs as part of our lives from this point forward. The overall hypothesis of this study is that if people are educated and aware of bed bugs, they can use minimally toxic, cost-effective methods to proactively suppress and manage bed bug infestations in low-income multi-unit housing facilities.

Chapter 3. Bed bug response to diatomaceous earth applications in laboratory evaluations

Introduction

Diatomaceous earth (DE) is hydrated amorphous silica, composed of the fossilized skeletons of *Diatomaceae,* a family of aquatic unicellular alga (Calvert 1930). These fossilized diatoms are mined, dried, and pulverized into a fine powder and used for many purposes all over the world (Calvert 1930). The use of diatomaceous earth as an insecticide is based on its absorbent properties. Each diatom has many pores, which allow 89% of its total volume to absorb liquids and oils (Calvert 1930). The mode of action of diatomaceous earth is to act as a desiccant by removing the waterproofing components of the insect epiculticle (Appel et al. 1999). It has been suggested that the abrasive properties of diatomaceous earth also lend themselves to the insecticidal mode of action, because as insects crawl through diatomaceous earth, the particles become imbedded in the cuticle and can rub against other surfaces (Ebeling 1971).

Diatomaceous earth is most commonly used to manage insect pests in bulk grain storage and as a surface treatment inside food storage facilities (Duke 2010). When used outdoors on plants, diatomaceous earth has been determined to effectively manage several species of aphid, including the green peach aphid and the cowpea aphid (Ulrichs et al. 2001, El-Wakeil et al 2009). Indoors, DE has proven effectiveness for treating crawling insect pests in agricultural facilities and in urban environments (Korunic 1998).

The EPA registration for insecticide-grade diatomaceous earth indicates that it is intended for indoor and outdoor use to control ants, cockroaches, fleas, miles, spiders, and other crawling insects, including bed bugs. Diatomaceous earth is effective for killing bed bugs because it can be applied within the bed bug habitat. Benoit et al. (2009b) determined that label rate applications of diatomaceous earth successfully killed first instar and adult female bed bugs in approximately four days. Wang et al. (2009) evaluated a diatomaceous earth-based integrated pest management (IPM) program for bed bug management. The Wang et al. (2009b) study determined that the diatomaceous earth-based IPM program was able to reduce the bed bug populations as well as an insecticide spray program, and was less expensive (Wang et al. 2009b). Diatomaceous earth applications are an effective, inexpensive, and practical non-chemical bed bug management strategy.

Many sources recommend the use of insecticide-grade diatomaceous earth for bed bug control and management. In a joint statement from the U.S. Centers for Disease Control and Prevention (CDC) and the EPA, diatomaceous earth is suggested as a low risk pesticide that should be included in a comprehensive IPM program to control bed bugs (2013). The U. S. Department of Defense's Armed Forces Pest Management Board lists diatomaceous earth as a bed bug control product that offers residual activity when applied correctly (Harlan 2012). University extension publications across the United States recommend diatomaceous earth as a minimally toxic product for bed bug management in homes, schools, multi-unit housing facilities, and shelters (Davis 2009, Miller 2009b, Bennett and Buczkowski 2012, Shindelar and Kells 2012, Potter 2012, Sutherland et al. 2013).

The purpose of this study was to determine the response of the bed bug, *Cimex lectularius*, to diatomaceous earth applications in laboratory evaluations. Our intention was to evaluate bed bug response (both pyrethroid-susceptible and pyrethroid-resistant strains) when exposed to different diatomaceous earth products and at different rates. Further, our intention was to determine if different diatomaceous earth products, application rates, or the feeding status of a bed bug would significantly influence the time to mortality.

Materials and Methods

Insects

Bed bugs from five different strains were used in laboratory bioassays. All five strains were maintained at the Dodson Urban Pest Management Laboratory at Virginia Tech, Blacksburg, VA. The first strain (Harlan) was a pyrethroid-susceptible laboratory strain acquired from Dr. Harold Harlan (National Pest Management Association, Fairfax, VA) in February 2005. Dr. Harlan originally collected this strain from Fort Dix, NJ and maintained the colony by feeding them on himself for over 37 years. The second bed bug strain (British) was a pyrethroid-susceptible laboratory strain collected in September 2006 from an apartment in London, England. A portion of this population was sent to the Dodson Urban Pest Management Laboratory in 2008 (Siva-Jothy 2008). The third bed bug strain was a field strain (Epic Center), which was collected from an apartment building in Cincinnati, OH, in 2009. The fourth bed bug strain was a field strain (Kramer), which was collected in 2006 from an apartment building in Arlington, VA. The fifth strain (Richmond) was also a field strain collected in 2008 from a group home for adult residents in Richmond, VA. The Epic Center, Kramer, and Richmond strains had high levels of resistance to pyrethroids relative to the susceptible Harlan strain. However, since 2011, the Kramer strain has shown a declining level of resistance to pyrethroid insecticides (Polanco et al. 2011a).

Bed bug colonies were kept in plastic jars (55 mm x 70 mm) with twist-off lids (Fisher Scientific International; Hampton, NH). The jars were inverted and the original bottoms were removed and replaced with mesh fabric to allow for feeding and airflow. Bed bug colonies were fed weekly with defibrinated rabbit blood (Hemostat Laboratories, Dixon, CA) using an artificial feeding system, that uses circulating water (~37°C) to warm the blood. Between feedings, colonies of bed bugs were kept in an environmental chamber at approximately 28°C, 55% RH, and a photoperiod of 12:12 h L:D cycle. None of the colonies were exposed to insecticides while in the laboratory.

Diatomaceous Earth Product Efficacy on Different Surfaces

Preliminary assays evaluated bed bug response to applications of four different diatomaceous earth products on three different household surface types. The four diatomaceous earth products were Safer® Brand Ant & Crawling Insect Killer (78% silicon dioxide from diatomaceous earth; Woodstream Corporation, Lilitz, PA), Harris® Bed Bug Killer (85% silicon dioxide from diatomaceous earth; P. F. Harris Manufacturing Company, LLC, Alpharetta, GA), PermaGuard™ Household Insecticide (85% silicon dioxide from diatomaceous earth, 1% piperonyl butoxide, 0.2% pyrethrins; Perma-Guard Inc., Bountiful, UT), and MotherEarth® D Pest Control Dust (100% diatomaceous earth; BASF Corporation, St. Louis, MO). Each product was applied using a handheld bulb duster at rates specified by the product label (Table 3-1) to three surface types of different porosity: painted white pine (10 x 10 cm; 2.5 cm thick), unpainted white pine (10 x 10 cm panels; 2.5 cm thick), and cotton fabric squares (10 x 10 cm; 0.1 cm thick). Each product had 5 replications per surface type. One panel of each surface type was left untreated to serve as a control.

Prior to testing, groups of 10 adult male bed bugs (Harlan pyrethroid-susceptible strain) were removed from their rearing containers with soft forceps and separated into Petri dishes (35 x 10 mm, FisherBrand, Pittsburg, PA). When ready for testing, the bottom half of each Petri dish containing bed bugs was inverted onto each panel then left in place to contain the bed bugs throughout the course of the bioassay. Bed bug mortality was recorded for each product on each surface at regular intervals until 100% mortality was achieved. The results of this assay allowed us to select the most effective product for use in all subsequent assays.

Desiccant Dust Product Comparison

The time to mortality for bed bugs exposed to three different desiccant dust products was determined. The three products were Prescription Treatment® brand Alpine® Dust Insecticide (0.25% dinotefuran, 95% diatomaceous earth; BASF Corporation, St. Louis, MO), CimeXa™ Insecticide Dust (100% amorphous silica gel; Rockwell Labs, Ltd., North Kansas City, MO), and MotherEarth® D Pest Control Dust (BASF Corporation, St. Louis, MO). Prior to application, each product was weighed to ensure that we applied the label volume (Table 3-2). Each of the products were then applied to hardboard panels (10 replications; 7 x 7 cm) using a cotton swab. Ten additional hardboard panels were left untreated to serve as controls.

Prior to testing, replicates of five adult male bed bugs (Epic Center pyrethroid-resistant strain) were removed from rearing containers and placed into separate Petri dishes (35 x 10 mm, FisherBrand, Pittsburg, PA). At the beginning of the assay, the bottom half of the Petri dish containing bed bugs was inverted onto each panel. Petri dishes were left over top of the bed bugs to contain them throughout the assay. Bed bug mortality was recorded for each product at regular intervals until it reached 100%. After complete mortality had been reached, each replicate of five insects was dried (~ 80°C for 24 h) to control for relative humidity, and weighed. Weights were recorded and used to determine the amount of dust on the bed bugs at the time of desiccation.

Diatomaceous Earth Efficacy and Feeding Status

The time to mortality of starved and recently fed adult male bed bugs (Harlan, British, Epic Center, Kramer, and Richmond strains) exposed to diatomaceous earth applications was compared. Hardboard panels (10 x 10 cm) were treated with MotherEarth® D Pest Control Dust at the label rate (at least 1.6 oz/100ft^2) using a power duster (Exacticide duster; Technicide™, San Clemente, CA, or Cyclone Duster; GL Enterprises, New Braunfels, TX). The amount of diatomaceous earth applied to each panel ranged from 49 mg to 100 mg.

Prior to testing, 400 individual adult male bed bugs from each strain (Harlan, British, Epic Center, Kramer, and Richmond) were removed from rearing containers and separated into 2 groups of 200 each. One group of 200 bed bugs from each strain were further separated into groups of 10 and placed in individual Petri dishes (35 x 10 mm) containing a folded piece of filter paper for a harborage. These bed bugs were denied access to blood meals (starved) for 14 days prior to the beginning of the bioassay. The second group of 200 bed bugs from each strain were placed in a rearing jar and stored in an environmental chamber at approximately 28°C, 55% RH and a photoperiod of 12:12 h L:D cycle. These bed bugs were fed defibrinated rabbit blood as previously described, 18 hours before beginning the bioassay. Approximately 2 hours before the bioassay, recently fed bed bugs were separated into groups of 10 and placed in individual Petri dishes. Two replicates of 10 adult male bed bugs (14-day starved and recently fed) from each bed bug strain (Harlan, British, Epic Center, Kramer, and Richmond) were prepared to serve as controls.

When ready for testing, the bottom half of each Petri dish containing a group of 10 bed bugs was inverted over a diatomaceous earth-treated panel, then left in place, so that bed bugs would be constantly exposed to the diatomaceous earth. Petri dishes containing bed bugs prepared for control replicates were inverted onto untreated hardboard panels. For each bed bug strain, 10 replicates of starved bed bugs and 10 replicates of recently fed bed bugs, as well as a control of 10 bed bugs for each, were observed. Mortality was recorded at regular intervals until it had reached 100%.

Bed Bug Response to Variation in Diatomaceous Earth Application Rate

Adult male bed bugs from three bed bug strains (Harlan, Kramer, and Richmond) were exposed to applications of diatomaceous earth (MotherEarth® D Pest Control Dust) at four different variations of the label rate (0.1x, 0.5x, 1x, and 2x). Prior to the start of the assay, adult male bed bugs from each strain (5 days post-feeding) were separated from rearing colonies into cohorts of ten replications (n = 5) and placed in individual Petri dishes (35 x 10 mm).

For each strain, four groups of ten hardboard panels (10 x 10 cm) were treated with a precise amount of diatomaceous earth: 2.4 mg (0.1x LR); 12.0 mg (0.5x LR); 23.3 mg (1x LR); and 47.9 mg (2x LR). The exact amounts of diatomaceous earth were calculated based on the area of the hardboard panels, weighed on a balance, and applied to each hardboard panel using a cotton swab. When ready for testing, the bottom half of each Petri dish containing a group of five bed bugs was inverted over a treated panel and left in place, so that bed bugs would be constantly exposed to the diatomaceous earth. Petri dishes containing bed bugs prepared for control replicates were inverted onto untreated hardboard panels. For each bed bug strain, there were ten replicates exposed to each of the four label rate (LR) variations, as well as two control replicates. Mortality was recorded at 24-hour intervals until all insects were dead (i.e. 24h, 48h, 72h, 96h, 120h, 144h, etc.). After complete mortality had been reached, each replicate of five insects was dried at approximately 80° C for 24 h, to control for relative humidity. After drying, each replicated weighed in order to determine the amount (mg) of DE on the bed bugs at desiccation.

Statistical Analysis

Diatomaceous Earth Product Efficacy on Different Surfaces. Mortality observed in the control replicates was corrected using Abbott's formula (Abbott 1925). Comprehensive mortality observations were fit to a Probit regression model (Robertson et al. 2003). The lethal time to mortality for 50% of the population (LT_{50}) was calculated for each product and surface type using Probit analysis (PoloPlus®, LeOra Software Company, Petaluma, CA). LT_{50} values were compared by product and surface type and significant differences between treatments were determined by the failure of the 95% confidence intervals to overlap. The mean time to 100% mortality was calculated for each product and surface type. Means were compared using analysis of variance (ANOVA), where values of $P \leq 0.05$ were used to indicate significant differences (JMP Pro 10, SAS Institute Inc., 2012).

Desiccant Dust Product Comparison. Mortality observed in the control replicates was corrected using Abbott's formula (Abbott 1925). LT_{50} values were calculated for each product and surface type using Probit analysis (PoloPlus®), where significant differences between treatments were determined by the failure of the 95% confidence intervals to overlap. The mean total times to mortality were calculated for each product and were compared using analysis of variance (ANOVA), where $P \leq 0.05$ indicated significance (JMP Pro 10).

To determine if there were differences in the amount of dust required to desiccate a bed bug for each of the products, the mean amount of insecticidal dust per set of bed bug replicates was determined. To calculate this, the mean weight of the replicates of dead control bed bugs was subtracted from the weight of each replicate of dead treated bed bugs for each amorphous silica product. Oneway analysis of variance (ANOVA) compared the mean amounts of insecticidal dust per replicate of desiccated insects (JMP Pro 10). Means were separated for all product pairs using the Tukey-Kramer (HSD) test, where significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10).

Diatomaceous Earth Efficacy and Feeding Status. Mortality observed in the control replicates was corrected using Abbott's formula (Abbott 1925). In order to estimate the time required to kill 50% of the test population, LT_{50} values were compared by feeding status and by strain. Significant differences between treatments were determined by the failure of the 95% confidence intervals to overlap. The mean times to 100% mortality for each strain and feeding status were compared using oneway analysis of variance (ANOVA) and separated using the Student's *T* test, with values of $P \leq 0.05$ indicating significance (JMP Pro 10). The least squares mean times to 100% mortality were separated by feeding status using the Student's *T* test to determine if fed bed bugs desiccated more rapidly than starved bed bugs (JMP Pro 10). Values of $P \leq 0.05$ were used to indicate significance. Mean total time to mortality was also compared by bed bug strain (Student's *T* test, $P \leq 0.05$; JMP Pro 10) to determine if pyrethroid-susceptible strain bed bugs desiccated more rapidly than pyrethroid-resistant strain bed bugs.

Bed Bug Response to Variation in Diatomaceous Earth Application Rate. Mortality observed in the control replicates was corrected using Abbott's formula (Abbott 1925). For each bed bug strain, the lethal time required to kill 50% of bed bugs (LT_{50}) was calculated for four different application rates (0.1x LR, 0.5x LR, 1x LR, and 2x LR). LT_{50} values were determined by fitting application rate variations and observed mortality to a Probit regression model

(PoloPlus®). At each application rate, significant differences between LT_{50} values for each bed bug strain were determined by the failure of the 95% confidence intervals to overlap. Correlation between the LT_{50} values of different application rates was determined for each strain using nonlinear regression analysis (JMP Pro 10).

The mean amount of diatomaceous earth on a bed bug at the time of desiccation was calculated to determine if a bed bug could pick up a lethal amount of diatomaceous earth from applications that were greater or less than the specimen label rate. For each treatment, the mean weight of the replicates of dead control bed bugs was subtracted from the weight of each replicate of dead treated bed bugs for each diatomaceous earth product. Oneway analysis of variance (ANOVA) was used to compare the mean amounts of diatomaceous earth per replicate of desiccated insects. Significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10). Within each bed bug strain, significant differences in the mean diatomaceous earth weights were determined for all application rate variations using the Tukey-Kramer (HSD) test ($P \leq 0.05$; JMP Pro 10).

In order to determine significant differences between the times to mortality at different application rates, the mean total number of days to mortality was calculated for each application rate and each bed bug strain. Means were compared using analysis of variance (ANOVA), and separated using the Tukey-Kramer (HSD) test ($P \leq 0.05$; JMP Pro 10). To determine significance within each bed bug strain, pairwise comparisons of the mean times to mortality of each application rate were made using the Student's *T* test ($P \leq 0.05$; JMP Pro 10).

Results

Diatomaceous Earth Product Efficacy on Different Surfaces

There were no significant differences between the LT_{50} values (18.9h - 24.4h) for the diatomaceous earth products on painted pine surfaces. However, on the untreated pine panels, the LT_{50} value for Safer® Brand Ant & Crawling Insect Killer was significantly greater (32.1h) than the other three diatomaceous earth products tested (Table 3-3). Also, on the fabric surfaces, the LT_{50} value for Harris® Bed Bug Killer was significantly greater (100.1 h) than the other three diatomaceous earth products. On all three surfaces, MotherEarth® D Pest Control Dust had the lowest LT_{50} values.

There were no significant differences between the mean times to 100% bed bug mortality for the four diatomaceous earth products or between the three surface types. The total time required to kill all bed bugs in this study was 165.5 h (6.9 d). The last insect to die was exposed to Harris® Bed Bug Killer on a fabric surface. The fastest mean time to 100% mortality was 47.3 h (~2 d) for bed bugs exposed to treatments of MotherEarth® D Pest Control Dust (all surface types). The mean time to 100% mortality for bed bugs exposed to PermaGuard™ Household Insecticide was 2d 12h. The two slowest mean times to 100% mortality were 110.7 h (4.6 d; Harris® Bed Bug Killer) and 115.0 h (4.8d; Safer® Brand Ant & Crawling Insect Killer).

Desiccant Dust Product Comparison

The LT_{50} value for bed bugs exposed to CimeXa™ Insecticide Dust was 4.4 h, which was significantly less than the other two products tested in this study (Table 3-4). The LT_{50} values for bed bugs exposed to Prescription Treatment® Alpine® Dust Insecticide and MotherEarth® D Pest Control Dust were 10.1 h and 9.9 h, respectively. The total time required to kill all bed bugs in this study was 48.3h. The mean time to 100% mortality for bed bugs exposed to treatments of CimeXa™ Insecticide Dust was 5.9 h, which was significantly less ($P < 0.001$) than the other two desiccant products tested. The mean times to 100% mortality for Prescription Treatment® Alpine® Dust Insecticide were 20.1h and for MotherEarth® D Pest Control Dust was 17h 46m.

Among the three desiccant dust products evaluated, the only significant difference in the mean amount of insecticidal dust per replicate of five adult male bed bugs after desiccation and death was between MotherEarth® D Pest Control Dust (4.9 mg) and CimeXa™ Insecticide Dust (3.95 mg). The mean amount of Prescription Treatment® Alpine® Dust Insecticide dust on a replicate of bed bugs after desiccation (4.70 mg) was not significantly different from either of the other two desiccant dust products evaluated.

Diatomaceous Earth Efficacy and Feeding Status

For the different bed bug strains evaluated, the LT_{50} values of the 14-day starved bed bugs were significantly less than the LT_{50} values of the recently fed bed bugs, with the exception of the Kramer strain, in which the LT_{50} value of the 14-day starved bed bugs was significantly greater than the LT_{50} value of the recently fed bed bugs. There were also significant differences in the LT_{50} values of different bed bug strains of the same feeding status (Table 3-5).

The total time required to reach 100% mortality for all bed bugs in this study was 100 hours. Overall, the mean time to 100% mortality for recently fed bed bugs was significantly greater than the mean for starved bed bugs. There were no significant differences between mean times to 100% mortality for bed bugs from different strains. However, when mean times to 100% mortality were compared by feeding status, there were significant differences among the bed bug strains (Table 3-6). The mean times to 100% mortality for recently fed bed bugs from the Epic Center and Richmond strains were significantly greater than the mean times to mortality for 14-day starved bed bugs, while within the Kramer strain, the mean time to mortality for recently fed bed bugs was significantly less than the mean time to mortality for starved bed bugs.

Bed Bug Response to Variation in Application Rate

For each bed bug strain, LT_{50} values were calculated for the bed bug response to different application rates of diatomaceous earth (Table 3-7). Because the Richmond strain bed bugs died more rapidly than the other strains, the lowest LT_{50} value observed was 18.1 h at 1x LR. However, within the Richmond strain, the LT_{50} value at 1x LR was not significantly different from the LT_{50} value calculated 2x LR (24.6 h). Logistic regression analysis of LT_{50} values indicated a strong dose-response relationship for the Harlan strain (R^2=0.956) and slightly strong dose-response relationship for the Kramer (R^2=0.873) and Richmond (R^2=0.845) bed bug strains. (Figure 3-1).

Overall, when mean amount of diatomaceous earth per bed bug replicate were compared, the Kramer strain bed bugs (4.6 mg) had significantly more diatomaceous earth on their bodies than either the Harlan (2.5 mg) and Richmond strain bed bugs (3.0 mg). Interestingly, the mean amounts of diatomaceous earth per replicate at 1x LR was not significantly different from the means at 2x LR for all bed bug strains evaluated. However, the overall mean amount of diatomaceous earth per replicate at 0.1x LR (1.2 mg) was significantly less than the mean amount at 0.5x LR (3.3 mg), and both were less than the means at 1x LR (4.1 mg) and 2x LR (4.8 mg). When comparisons were made between application rates within each bed bug strain, there were also similar significant differences in the mean amounts of diatomaceous earth per desiccated bed bug replicate (Table 3-8). In each bed bug strain, the mean amounts of diatomaceous earth per replicate exposed to 0.1x LR applications of diatomaceous earth, were significantly lower than those of all other application rates.

The total time required to reach 100% mortality for all bed bugs evaluated in this study was 12 days. The overall mean time to reach 100% mortality for Richmond strain bed bugs (49.8 h) was significantly less than that of both Harlan (93.6 h) and Kramer strain bed bugs (84.0 h) at all application rates. In all bed bug strains, the mean time to reach 100% mortality at 1x LR was not significantly different from the mean at 2x LR. However, for all bed bug strains the overall mean time to 100% bed bug mortality at 0.1x LR (163.2 h) was significantly greater than the overall means at higher rates: 0.5x LR (66.4 h); 1x LR (36.8 h); and 2x LR (36.8 h). When individual comparisons were made between application rates within a bed bug strain, there were significant differences in the mean times to 100% mortality (Table 3-9).

Discussion

Very few laboratory studies have evaluated bed bug response to diatomaceous earth applications. However, the effects of diatomaceous earth and desiccant dust insecticides on other insect pests have been widely studied. Vayias et al. (2005) evaluated the effects of three diatomaceous earth products on confused flour beetle pupae and determined that certain products performed better than others. While all of the products produced mortality, the percent mortality ranged from 34% to 100%, based on which product was used.

Because diatomaceous earth and inert dust insecticides are often used as surface treatments to kill stored-products pests in food storage and production facilities, studies have evaluated insect responses to dust applications on different surface types, including aluminum

(McLaughlin 1994), fabric (Wang et al. 2013), glass (Athanassiou and Palyvos 2006, Wakil et al. 2010), wood (Collins and Cook 2008), and vinyl (Gowers and le Patourel 1984).

In our study, we evaluated four diatomaceous earth insecticide products on three different surface types in order to determine which product would be most effective for use in future bioassays (Table 2-1). The statistical analysis indicated that there were no significant differences between the mean times to 100% bed bug mortality for the four diatomaceous earth products or the three surface types. However, bed bugs exposed to treatments of MotherEarth® D Pest Control Dust had the lowest LT_{50} values and reached 100% mortality more rapidly on all three surface types than the other products tested. In addition, MotherEarth® D Pest Control Dust was the only product tested that was 100% diatomaceous earth. Therefore, the MotherEarth® D product was chosen for use in subsequent bioassays. Hardboard panels, though not evaluated in the surface type comparison, were used in subsequent bioassays because they are widely used in laboratory insecticide evaluations and because we found no significant differences among the surface types that we tested.

Studies have also evaluated insect responses to insecticide dusts with varying compositions, especially dusts primarily formulated with diatomaceous earth and amorphous silica. Athanassiou et al. (2011) evaluated coleopteran grain pest responses to ten freshwater products and one commercial formulation of diatomaceous earth, which were all mined from different sources. Athanassiou et al. (2011) determined that there were significant differences in the times to complete insect mortality based on the product used. Saez and Fuentes Mora (2007) evaluated the efficacy of freshwater and marine diatomaceous earth products used to control four species of insect grain pests. Saez and Fuentes Mora (2007) determined that the composition of diatomaceous earth products significantly contributed its efficacy, and that freshwater diatomaceous earth products were ultimately more effective as an insecticide. Rojht et al. (2010) geochemically analyzed the rock composition of diatomaceous earth collected from different geographical locations and determined that, if present in diatomaceous earth, certain minerals (Al_2O_3, Fe_2O_3, K_2O, TiO_2, Cr_2O_3, P_2O_5, and MgO) played a significant role in effectively killing adult rice weevils. Shawir et al. (1988) determined that when amorphous silica was added to certain insecticides (malathion, pirimiphos methyl), they became more toxic to species of grain beetle, and less toxic to humans. The Shawir et al. (1988) observation led chemical manufacturers to use amorphous silica as a pesticide carrier in many insecticidal dust formulations. Vayias et al. (2009) evaluated the effectiveness of diatomaceous earth combined with the insecticide spinosad for control different tenebrionid species and determined that beetle survival decreased as the percentage of diatomaceous earth in the spinosad formulation increased.

In our study, we compared three different formulations of desiccant dust products.. Interestingly, Prescription Treatment® Alpine® Dust Insecticide was the only product with an additional insecticide component, but had both the greatest LT_{50} value (10.1h) and took the longest to produce 100% bed bug mortality (~20h). MotherEarth® D Pest Control Dust was the only product composed of 100% diatomaceous earth. CimeXa™ Insecticide Dust was composed of 100% synthetic amorphous silica gel. The LT_{50} value for MotherEarth® D Pest Control Dust (9.9h) was approximately two times greater than the LT_{50} value for CimeXa™ Insecticide Dust (4.4h). This was also reflected in the times to 100% mortality, where MotherEarth® D Pest Control Dust took three times longer (~18h) than CimeXa™ Insecticide Dust (~6h) to reach 100% mortality.

While applying the CimeXa™ Insecticide Dust, we noticed that the consistency of the dust was much lighter than the consistency of products made with diatomaceous earth. The CimeXa™ consistency may make it a superior bed bug killer, however, the lighter consistency may make the product more prone to disruption by air currents and may be transferred to non-target locations in people's homes. Amorphous silica products should be evaluated further in the future, both in the laboratory and the field.

The amount of desiccant dust on a replicate of bed bugs after their death was particularly interesting. There was less insecticide dust on the bed bugs treated with CimeXa™ Insecticide Dust than on the bed bugs treated with either of the other desiccant products tested. CimeXa™ Insecticide Dust was particularly remarkable because, although bed bugs had less dust on their bodies (3.95 mg), they were killed more rapidly than those treated with the other desiccant products. These results indicated that the 100% amorphous silica composition of CimeXa™ Insecticide Dust may be more effective for bed bug desiccation than the diatomaceous earth composition of the other two products evaluated. Also of note, because the amount of dust observed on the bed bugs exposed to Prescription Treatment® Alpine® Dust Insecticide was not significantly different from the other two desiccant dust products, we can assume that the addition of dinotefuran did not significantly contribute to the product's efficacy. While there are several more desiccant dust products that are registered for use to control bed bugs, only three were evaluated in this study. Additional product formulations should be evaluated for bed bug efficacy to determine which product is truly the most effective.

When some insects feed, particularly haematophageous insects, their abdomens expand and increase the surface areas of their bodies (Usinger 1966). This increased surface area makes more of the insect cuticle available for insect contact. David and Gardiner (1950) documented factors that influenced the action and efficacy of insecticidal dusts. They particularly noted that the abdomens of crawling insects were the most susceptible to picking up dusts as the insects moved through their environments. Benoit et al. (2007) determined that blood-feeding is responsible for the majority of the internal body water content of bed bugs. The combined effects of increased moisture content and abdominal surface area after blood-feeding make bed bugs highly susceptible to desiccation. In contrast, some insect species (i.e. Merchant grain beetle, confused flour beetle, and German cockroach), are more susceptible to desiccation and insecticide exposure after the prolonged deprivation of food (White and Loschiavo 1989, Kramer et al. 1990).

In our study, we determined that 14-day starved bed bugs exposed to label rate applications of MotherEarth® D Pest Control Dust died more rapidly than recently fed bed bugs exposed to the same treatment. For the pyrethroid-susceptible strain bed bugs (Harlan and British), statistical analysis determined that neither the LT_{50} values nor the times to 100% mortality for starved bed bugs were different from those values for recently fed bed bugs. These bioassays indicated that feeding status had no effect on bed bug mortality in pyrethroid-susceptible bed bugs.

However, in the pyrethroid-resistant bed bugs strains, statistical analysis determined that there were significant differences between the LT_{50} values and time to mortality of starved bed bugs and recently fed bed bugs. In the Epic Center and Richmond strains, starved bed bugs died more rapidly than recently fed bed bugs. However, in Kramer pyrethroid-resistant strain bed bugs, recently fed bed bugs died more rapidly than the starved bed bugs. Recent studies of these pyrethroid-resistant bed bug strains have been conducted at Virginia Tech. Koganemaru et al. (2013) determined that Richmond strain bed bugs exhibited high levels of cuticular penetration resistance to pyrethroid insecticides and had physically thicker cuticles as compared to the Harlan strain. Polanco et al. (2011) determined that the Kramer strain also has a declining level of resistance to pyrethroid insecticides. Our results suggest that, as pyrethroid resistance changes within a bed bug strain, bed bugs may also physically change, which could influence the efficacy of diatomaceous earth for bed bug control. The effect of bed bug feeding status should be further evaluated in order to determine its affect on insecticides, dusts, or other bed bug control products.

When applying diatomaceous earth in urban environments, it is often difficult to ensure that the label rate has been applied evenly or precisely in all locations. Studies have been conducted using many different insecticide products to evaluate insect mortality at different application rates. Manda et al. (2013) evaluated the frequency of mosquito contact (and subsequent mortality) with pyrethroid insecticides and determined that there was significant mosquito mortality at half of the label rate. Gowers and le Patourel (1983) evaluated grain beetle response to insecticide dust and determined that the amount of insecticide dust picked up by a beetle reached a maximum within approximately 12h, regardless of the application amount. Gowers and le Patourel (1983) also suggested that the maximum amount of dust picked up from a surface within 24h was not correlated with the toxicity of the insecticide. Therefore, a beetle might acquire a lethal dose of insecticide dust without picking up its maximum load of dust. Very few laboratory studies have evaluated different application rates of desiccant dusts. A recent laboratory evaluation determined that bed bugs were able to horizontally transfer lethal amounts of diatomaceous earth to other bed bugs when one treated bed bug was exposed to five untreated bed bugs (Akhtar and Isman 2013). To our knowledge, there have been no studies evaluating diatomaceous earth application rates or minimum dust volumes required for the desiccation and subsequent death of bed bugs.

In our study, we determined that there were no significant differences in the amount of diatomaceous earth on the desiccated bed bugs between those exposed to the label rate and those exposed to twice the label rate. This result suggests that the bed bug cuticle can pick up a finite amount of dust and that over-applications do not increase the efficacy of the product. At one-tenth (0.1x LR) and half (0.5x LR) of the label rate, bed bugs died much more slowly than at the 1x LR and 2x LR and had significantly less diatomaceous earth on their bodies. However, 100% mortality was eventually achieved for all bed bugs, indicating that diatomaceous earth applied at rates as low as one-tenth of the label rate will eventually provide a lethal dose to desiccate bed bugs after constant exposure.

Interestingly, the pyrethroid-resistance level of a bed bug strain played a role in the rate of bed bug mortality at different diatomaceous earth application rates. Richmond strain bed bugs, which were the most pyrethroid-resistant insects evaluated, died significantly faster than bed bugs of the other two strains. Within the Richmond strain, the amounts of diatomaceous earth on the desiccated bed bugs at 2x LR were not significantly less than the amounts at 1x LR or at 0.5x LR, but both amounts were significantly greater than at 0.1x LR. The Richmond strain is known for having reduced cuticular penetration-type resistance, due, in part, to the increased up-regulation of bed bug cuticular proteins (Koganemaru et al. 2013). Increased numbers of cuticular proteins have made the bed bug cuticles more dense, which may allow Richmond strain bed bugs to pick up significantly more diatomaceous earth than pyrethroid susceptible strain bed bugs.

In this study, we evaluated many factors that have influenced the effectiveness of diatomaceous earth applications. Overall, however, diatomaceous earth was shown to be efficacious for killing bed bugs in the laboratory. In the field, other factors such as bed bug life stage, environmental temperature and humidity, and application location may affect the success of diatomaceous earth when used for bed bug control. While only five diatomaceous earth insecticide products and one amorphous silica insecticide product were tested in this study, many more desiccant dusts are available and labeled for bed bugs. Future evaluations of diatomaceous earth and other desiccant dusts for bed bug control should be conducted in both the laboratory and the field.

Table 3-1. Comparison of the active ingredients and product label instructions for four different diatomaceous earth insecticide products used in an evaluation of the effects on bed bug mortality.

Product	Active Ingredients	Label Instructions
Safer® Brand Ant & Crawling Insect Killer	Silicon dioxide from diatomaceous earth (78.0%)	**Indoor Use**: Lift open spout to desired setting and lightly coat a thin layer of dust in the areas where these pests are found or may hide. **Bed Bugs:** Take bed apart. Dust into joints and channels. If hollow, such as square or round tubing, see that the interior of the framework is well dusted. Mattresses should be dusted, especially tufts, folds and edges. Picture frame molding and all cracks and crevices in the room should be treated.
Harris® Bed Bug Killer	Silicon dioxide from diatomaceous earth (85.0%)	**Indoor and Outdoor Applications:** This product is intended for application with a hand duster, power duster or other similar means for application to areas where crawling insects are found. Apply this product to cracks and crevices with the use of a bulbous duster or other suitable equipment. Apply lightly and uniformly. **Bed Bugs:** Dismantle bed. Use this product in joints, crevices and where rungs are inserted. See that all interior areas are dusted. Dust mattresses, especially folds and edges. All cracks and crevices in the bedroom should be treated.
PermaGuard™ Household Insecticide	Silicon dioxide from diatomaceous earth (85.0%) Technical piperonyl butoxide (1.0%) Some pyrethrins (0.2%)	**Bed Bugs:** Take bed apart. Dust directly into all cracks, joints & inside framework, as well as box springs. Dust tufts, folds & edges of mattress. Cover mattresses after treatment. Picture frames, moldings & cracks or crevices in the room must also be treated for best results.
MotherEarth® D Pest Control Dust	Diatomaceous earth (100%)	**Bed Bugs:** Apply at a minimum rate of 1.6 oz/100ft^2 to cracks, crevices and voids associated with mattresses, box springs, bed frames and other furniture where these insects may harbor, travel, breed or enter the room. Treat mattresses, especially tufts, folds and edges. Cover with clean bedding before using. Bed Bugs may also harbor in areas of the room away from the bed or furniture. Apply product to wall voids, behind wall hangings, floor molding, window casings, carpet's edge, popcorn ceilings and other cracks, crevices or voids.

Table 3-2. Comparison of the active ingredients and product label instructions for three desiccant dust products used in an evaluation of bed bug mortality.

Product	Active Ingredients	Application Rate	Label Instructions
MotherEarth® D Pest Control Dust	Diatomaceous earth (100%)	At least 1.6 oz/100 ft^2 23.9 mg[1]	**Bed Bugs:** Apply at a minimum rate of 1.6 oz/100ft^2 to cracks, crevices and voids associated with mattresses, box springs, bed frames and other furniture where these insects may harbor, travel, breed or enter the room. Treat mattresses, especially tufts, folds and edges. Cover with clean bedding before using. Bed Bugs may also harbor in areas of the room away from the bed or furniture. Apply product to wall voids, behind wall hangings, floor molding, window casings, carpet's edge, popcorn ceilings and other cracks, crevices or voids.
Prescription Treatment® brand Alpine® Dust Insecticide	Dinotefuran (0.25%) Diatomaceous earth (95%)	0.16 - 0.32 oz/10 ft^2 23.9-47.9 mg[1]	**Bed Bugs:** Apply to cracks and crevices where evidence of bed bugs occurs. This includes bed frames, box springs, inside empty dressers, clothes closets and carpet edges, high and low wall moldings and wallpaper edges. Do not use this product on mattresses, pillows, bed linens, or clothes. Remove all clothes and other articles from dressers or clothes closets before application. Reapply as necessary. Direct contact with dry dust is required to be effective. Not recommended for use as sole protection against bed bugs. If evidence of bed bugs is found in/o mattresses, use products approved for this use.
CimeXa™ Insecticide Dust	Amorphous silica gel (100%)	2 oz/100 ft^2 29.9 mg[1]	**Bed Bug Treatment**: Remove bedding and take the bed apart. Treat the interior framework, joints and cracks in the bed frame. Treat the mattress and box spring, paying particular attention to tufts, folds, and edges, and then interior framework of the box spring. Remove wall-mounted headboards and treat the backside. Treat picture frames, moldings, hollow furniture legs, cracks and crevices, along baseboards, and any areas with visible signs of infestation, including rugs and carpets. Treat upholstered furniture by removing or lifting (if possible) the cushions and treating the undersurface. Treat the interior framework, cracks and crevices and joints of the furniture, and the folds, tufts and edges of cushions and other upholstered areas. Do not treat toys and stuffed animals with product. Treat wall voids by removing electrical switch plate covers to allow access, but don't apply dust directly in electrical boxes. Apply about 1/4 oz of dust to each accessible void.

1. Application amounts were calculated based on the label rate of application for the surface area of the hardboard panels (7 x 7 cm)

Table 3-3. Comparison of the lethal times (h) to mortality for 50% of the bed bug population (LT_{50}) exposed to four diatomaceous earth insecticide products on three different surface types.

	Diatomaceous Earth Products			
Surface Type	MotherEarth® D Pest Control Dust LT_{50} (h)	PermaGuard™ Household Insecticide LT_{50} (h)	Harris® Bed Bug Killer LT_{50} (h)	Safer® Brand Ant & Crawling Insect Killer LT_{50} (h)
Untreated Pine	12.5 A	16.6 A	16.3 A	32.1 B
Painted Pine	18.9 C	19.4 C	24.2 C	24.4 C
Cotton Fabric	35.8 D	45.5 D	100.1 E	44.1 D

1. Five replications of ten adult male bed bugs from the Harlan pyrethroid-susceptible strain were evaluated for each product and on each surface-type.
2. LT_{50} values within each row (surface type) that are not followed by the same letter are significantly different.
3. Significant differences were determined by the failure of the 95% confidence intervals to overlap (PoloPlus, Leora Software, Inc.).

Table 3-4. Comparison of the lethal times (h) to mortality for 50% of the bed bug population (LT_{50}) exposed to label rate applications of three desiccant dust products and the mean amount (mg) of desiccant dust per replicate of five adult male bed bugs.

	Desiccant Dust Products		
	Mother Earth® D Pest Control Dust N = 50	Prescription Treatment® Alpine® Dust Insecticide N = 50	CimeXa™ Insecticide Dust N = 50
LT_{50} (h)[2,3]	9.9 A	10.1 A	4.4 B
Mean amount of desiccant dust (mg) ±SE [4,5,6]	4.9 (±0.3) a	4.7 (±0.2) a	4.0 (±0.3) b

1. Ten replicates of five adult male bed bugs from the Epic Center pyrethroid-resistant strain were evaluated for each product
2. Significant differences were determined by the failure of the 95% confidence intervals to overlap.
3. LT_{50} values that are not followed by the same letter are significantly different.
4. The amount of desiccant dust applied to each panel (7 x 7 cm) was calculated based on the surface area.
5. Means were compared using the Tukey-Kramer HSD test, where significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10, SAS Institute Inc., 2012).
6. Means that are not followed by the same letter are significantly different.

Table 3-5. Comparisons of the lethal times (h) to mortality for 50% of the bed bug populations (LT_{50}), from five different bed bug strains, exposed to label-rate applications of MotherEarth® D Pest Control Dust (100% diatomaceous earth; 1.6 oz/100 ft^2), after either having been starved of blood meals for 14 days or having been recently (within 18 hours) fed a blood meal.

	Bed Bug Strain				
Feeding Status	Harlan N = 200 LT_{50} (h)	British N = 200 LT_{50} (h)	Epic Center [4] N = 200 LT_{50} (h)	Kramer [4] N = 200 LT_{50} (h)	Richmond [4] N = 200 LT_{50} (h)
14-day Starved[2,3]	13.5 A	9.9 B	10.1 B	18.3 C	10.6 A
Recently Fed[2,3]	15.9 a	15.5 a	19.2 b	15.3 b	18.6 b

1. Twenty replicates of ten adult male bed bugs from each strain were evaluated for each feeding status.

2. Significant differences were determined by the failure of the 95% confidence intervals to overlap (PoloPlus, Leora Software, Inc.).

3. LT_{50} values within each row (feeding status) that are not followed by the same letter are significantly different.

4. LT_{50} values for recently fed bed bugs of a strain were significantly different from LT_{50} values of 14-day starved bed bugs from that strain.

Table 3-6. The mean times (h) to 100% mortality for bed bugs from five different strains that were exposed to label-rate applications of MotherEarth® D Pest Control Dust (100% diatomaceous earth), after either having been starved for 14 days or having been recently (within 18 hours) fed.

Feeding Status	Bed Bug Strain				
	Harlan N = 200	British N = 200	Epic Center [4] N = 200	Kramer [4] N = 200	Richmond [4] N = 200
14-day Starved (h) ±SE [2,3]	33.3 (±3.0) A	30.7 (±3.1) B	28.5 (±3.2) B	49.6 (±4.8) C	29.5 (±3.0) A
Recently Fed (h) ±SE [2,3]	31.4 (±1.3) a	36.6 (±2.5) a	51.4 (±5.6) b	28.7 (±1.6) b	47.1 (±4.7) b

1. Twenty replicates of ten adult male bed bugs from each strain were evaluated for each feeding status.

2. Means were compared using the Student's *T* test, where significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10, SAS Institute Inc., 2012).

3. Means within each row (feeding status) that are not followed by the same letter are significantly different.

4. Means for recently fed bed bugs of a strain were significantly different from means of 14-day starved bed bugs from that strain.

Table 3-7. Comparison of the lethal times (h) to mortality for 50% of the bed bug populations (LT_{50}) that were exposed to different application rates of MotherEarth® D Pest Control Dust (100% diatomaceous earth).

Bed Bug Strain[1]	Variations in the Application Rate			
	0.1x LR LT_{50} (h)	0.5x LR LT_{50} (h)	1x LR LT_{50} (h)	2x LR LT_{50} (h)
Harlan[2,3]	149.6 A	61.8 B	30.3 C	24.3 C
Kramer[2,3]	122.0 D	42.4 E	24.6 F	30.1 F
Richmond[2,3]	59.8 G	30.1 H	18.1 H	24.6 H

1. For each bed bug strain, ten replicates of five adult male bed bugs were evaluated at 0.1x, 0.5x, 1x, and 2x the label rate for MotherEarth® D Pest Control Dust.

2. LT_{50} values within each row (bed bug strain) that are not followed by the same letter are significantly different

3. Significant differences were determined by the failure of the 95% confidence intervals to overlap (PoloPlus, Leora Software, Inc.).

Table 3-8. Comparison of the mean amounts (mg) of diatomaceous earth per bed bug replicate exposed to four application rates of Mother Earth® D Pest Control Dust (100% diatomaceous earth).

	Variations in the Application Rate			
Bed Bug Strain[1]	0.1x LR	0.5x LR	1x LR	2x LR
Harlan (mg) ±SE [2,3]	0.6 (±0.2) A	2.3 (±0.2) B	3.1 (±0.2) C	3.8 (±0.2) C
Kramer (mg) ±SE [2,3]	2.0 (±0.2) D	4.6 (±0.1) E	5.6 (±0.2) F	6.2 (±0.2) F
Richmond (mg) ±SE [2,3]	0.9 (±0.2) G	3.1 (±0.1) H	3.6 (±0.2) H	4.4 (±0.2) H

1. For each bed bug strain, ten replicates of five adult male bed bugs were evaluated at 0.1x, 0.5x, 1x, and 2x the label rate for MotherEarth® D Pest Control Dust.

2. Means were compared using the Tukey-Kramer HSD test, where significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10, SAS Institute Inc., 2012).

3. Means within each row (strain) that are not followed by the same letter are significantly different.

Table 3-9. Comparison of the mean times (h) to 100% mortality for bed bugs from three different strains that were exposed to different application rates (0.1x Label Rate, 0.5x LR, 1x LR, 2x LR) of MotherEarth® D Pest Control Dust (100% diatomaceous earth).

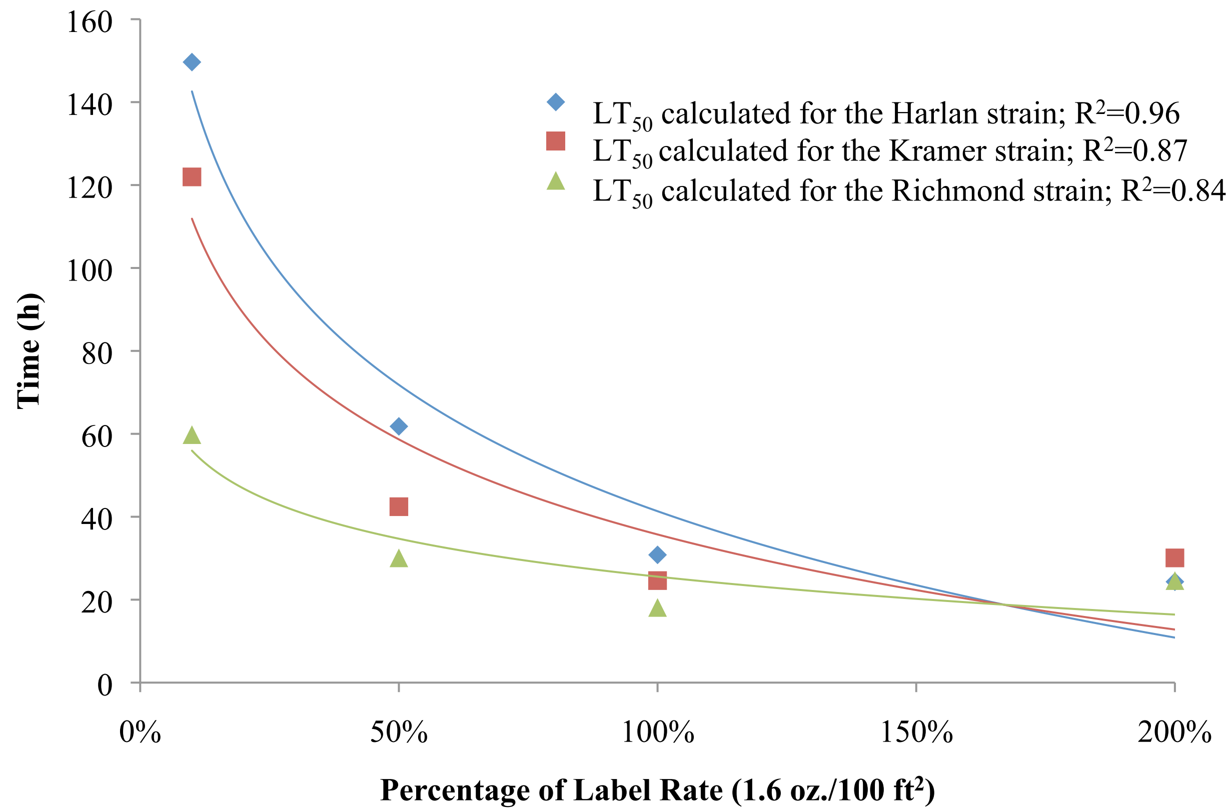
	Variations in the Application Rate			
Bed Bug Strain[1]	0.1x LR (h)	0.5x LR (h)	1x LR (h)	2x LR (h)
Harlan (h) ±SE [2,3]	206.4 A	86.4 B	48.0 C	33.6 C
Kramer (h) ±SE [2,3]	189.6 D	67.2 E	36.0 E	43.2 E
Richmond (h) ±SE [2,3]	93.6 F	45.6 G	26.4 G	33.6 G

1. For each bed bug strain, ten replicates of five adult male bed bugs were evaluated at 0.1x, 0.5x, 1x, and 2x the label rate for MotherEarth® D Pest Control Dust (1.6 oz./100 $PMft^2$)

2. Means were compared using the Student's *T* test, where significant differences were determined by values of $P \leq 0.05$ (JMP Pro 10, SAS Institute Inc., 2012).

3. Means within each row (strain) that are not followed by the same letter are significantly different.

Figure 3-1. Logistic regression analysis of the lethal times required to kill 50% of the bed bug population (three bed bug strains) exposed to different application rates (10%, 50%, 100%, and 200% of the label rate) of MotherEarth® D Pest Control Dust (100% diatomaceous earth). LT_{50} values for each strain and application rate were plotted as a function of time and were fit to a non-linear logistic regression curve in order to assess the strength of the dose-response relationship (JMP Pro 10).



Chapter 4. The development and evaluation of a proactive bed bug suppression program, using minimally toxic and cost-effective methods, for use in multi-unit housing facilities

Introduction

Controlling a bed bug infestation in a home often requires that each bed bug be located and treated. This is tedious, invasive, and time consuming, and is therefore very expensive. Bed bug remediation requires an integrated pest management (IPM) approach that uses chemical (liquid, dust, and aerosol) insecticide applications combined with non-chemical methods (Kells 2006, Romero 2011). Non-chemical bed bug treatment strategies may include heat, freezing, vacuuming, and the installation of mattress encasements and passive monitoring devices (Wang et al. 2009, Doggett et al. 2011). An integrated approach to bed bug management is essential to effectively eradicate bed bug infestations (Wang and Cooper 2011).

Bed bug remediation costs vary depending on the treatment strategy used. The cost of an insecticide treatment in an average apartment unit is approximately $500. Moreover, the National Pest Management Association's (NPMA) bed bug treatment guidelines recommend three treatments be applied at two-week intervals (Potter et al. 2010, NPMA 2011). The average cost of a whole unit or stand-alone heat treatment in a single apartment typically ranges from $800 to $1200. If done properly, heat treatments can be very effective. However, because a heat treatment offers no residual activity, it is possible for new bed bugs to be introduced the day after treatment and nothing would stop the population from growing. While bed bug remediation would be considered expensive by any standard, the low-income, multi-unit apartment industry is being financially devastated by this pest (Wong et al. 2013).

Bed bug infestations are a particular challenge to low-income, multi-unit apartment facilities, because they are at high risk for repeated infestations. Residents of these facilities are vulnerable to bed bug infestations because many are elderly, physically or mentally handicapped, and unable to recognize the signs of an infestation (Wang et al. 2010). These residents are at high risk for repeated bed bug infestations due to their low relocation ability and the high transfer of secondhand goods among apartments. The problem is exacerbated in multi-unit facilities because of shared interior walls and common ventilation, electrical, and plumbing systems, that allow bed bugs to easily travel from one unit to another unit (Doggett and Russell 2008). The potential for bed bugs to move between units has forced many multi-unit facilities to treat not only the infested apartment but, also, the eight surrounding units (NPMA 2011), further increasing the cost of control.

Apartment management companies in Virginia have paid between \$8,000 and \$500,000 in a single year for bed bug treatments (Miller 2012). Consequently, apartment managers are desperate to reduce bed bug control costs and prevent future infestations. The implementation of proactive measures could potentially decrease costs by reducing bed bug introductions and limiting their potential spread.

Desiccant dusts are highly effective for killing bed bugs (Romero et al. 2009). Diatomaceous earth (DE) is a desiccant dust that can be applied proactively by facilities staff and residents as part of a bed bug management program. When used effectively, diatomaceous earth applications may reduce the spread of infestations between units. Different brands of insecticide-grade diatomaceous earth have label application rates ranging from 1.6 oz/100 ft^2 to 2 oz/100 ft^2. DE products can be applied to a wide range of furniture items and locations including mattresses, box springs, bed frames, and other furniture, as well as wall voids, behind wall hangings and floor molding, along window casings and carpet edges, on popcorn ceilings, and inside other cracks, crevices, or voids (MotherEarth® D Pest Control Dust, BASF Corp., St. Louis, MO, Safer® Brand Diatomaceous Earth, Woodstream Corporation, Lititz, PA, Harris® Bed Bug Killer, P F Harris Manufacturing Company, LLC, Alpharetta, GA). Because of the broad application label and low cost, diatomaceous earth is a practical and minimally toxic bed bug management tool. With the proper training and certification, housing facilities staff could potentially apply diatomaceous earth proactively to prevent bed bug spread and reduce the cost of treating multiple units surrounding an infestation (Wang et al. 2012).

The purpose of this study was to develop a proactive bed bug suppression program that is minimally toxic, cost effective, and practical to apply in multi-unit apartment facilities. This proactive approach to preventing bed bug infestations in multi-unit facilities is the first step towards comprehensive bed bug management. The goal for this study was to successfully apply the program and quantify the labor and product costs associated with implementation. Our ultimate intention will be to determine if the number of infestations, and subsequent treatment costs of bed bug management, could be reduced over time.

Materials and Methods

Suppression Program Components

A proactive bed bug suppression program was developed for implementation in multi-unit facilities. Multiple methods of bed bug suppression were evaluated for their efficacy, ease of application, low cost, and practicality for use in different facilities. Ultimately, the suppression program incorporated seven potential components (Table 4-1), including interior perimeter DE applications, heat and other proven non-chemical management methods, and the production of bed bug education materials and their delivery to both residents and staff. The components could be used separately, but were most effective when employed together as part of an integrated bed bug suppression program, particularly for early detection and limitation of bed bug spread within the building. This program was not intended to remediate current infestations.

Once the proactive bed bug suppression program was initiated, the management and maintenance staff of each facility became responsible for implementing its components. The building managers handled the building-wide components (i.e. the construction and use of the heat chamber, the distribution of educational materials, and the coordination of educational seminars), while the maintenance staff implemented other program components (diatomaceous earth application) in each unit.

Evaluation of Program Components

Barbara's House (534 S. Main St., Madison, VA 22727) is a five-unit family shelter for women and children, managed by Madison Emergency Services Association (MESA), a non-profit organization. Residents of Barbara's House may live there for up to one year.

The manager of Barbara's House contacted the Dodson Urban Pest Management Laboratory (DUPML) at Virginia Tech (701 Old Glade Rd. Blacksburg, VA 24060) in the fall of 2011. She was concerned that two apartment units were infested with bed bugs. After having a pest management professional with a bed bug detecting canine inspect the units, the manager was quoted $4000 to treat the building. As a non-profit organization, MESA was unable to afford this treatment so the manager, concerned about future infestations, was looking for alternative low-cost methods to prevent future bed bug infestations.

Our main goal for this facility was to evaluate the practicality and efficacy of specific program components, and to train the staff and residents how to implement the proactive bed bug suppression program. Each element of the program was implemented for each unit. Working in Barbara's House was an opportunity to develop and troubleshoot the program before using it in a larger facility. An additional reason for working with Barbara's House was to determine if the program could be applied without a pest management professional's oversight. Ultimately, we found that all elements worked successfully, and the program could be implemented in other facilities.

Program Evaluation Site

The J. R. "Polly" Lineweaver Apartments and the Lineweaver Annex are intersecting apartment buildings that form a single community in Harrisonburg, Virginia (265 North Main St. Harrisonburg, VA 22803). These facilities are classified as a Section 8 New Construction Project for seniors. The community is owned and operated by the Harrisonburg Redevelopment and Housing Authority (HRRA). Lineweaver Apartments is a five-story, 61-unit building, consisting of 47 efficiency units and 14 one-bedroom apartments. Tenants are required to be at least 62 years old or disabled and have an annual income below 80% of the local median. Rent is subsidized by HRRA, the Virginia Department of Housing and Urban Development, and the Federal Department of Housing and Urban Development. The Lineweaver Annex contains 60 one-bedroom units. Tenants are required to be at least 55 years old and have an annual income below 60% of the local median. The Annex is not fully subsidized so some tenants are required to pay the entire rent amount ($476 per month including all utilities).

At the Lineweaver facility, the first three reported bed bug infestations occurred in December 2010. Prior to these reported infestations, there had been no bed bug incidence for the previous nine years (duration of the current HHRA Director's tenure, personal communication, Michael Wong 2011). The apartment management hired a local company to provide "whole-unit" heat treatments using the Thermal Remediation System from Temp-Air (Temp-Air, Burnsville, MN). The contract stipulated that treatments would cost $625 for efficiency units and $825 for 1-bedroom units, and included a no-cost re-treatment warranty if bed bugs were found in a unit within 30 days of treatment. Although only three units with infestations were reported, an additional four units were treated because they were adjacent to infested units. The total treatment cost was $4,975.

In 2011, the number of infestations in the Lineweaver facility increased to thirteen. Lineweaver management paid $8,525 for heat treatments and the inspection of the units surrounding the infested units. It was in 2011 when the HHRA director (Mr. Michael Wong) contacted DUPML for advice about how to control the growing bed bug population at Lineweaver. Mr. Wong was concerned about pesticide use at Lineweaver because the community was a sensitive environment due to the elderly and disabled residents. Mr. Wong was specifically looking for bed bug management strategies that were not only effective, but also minimally toxic, cost-effective, and sustainable. Between January 2012 and June 2012, DUPML members and Lineweaver facilities staff implemented multiple components of the proactive bed bug suppression program in the entire Lineweaver facility.

Program Implementation

In January 2012, members of the DUPML and Lineweaver facilities staff began applying components of the proactive bed bug suppression program in the Lineweaver facility. The management staff at Lineweaver initially circulated a notice to residents stating, "Virginia Tech had found a way to prevent bed bugs from entering their homes" (Figure 4-1). While this statement was not true (the administrative assistant who wrote the notice did not fully comprehend the suppression program), the notice did enhance resident cooperation. Between January 2012 and June 2012, each component of the bed bug suppression program was explained and offered to the building management. Ultimately, not all of the components were used in the Lineweaver facility because the management either could not afford or were unable to implement them. The components that were offered consisted of the following:

Vacuuming. Upon entering each unit, the DUPML and Lineweaver facilities staff vacuumed the perimeter at the floor-wall junction. This was done prior to the application of the DE perimeter barrier, in order to clear clutter and debris and remove any old bed bug evidence.

Diatomaceous Earth. The perimeter barrier of diatomaceous earth was the foundation of the bed bug suppression program. Because many of the residents of the Lineweaver facility were elderly or disabled, they were unable to prepare their units for the implementation of the prevention protocol, which included removing clutter, covering electronics, and moving some furniture away from the baseboards. Therefore, in most units, the DUPML and Lineweaver facilities staff moved furniture and removed clutter and debris before beginning the diatomaceous earth application.

Diatomaceous earth was applied using one of two power dusters: the Exacticide Power Duster (Technicide™, San Clemente, CA) or the Cyclone Power Duster™ (GL Enterprises, Inc., New Braunfels, TX). Diatomaceous earth was applied in wall voids, which were accessed by wedging the tip of the application wand under a vinyl baseboard at regular intervals along the entire perimeter of each unit. All plumbing penetrations, electrical outlets, and light switch plates were also treated with DE using a hand-held bulb duster.

Monitors and Encasements. Because HHRA was not able to afford to purchase passive bed bug monitors or mattress and box spring encasements for all of the Lineweaver's residents, these elements of program were not actualized in the entire building. The HHRA procurement department purchased monitors and encasements and made them available for residents to purchase at wholesale cost. Due to this expense, not all of the residents purchased monitors or encasements. The individual purchase of monitors necessitated that the residents would inspect the monitors themselves, therefore, no regular, building-wide, bed bug inspections are being conducted in the apartment units.

Household Clothes Dryer. The management and residents readily adopted this element of the program because Lineweaver Apartments has an on-site coin-operated laundry facility. While commercial dryers have a higher capacity, the bank of common household dryers in the building's laundry facility all reached lethal temperatures, and allowed multiple residents to use them simultaneously. In order to accommodate the cost of frequent dryer use, the HHRA accepted late rent payments from residents, exchanged paper money for coins to operate the machines, and in some cases, even provided vouchers to cover the cost of using the dryer.

Heat Chamber. HHRA was very interested in building a heat chamber. Mr. Wong and the facilities staff planned to build a permanent heat chamber on a trailer that could be moved among different HHRA properties. This proposed chamber would be able to heat treat more and larger items than the Do-It-Yourself heat chamber described in Table 4-1. However, as of

December 2013, neither the recommended heat chamber nor the proposed heat trailer had been constructed.

Education. Two 45-minute bed bug education seminars were offered to the Lineweaver residents (See Chapter 5; Appendix 5C). In addition to basic bed bug biology and control, residents were taught how to identify live bed bugs, how to install and check passive monitors in their units, and how to install mattress encasements on their beds. A two-hour bed bug education seminar was also presented to the HHRA administration, maintenance and facilities staff, and the Lineweaver management. In addition to an in-depth review of basic bed bug biology, identification, and control, Lineweaver personnel were taught how to apply DE and implement the other bed bug suppression program components.

Program Implementation Assessment

A face-to-face survey (IRB-12-491, Virginia Tech) was administered to all residents, asking their opinions about the implementation of the bed bug suppression program. Three questions were asked to determine if the residents had any concerns about the program or its execution.

In each apartment unit, the amount of time spent on preparation and DE application was recorded, as well as the number of laborers, unit size, and amount of diatomaceous earth applied (g). In order to determine the potential cost of implementing the proactive DE perimeter barrier, the combined labor and supply costs were calculated. The cost of the diatomaceous earth applied was based on the market price ($69.95/10 lb.) of a pail of diatomaceous earth (MotherEarth® D Pest Control Dust, BASF) at a rate of $15.42 per 1000 g DE applied. Labor cost for implementing the program at Lineweaver was calculated at a rate of $1 per minute per laborer (break-even cost for the pest management industry).

Data Analysis.

Mean application times and amounts of DE applied were calculated for different sized units and number of laborers. Tukey's HSD test (JMP Pro 10, SAS Institute Inc., 2012) was conducted to compare means (time and product used) and determine significant differences between treatments. Application data were used to calculate the estimated per unit cost (labor and supplies) needed to implement the proactive perimeter barrier.

Program Efficacy Assessment. Bed bug treatment records, from January 2011 through December 2013, were used to calculate the number and cost of heat treatments for each year. Whole-unit heat treatments were the only type of remediation used in the three-year test period. In the second year (2012), the proactive bed bug suppression program was implemented (January through June) in addition to the whole-unit heat treatments. Because Lineweaver Apartments was our study site, they did not pay for the implementation of the bed bug suppression program. Percent change from year to year was calculated using annual total cost, number of new infestations, and number of heat treatments.

Results

Resident Perceptions

The residents of Lineweaver apartments were asked three questions concerning the diatomaceous earth barrier application applied in their units. The first question asked residents if they had had any concerns about the diatomaceous earth being applied in their homes prior to the perimeter application. Half (50.9%) of the residents responded that they were not concerned or did not care about the application. Twenty-seven percent of residents stated that they had questions that were answered by either Lineweaver staff, DUPML staff, or other residents. While, approximately 14% of the residents were interested and curious about the DE application, 7.4% stated that the pending DE application made them nervous, upset, or afraid. The second question asked residents if they noticed anything about the DE application after it had been applied. The majority (74.1%) of respondents stated that they did not notice anything. The remaining respondents (25.9%) noticed things such as DE in the air for an hour or less; DE on the carpet around the edge of the rooms; or a slight smell for an hour after treatment. The last question asked residents if they had any further concerns (living conditions, re-treatments, health effects) after the diatomaceous earth was applied. Approximately 13% of residents had negative opinions about the application. Some expressed their annoyance about the disruption to their homes, while others stated that they could feel a dusty residue on surfaces. One respondent expressed concern that future research might prove exposure to diatomaceous earth to be fatal. Although not all residents were content with the application, the majority (87%) of respondents had no concerns after treatment. Many expressed relief that proactive bed bug management measures had been put in place.

Cost of Program Implementation

The Lineweaver and DUPML staff members were not available to work on the suppression program every day or even every week, yet the perimeter DE barrier was applied in all 121 units within five months. The time spent applying the DE barrier and the amount of DE applied varied depending on unit size (efficiency or one bedroom) and the power duster used

(Exacticide or Cyclone™). To determine a potential per unit cost for applying the perimeter DE barrier, mean application time (assuming two laborers) and mean amount of diatomaceous earth applied per unit were calculated (Table 4-2). The cumulative application time spent at Lineweaver Apartments was 189 hours and 15 minutes, or a mean of 47.3 minutes per unit with two laborers. If labor is to be calculated at $1 per minute, the cost per unit would be $47.31 per laborer (2) or $94.62 per unit. The theoretical labor cost for the 121 units in the Lineweaver facility would have been $11,355. The total amount of diatomaceous earth applied in the units was 7,140 g (approximately 60 g per unit). The total cost of the diatomaceous earth applied was $110.10 or $0.92 per unit. Had the Lineweaver facility paid to implement the bed bug suppression program, the theoretical cost for two laborers to apply the proactive DE perimeter barrier in all 121 units would have been $11,465.10.

Reduction in Treatments and Expenses

Between January 2011 and December 2013, there were a total of 105 whole-unit heat treatments applied at Lineweaver Apartments. Of those treatments, 40 were initial treatments indicating a new bed bug occurrence or infestation, and 65 were re-treatments (Table 4-3). In 2012, there were 171% more initial treatments and 383% more re-treatments than there were in 2011. In 2013, there were 26% fewer initial treatments and 8% fewer total treatments than there were in 2012.

Total annual expenses for heat remediation in Lineweaver Apartments were assessed and compared for the years 2011, 2012, and 2013. In 2012, as more bed bug infestations were reported and treated, the costs of bed bug remediation increased by 308%, when compared with the expended costs from 2011. In 2013, while bed bug infestations were still often reported and treated, the costs of bed bug remediation were reduced by 2%, when compared with the costs from 2012. Over the three years of the study, the annual heat treatment cost changed from $8,525.00 (2011) to $34,075.00 (2013), an increase of approximately 300%. Lineweaver's total expenditure for the three years of the study was $77,375.00.

Discussion

The use of non-chemical and reduced toxicity bed bug management methods is not new. Researchers have evaluated several "reduced-risk" bed bug management programs and found that they could effectively eliminate light bed bug infestations in low-income housing (Singh et al. 2013). While comparisons of non-chemical, chemical, and IPM programs for bed bugs have been performed in multi-unit facilities (Wang et al. 2012), no study to date has included the implementation of a proactive diatomaceous earth barrier as part of a program to limit bed bug spread and maximize bed bug suppression, in multi-unit facilities.

In this study, our focus was to develop and evaluate a low-cost, reduced toxicity bed bug suppression program that integrated non-chemical management methods, resident education, staff training, and the implementation of a proactive diatomaceous earth perimeter barrier application in each unit of multi-unit facilities. One year after the implementation of a bed bug suppression program, we found that we were able to slightly reduce both the number of new bed bug infestations and, subsequently, the costs associated with bed bug treatments in a low-income multi-unit apartment facility. The most compelling result of this study was that the year 2013 was the first year where the number of initial infestations (and number of apartment units treated) did not increase. This suggestion of a downward trend in infestations at the Lineweaver Apartments was reinforced by several noteworthy observations.

First, the program was economical. While the theoretical labor expenses of implementing the DE barrier in the building was $11,465.10, the overall cost of its implementation would be a one-time expense. The mean cost per unit was between $67 and $149, depending on unit size and power duster used. These data suggest that a small per unit financial investment may reduce the number of whole-unit heat treatments ($625 to $825) needed in future years.

The proactive diatomaceous earth perimeter barrier did not require a large amount of time to implement, even with no prior preparation from residents. While the mean time to apply the perimeter barrier was 29 minutes per unit, actual times ranged between 9 minutes and 80 minutes for two laborers. Factors that influenced application time included unit size, clutter level in the apartment, resident presence, and the diatomaceous earth applicator used. It is important to note that in an apartment complex, facilities workers could apply the DE perimeter barrier as part of the regularly scheduled maintenance routine or at unit turnover.

In order to find the most efficient method of applying the diatomaceous earth, we tried several different applicators. The first applicator was the Exacticide power duster, which was battery powered and had a plastic applicator tip. The Exacticide required constant agitation to maintain the flow of the DE. This duster was used successfully to treat the carpet tacking in the five units at Barbara's House. However, once treatment was initiated at the Lineweaver facility, we found that Exacticide's plastic applicator tip was inadequate for moving under the vinyl baseboards. The tip frequently detached and slowed the application progress.

Overall, the Exacticide power duster was much slower to work with because it required the person using it to move the duster inch-by-inch around the perimeter of the room. Also, because of the limited range, laborers were required to move all furniture approximately one foot from the walls (and back after treatment), which increased the time spent in each unit and laborer fatigue.

After treating 27 of the 121 units, a rubber gasket inside the Exacticide duster eroded because of constant abrasion by the DE. This allowed the DE to be sucked into the body of the duster, causing the motor to fail. At that point, we began using the Cyclone Power Duster™, which used pressurized carbon dioxide (from a portable 2.5 lb. tank) to distribute the dust at a pressure of up to 250 pounds per square inch. The remaining 94 Lineweaver units were treated using the Cyclone™ power duster.

The Cyclone™ power duster was more time efficient than the Exacticide duster because of its ability to expel diatomaceous earth at higher pressures and because of its durable metal application wand. These features allowed the person using it to apply the DE under the baseboards at 6-foot intervals, which reduced the need to move all of the furniture away from the walls. Because of its ease of use, durability, and reduction of time spent in each unit, the Cyclone™ power duster allowed us to treat more units each day and was the preferred application device. However, it was necessary to use bulb dusters specifically to treat electrical outlets, because the steel application tip of Cyclone™ duster often resulted in the appliance getting shocked.

Because we were concerned about the DE application disturbing, annoying, or causing breathing problems in the elderly the residents of Lineweaver Apartments, we conducted a brief survey of the residents after the diatomaceous earth applications to assess their opinions and concerns. We were particularly interested in what the residents thought of the proactive diatomaceous earth barriers after they had been applied. Because some of the elderly residents had a reputation of being "difficult," we expected complaints about their homes, activities, and time being disrupted. We also expected residents to express confusion as to why they were receiving the application if they did not have bed bugs, or to express fear of the diatomaceous earth causing breathing problems. Interestingly, however, while some residents stated that the intrusion had been “a nuisance” or that they were “miffed to be bothered,” the majority of residents had no concerns before or after the diatomaceous earth applications. Residents stated that they were “glad it was over, but glad to have it,” “felt more comfortable,” “safer,” “gave me piece of mind,” or expressed that they were “relieved.” These positive responses indicated that not only was the program easy to implement, but also, the majority of residents received the program well.

While the true efficacy of the proactive bed bug suppression program will only be revealed over the next few years, we consider the installation of the program to be a success. Our data indicate a downward trend in new bed bug infestations (26.4%) and a slight reduction in bed bug treatment costs (2%) since the beginning of 2013. However, in spite of this slight decrease in costs from 2012, the overall cost of bed bug control at Lineweaver Apartments had increased by approximately 300% between 2011 and 2013.

It should be noted that while we were implementing the program, we were not inspecting for active infestations. In June 2012, the Lineweaver Apartment manager and HHRA administration agreed to allow another researcher to conduct a simultaneous study in the building, without our knowledge. The researcher, from a private research organization, inspected each unit in the building for bed bugs (Vaidyanathan 2013). Vaidyanathan (2013) intended to collect different bed bug populations from within the same building for use as test specimens in the development of a “rapid and specific bed bug detection kit”. Because of this comprehensive inspection of the building, more infested units were found than had previously been reported by residents or identified by the apartment management. These units were subsequently treated, contributing to the large increase in bed bug remediation costs observed in 2012. Fortunately, the bed bug education seminar was presented to the residents several days after these new infested units had been reported. Since June 2012, there has been more communication between residents and the management regarding bed bugs, and infestations are being reported earlier and treated prior to the infestation becoming too difficult to control.

We anticipate that the number of new bed bug infestations and the cost of bed bug remediation will continue to decline in the Lineweaver facility in subsequent years. We are optimistic that the success of the diatomaceous earth application will result in the Lineweaver facility's adoption of additional program components in the future, particularly, the construction and utilization of a heat chamber. In order to evaluate the cost-effectiveness of this IPM program, this community will be monitored over the next three years to determine the true potential of the bed bug suppression program. We hope to see a reduction in the number of bed bug infestations and the cost of bed bug remediation.

Efforts to successfully manage bed bugs have increased across the country. As of 2013, additional multi-unit facilities have adopted this proactive bed bug suppression program and their personnel have been trained to implement it. In each case, the program has been easily modified to fit the specific needs of each community. The overwhelming economic impact of bed bug infestations necessitates that IPM strategies be investigated and improved to gain better control of this epic pest.

Table 4-1. Elements of the proactive bed bug suppression program are listed and described.

Program Element	Description
Heat Chamber	Using heat is the most effective way to kill bed bugs. Heat chambers can be used to treat infested furniture, electronics, and other household items. Pereira et al. (2009) developed an inexpensive "Do-it-Yourself" heat chamber constructed with common materials that can be purchased at hardware stores. Low-income multi-unit facilities can use this homemade heat chamber before a tenant moves in to treat potentially infested items or after an infestation has been reported.
Household Dryer*	Using a household dryer on a high heat cycle for approximately 30 minutes is an effective method of treating infested or potentially infested clothes and linens. The high heat setting on most household dryers easily reaches the thermal death point for bed bugs (118º F) and eggs (122º F) and will kill all life stages as long as the dryer is loosely packed with room for air to flow (Potter et al. 2007, Naylor and Boase 2010).
Passive Monitors*	Passive bed bug monitors, such as the Climb-Up Interceptor© (Susan McKnight Inc., Memphis, TN) or The Bed Moat® (The Bed Moat, Inc., Toronto, Canada), can be installed under the legs of all beds, sleeping furniture, couches, chairs, and near sleeping areas where mattresses sit directly on the floor (Wang et al. 2009). Monitoring devices are important for early detection of low-level infestations, to recognize bed bug reintroductions, and to determine if bed bugs are still present after a treatment.
Mattress and Box Spring Encasements*	Mattress and box spring encasements (Mattress Safe® Inc., Cumming, GA, Protect-a-Bed®, Wheeling, IL) prevent bed bugs from infesting a bed so that the mattress and box spring do not have to be discarded. The purpose of an encasement is to trap any bed bugs already on the mattress and prevent new bed bugs from aggregating within the box spring (Cooper 2007, 2011). The cost of an encasement is less than the cost of replacing a mattress and box spring. If mattresses and box springs are encased prior to being infested, bed bugs would not be able to harbor inside and the mattresses and box springs would not have to be disposed of or replaced. If installed after an infestation has been discovered, an encasement would seal bed bugs inside, preventing them from biting the host.
Vacuuming*	A commercial grade backpack vacuum can be used to immediately remove live and dead bed bugs and exuvia from an infestation, thus reducing the population and making it easier to distinguish any new bed bug evidence in future inspections. To prevent the vacuum from becoming infested, a nylon knee-high stocking should be secured over the suction hose to contain bed bugs and for easy disposal.
Diatomaceous Earth*	Insecticide grade diatomaceous earth can be applied to bed frames, box springs, upholstered furniture, electrical outlets, and switch plates. The protocol includes the application of a physical barrier of diatomaceous earth around the perimeter of the unit. The perimeter barrier is intended to intercept bed bugs as they attempt to spread between units in an infested building, thus forcing them to either avoid the application and stay within the unit or cross the barrier, picking up a lethal dose of DE. The application of the perimeter barrier varies depending on the construction of the building. Building construction offers bed bugs a variety of passages between units, each of which needs to be treated with DE. Common locations that need to be treated are between the tacking strip and the baseboard of carpeted rooms, under vinyl baseboards, or in drilled wall voids.
Education	Bed bug education and hands-on training was provided for all apartment staff and residents. The educational efforts included seminars, training workshops, and the distribution of easy-to-read printed material covering bed bug identification, basic biology and behavior, control methods, and prevention. Printed materials included a basic bed bug information booklet for residents (Appendix 4A), a 1-page brochure explaining the construction and supplies needed for the "Do-It-Yourself" heat chamber (Appendix 4B), and a 1-page supplies list for diatomaceous earth applications (Appendix 4C).

Elements denoted with an asterisk (*) are those that were to be implemented in each unit of Lineweaver Apartments.

Table 4-2. Mean application time for two laborers and mean amount of diatomaceous earth applied per unit in grams based on unit size and duster used. The mean application time and mean amount of diatomaceous earth were used to determine the potential financial investment for multi-unit facilities, where the proactive perimeter diatomaceous earth barrier might be applied.

	Efficiency Unit		1-Bedroom Unit	
	Exacticide	Cyclone™	Exacticide	Cyclone™
Mean Treatment Time (min) ± SE	60.5 (± 6.5) AB[1,2]	33.4 (± 2.5) C	73.4 (± 9.3) A	45.3 (± 3.0) BC
Cost per laborer	*$60.50*	*$33.37*	*$73.44*	*$45.28*
Mean Diatomaceous Earth Applied (g) ± SE	54.3 (± 8.1) a[1,2]	48.5 (± 1.8) b	74.1 (± 6.8) b	67.8 (± 2.3) a
Cost	*$0.84*	*$0.75*	*$1.14*	*$1.05*
Total Mean Cost per Unit	*$121.84*	*$67.49*	*$148.02*	*$91.61*

1. Means not followed by the same letter are significantly different.
2. Means were compared using Tukey's HSD test (JMP Pro 10, SAS Institute Inc., 2010) and $P \leq 0.05$ was used to indicate significant differences.
3. Mean treatment time was calculated based on two laborers working in each unit.

Table 4-3. Assessment of the whole unit heat treatment schedule of the Lineweaver Apartment for bed bug remediation in 2011, 2012, and 2013.

Year	Initial Treatments	Re-Treatments	Total Treatments
2011	7	6	13
2012	19 (171.4% ↑)	29 (383.3% ↑)	48 (269.2% ↑)
2013	14 (26.4% ↓)	30 (3.5% ↑)	44 (8.3% ↓)

1. Percent increase (↑) and decrease (↓) from year to year and are reported in parentheses.
2. There were 40 initial treatments, 65 re-treatments, and 105 total treatments.

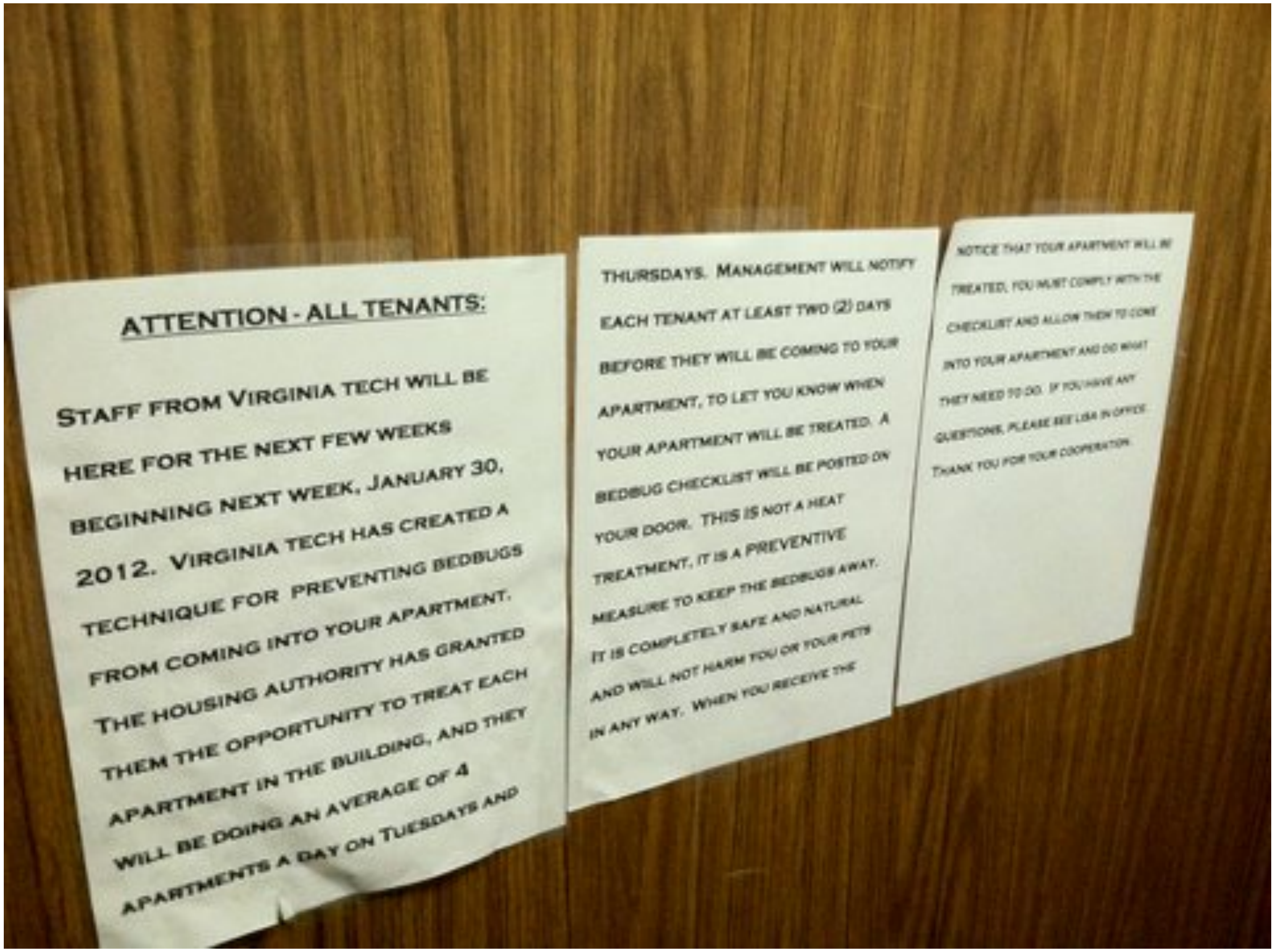


Figure 4-1. In January 2012, a Lineweaver Apartments (Harrisonburg, VA) administrative assistant posted this community-wide notice to its residents, alerting them to the pending proactive diatomaceous earth perimeter barrier applications. While this statement was not true, the notice did enhance resident cooperation.

Chapter 5. Assessment and improvement of bed bug knowledge among low-income, mult-unit housing residents

Introduction

Since their resurgence in the 1990s, bed bugs have become one of the major household pests in the United States (Eddy and Jones 2011a, Harlan 2006). As of 2006, bed bug infestations have been reported in all of the 50 states, occurring in single-family homes, apartments, hotels, health care facilities, theaters, college dormitories, and public transportation (Hwang et al. 2005, Gangloff-Kaufmann et al. 2006). The bed bug resurgence can be attributed to many factors including increased international travel and immigration, change in pest control methods, insecticide resistance, and the unregulated transfer of secondhand clothing and goods (Potter et al. 2010). However, the single most important factor contributing to the bed bug spread in the United States is the lack of societal awareness, specifically, our lack of basic bed bug knowledge, and our subsequent lack of precautions against bringing bed bugs home.

Surveys have been conducted to assess public knowledge and awareness of urban pests and their control for more than 30 years. Wood et al. (1981) surveyed public housing residents in Virginia and Maryland to assess their cockroach knowledge and attitudes about cockroach control. Levenson and Frankie (1983) conduced a survey of apartment residents in Texas, California, and New Jersey to determine if common attitudes about pests and pesticide use were shared among people of different socioeconomic groups. Zungoli and Robinson (1984) surveyed public housing residents in Virginia and Maryland to assess resident perceptions of the German cockroach's pest status. Baldwin (2005) surveyed Florida residents about public perceptions of urban pests and their management. Baldwin (2005) determined that 68% of the Florida population considered insect pests harmful to their households, and that when an insect was found in a home, most residents would make efforts to exterminate (i.e. making a pesticide application, hiring a pest management company, etc.) the insect, regardless of the insect's species or pest status.

As an established urban pest in the United States, bed bugs have been the topic of several recent surveys. In 2010, 2011, and 2013, the University of Kentucky and the National Pest Management Association surveyed pest management companies regarding the state of the bed bug resurgence in the United States (Potter et al. 2010, Potter et al. 2011, Potter et al. 2013). Goddard (2011) conducted a survey of entomologists with the Mississippi Department of Health and Mississippi pest management professionals in order to determine the distribution of bed bug infestations, as well as the bed bug control methods being used within that state. Goddard (2011) determined that there were approximately 40 bed bug infestations throughout Mississippi and pest management professionals relied heavily on insecticides for bed bug control. Goddard (2011) suggested that insecticides might be ineffective due to widespread resistance. Eddy and Jones (2011b) conducted a survey of public health practitioners, social workers, and other community stakeholders in central Ohio and determined that an overwhelming majority of respondents found bed bugs to be a public health concern. The results of the above surveys suggest that in order to attempt to manage bed bug infestations, educational efforts needed to be developed and/or expanded so that more people were aware of bed bugs and bed bug control methods.

The lack of bed bug knowledge is particularly evident in low-income apartments (Wang et al. 2012). Rossi and Jennings (2010) described bed bug control as a particular challenge in multi-unit housing facilities because control is much more difficult than in single-family homes.

In multi-unit housing, bed bugs frequently travel between units, either by direct human transport or by moving through the wall voids. McGrath (2011) presented a bed bug control program for public housing communities in Boston, MA, and specifically noted that, in addition to employing integrated bed bug management methods, the apartment staff and residents desperately needed to be educated about bed bugs. The National Apartment Association and Orkin Pest Control, Inc. collaborated to produce a guide for dealing with bed bugs in apartments. The guide specifically instructed apartment managers to educate their residents, even if bed bugs had not yet been found in a community (Harrison and Semko 2010).

In this study, our first objective was to assess the bed bug knowledge base of low-income, multi-unit housing residents through face-to-face surveys. Next, we intended to improve the residents' bed bug knowledge through an educational seminar. Our last objective was to assess any change in the residents' bed bug knowledge by conducting a second survey of residents who attended the educational seminar and comparing the responses with those of the initial survey. Our overall intention was to educate the apartment residents about bed bug biology, behavior, and control methods, so that they (1) could recognize bed bugs and bed bug evidence; (2) could prevent bringing bed bugs into their homes; and, (3) would be familiar with common bed bug management methods.

Materials and Methods

Apartment Selection and Community Descriptions

Four apartment communities were selected for surveying because of their classification as multi-family facilities that house underserved, low-income, elderly or disabled residents. They included : (1) the J. R. Polly Lineweaver Apartments, (2) Annunciation Inn, (3) Renaissance Place, and (4) Essex Village Apartments. The apartment communities are described:

1. *Lineweaver Apartments.* The J. R. "Polly" Lineweaver Apartments and the Lineweaver Annex are adjoining but continuous apartment buildings in Harrisonburg, Virginia (265 North Main St. Harrisonburg, VA 22803). The community is classified as a Section 8 New Construction Project for elderly and disabled residents. This development is owned and operated by the Harrisonburg Redevelopment and Housing Authority (HRRA). The Lineweaver Apartment community has 121 units (47 efficiencies and 74 one-bedroom apartments). To qualify for government-subsidized rent, tenants are required to be at least 62 years old or disabled with income below 80% of the area median income, or at least 55 years old with income below 60% of the area median income. The latter group must pay the full rent amount ($476 including all utilities) each month.

2. *Annunciation Inn.* Annunciation Inn is a 106-unit apartment building in New Orleans, LA (1220 Spain St., New Orleans, LA 70117). These apartments are owned and operated by Christopher Homes, Inc. (1000 Howard Ave., Suite 100, New Orleans, LA 70113), a division of the Archdiocese of New Orleans that provides affordable living for senior citizens. Annunciation Inn is a project-based Section 8 rental property. Residents are either elderly (62 years or older) or disabled in need of accessible units. Rent is subsidized based on each resident’s income by the U. S. Housing and Urban Development Authority (HUD) and the Louisiana Housing Financing Agency.

3. *Renaissance Place.* Renaissance Place Apartments is an apartment building in New Orleans, LA (3601 Texas Dr., New Orleans, LA 70114) managed by HSI Management, Inc. (5505 Interstate North Parkway NW, Atlanta, GA 30328). HSE Management, Inc. currently

manages over 3,500 housing units in nine different states. Renaissance Place has 307 one-bedroom apartments and is classified as Section 202 for elderly residents. All residents are at least 62 years old, which is the only restriction for resident eligibility.

4. *Essex Village Apartments.* Essex Village Apartments is an apartment community in Richmond, VA (3901 Pilots Ln., Richmond, VA 23222). This property is managed by PK Management, LLC. (15301 Ventura Blvd., Suite B570, Sherman Oaks, CA 91403). Essex Village is classified as Section 8 and is financed by the state of Virginia as a Housing Finance and Development Agencies (HFDA) housing program. Essex Village has 496 units: 80 one-bedroom units, 208 two-bedroom units, and 208 three-bedroom units. This apartment community has no age restrictions, but accepts HUD housing vouchers for low-income families.

Surveys and Educational Program

An educational program was conducted from June 2012 to April 2013 in the four low-income apartment communities in three U.S. cities (Harrisonburg, VA; Richmond, VA; New Orleans, LA). The program consisted of an initial survey, an educational seminar, and a post-seminar survey. The design of the educational program was based on the value-added model of educational performance, which is intended to quantify the difference between a person's knowledge prior to attending an educational program and their knowledge immediately after the program's completion (Saunders 2001).

Before the initial survey was administered, the surveyor read a script to introduce the purpose of the survey to the respondent (Appendix 5A). Apartment residents were then given the option to decline from participating in the survey. If the apartment resident agreed to participate, the surveyor recorded the date and unit number on the survey. Surveys were administered to apartment residents directly in face-to-face interviews by members of the Dodson Urban Pest Management Laboratory (Virginia Tech, Blacksburg, VA), or employees of the City of New Orleans Mosquito, Termite, and Rodent Control Board (New Orleans, LA). Surveyors went door-to-door in the apartment communities over multiple days to contact as many residents as possible. All survey responses were recorded on paper (hardcopy).

The initial survey was intended to assess the current status of apartment residents' bed bug knowledge. Specific questions determined if a resident would be able to recognize a bed bug on sight; if the respondent knew how bed bugs get into homes; if the respondent was familiar with common bed bug control methods; and, if the respondent knew how to avoid bringing bed bugs into their home (Appendix 5B). In general, survey questions covered basic bed bug identification (size, shape, color), biology (feeding habits, life cycle, reproductive behavior), prevention, and management practices. Survey questions were either formatted as multiple choice (single response), multiple response, or free-response. The wording of each survey question was designed not to lead either the respondent or the interviewer to a particular answer. The survey also recorded the respondent's bed bug infestation history in their home, including any bed bug management methods that the respondent used or were used by a professional pest management company to control the infestation.

After the initial survey, apartment residents were invited to attend an educational seminar (slide presentation, Appendix 5C). The seminar was developed to teach low-income apartment residents about bed bugs. Training focused on bed bug identification, basic biology and behavior, treatment and prevention methods. Seminar attendees were shown how to distinguish live bed bugs from other pests, and taught about non-chemical management methods. Residents were taught about desiccant dust, including diatomaceous earth (DE), and how DE could be used as a proactive treatment to stop bed bug spread if applied inside the wall voids between apartments. Residents were shown how passive bed bug monitors could be placed under the legs of furniture to intercept and trap bed bugs as they searched for a host. Residents were instructed how to select mattress and box spring encasements that are appropriate for protecting their beds from infestation and, finally, how to use heat to kill bed bugs, specifically the usefulness of a clothes dryer for killing bed bugs in fabric items.

Immediately after the bed bug seminar, attendees were re-surveyed to assess any change in their knowledge base (Appendix 5D). The post-seminar survey included the same questions as the initial survey with the exception that respondents were asked to describe the function of the non-chemical management methods presented in the seminar.

Data Collection and Statistical Analysis

After completion, all hardcopy surveys from each apartment community were separated and entered into a web-based database (survey.vt.edu, VTSurvey, Blacksburg, VA, 2005). The database provided a summary of responses for each group (initial and post-seminar) of surveys, which was exported to a secondary analysis tool (i.e. Microsoft Excel, Apple Pages) for data manipulation and statistical analysis.

Contact rates based on the size of each apartment community were calculated for each survey. Analysis of means for proportion ($\propto=0.05$) was used to determine if the proportion of an apartment community that was contacted significantly represented the entire community population (JMP Pro 10, SAS Institute). Initial survey responses from all locations were compiled and frequency tables were generated for each survey question. For each survey question, response similarities among apartment communities were tested with a Pearson's chi-square test of homogeneity (JMP Pro 10, SAS Institute). It is important to note that a number of survey respondents chose not to answer certain questions or responded with "don't know" or "not sure." Thus, the responses for different questions do not all total 100%. "No response" or "don't know" responses were omitted from the chi-square analysis.

In order to assess any change in the bed bug knowledge as a result of the educational seminar, comparisons between the initial survey and the post-seminar survey were made using the value-added model of educational performance (Saunders 2001). The proportions of responses for initial survey questions were compared to the response proportions for the post-seminar survey questions to quantify the change in bed bug knowledge. Analysis of means for proportion ($\propto=0.05$) was used to determine if the number of post-seminar surveys was a significant proportion of each apartment community's number of initial surveys (JMP Pro 10, SAS Institute). If it was determined that the number of post-seminar surveys did not represent the number of initial surveys for a community, surveys from that location were omitted from the value-added comparison. Post-seminar survey responses from the different apartment communities were compiled and frequency tables were generated for each survey question. Correlation coefficients were calculated to compare initial survey data with post-seminar survey data. Associations were tested with a Pearson's chi-square test of homogeneity, with values of $P \leq 0.05$ used to indicate significance. The closer the Pearson coefficient was to zero, the greater the difference between the initial and post-seminar surveys (Hinkle et al. 2003).

Results

Initial Surveys

Between June 2012 and April 2013, four hundred and seventy-nine (n = 479) initial surveys were successfully administered to apartment residents in the four apartment communities. The total number of apartment units in the four communities was 1030, therefore the contact rate for the initial surveys equaled 46.5% (Table 5-1).

Demographics. For the initial survey, the respondent population consisted of 62% females and 38% males, all of whom rented and lived in the apartments. Eighty-six percent of respondents lived in their apartments alone, and the majority of respondents had no children (Table 5-2). Sixty-one percent of respondents had an annual household income of less than $10,000. Over half of the survey population was over the age of 50 (69.7%).

Bed Bug History. To begin the survey, respondents were asked if they were currently living with bed bugs. The majority (79.5%) of respondents replied, "no, and I have never had bed bugs," followed by 11.5% that were not currently living with bed bugs but had had bed bugs in the past and 7.7% that were currently living with bed bugs (Table 5-3).

Those respondents that were currently living with bed bugs or had had bed bugs in the past were asked how they determined that their insect infestation was bed bugs as opposed to another insect pest. Respondents gave a variety of answers (Table 5-4). However, the greatest percentage of respondents indicated that they were still not sure if the insect pests were bed bugs or not. The majority of respondents that were currently living or had lived with bed bugs in the past did indicate that they had bumps or sores that itched as a reaction to bed bug bites (37.8% and 40%; Table 5-4). When asked what effects the bed bugs have had on their quality of life, many respondents (36-49%) indicated no impact. Yet the remaining respondents said that they had experienced: trouble relaxing, feelings of isolation, loss of friend or family connections, loss of sleep, increase in smoking or alcohol consumption, feelings of depression or desperation, loss of job, decline in health, increase in mental health problems, or a fear that they had transferred bed bugs to another home (Table 5-4). When asked what had been done to "get rid of" the bed bugs, respondents indicated that they had applied pesticides themselves, and had professional heat treatments or professional pesticide applications (Table 5-4). One respondent claimed that she had applied "I don't know how many gallons of this stuff," as she pointed to a container of HotShot™ Bed Bug and Flea liquid spray insecticide.

All respondents were asked the number of times they had moved in the last five years, as well as how frequently they stayed overnight in places other than their apartments. All respondents were also asked how frequently they had visitors stay overnight in their apartments, and how frequently they purchased or received secondhand items (Table 5-5). Respondents who were not currently living with bed bugs were asked if they took any precautions in an attempt to avoid bringing bed bugs into their homes. Approximately half of respondents replied that they did not currently take any precautions to avoid bringing bed bugs into their homes (Table 5-5). Those who were actively trying to avoid bringing bed bugs into their homes indicated that they laundered their sheets frequently, did not place things on bed, hung up their coats, and checked beds and couches regularly. Other precautions included, washing all thrift store purchases or avoiding thrift stores altogether, not accepting gifts, not having company over, reducing clutter, and cleaning constantly. One respondent told the surveyor, "I don't let people come over, but if they do, I make them sit in this metal chair." One respondent claimed, "I used the dryer, bleach, and whatever else I can get my hands on." Another respondent stated, "I avoid people who have them, and people who don't look right."

Assessing Bed Bug Knowledge. Respondents were asked questions to assess their general bed bug knowledge. When asked about the size of a bed bug (approximately the size of an apple seed), 30.7% of respondents answered correctly (Table 5-6). When asked, "What does a bed bug eat," 37.6% of respondents answered correctly with "blood," while 35.1% were not sure (Table 5-7). Twelve percent of respondents responded with "skin," and the remaining 15.0% of responses included: other bugs, skin cells, dead skin, crumbs, things that roaches eat, bones, fabric, bedding, furniture, carpet, trash, and hair. When asked when bed bugs are active, 49.9% of the respondents answered "at night," 7.9% answered "during the day," and 9.8% answered that bed bugs could be active at anytime (Table 5-8). When respondents were asked the following questions: "How often does an adult bed bug need to feed?", "How long can an adult bed bug live?", "How does a bed bug find a host?", "What does a bed bug bite look like?", and "Can bed bugs transmit disease?", the most frequent response was "not sure/no answer" (Table 5-9).

Respondents were also asked questions about recognizing bed bugs in their homes. When asked, "What would be some indicators of bed bug presence in a home?", 40.0% of respondents replied "bites on the skin," and 28.1% responded that they would notice fecal spotting on the furniture and walls. Less than 1% of respondents indicated that they would notice exuvia, and only 13.3% of respondents indicated that they would notice live bed bugs (Table 5-10). When asked where bed bugs might be found in a home, the most frequent response was that bed bugs could be found on a bed or mattress (Table 5-11). When the respondents were asked about common bed bug control methods or products, only 29.4% had heard of heat treatments. Twenty percent of had heard of using mattress encasements. Only 6.4% had heard of using diatomaceous earth as a desiccant dust, and only 3.3% had heard of using traps or monitoring devices (Table 5-12).

Educational Seminar

Although initial survey respondents were enthusiastic about learning about bed bugs, attendance at the educational seminar was relatively low. The overall number of contacts from 1030 units in the four communities was 11.5% (Table 5-1). These contacts represented only 24.6% of the initial survey respondents.

Post-Seminar Survey

The overall contact rate for the post-seminar survey in the four apartment communities was 11.2% (Table 5-1). The post-seminar surveys were typically conducted immediately after the seminars and, thus, only seminar attendees were surveyed. So although the contact rate for the post-seminar survey was 97.5% of the seminar attendees, the contact rate for the post seminar surveys was low, overall. Within the Essex Village Apartment community, the post-seminar survey proportion of potential respondents exceeded the lower limit for the group proportion (analysis of proportion; JMP Pro 10), indicating that those responses were not significantly representative of the apartment community as a whole. Therefore, the Essex Village post-seminar survey responses were omitted from the post-seminar survey analysis, and both the initial survey responses and post-seminar survey responses were omitted from the value-added comparison.

Demographics. For the post-seminar survey, the population consisted of 66% females and 34% males, all of whom rented and lived in the apartments. Ninety-one percent of respondents lived in their apartments alone, and the majority of respondents did not have children living with them (Table 5-13). Fifty-six percent of respondents had an annual household income of less than $10,000. Ninety-seven percent of the survey population was over the age of 40.

Bed Bug History. To begin the post-seminar survey, respondents were asked if they were currently living with bed bugs. The majority (77.7%) of respondents replied, "no, and I have never had bed bugs." Another 15.2% of respondents stated that they were not currently living with bed bugs but had had bed bugs in the past. The final 7.1% of respondents said that they were currently living with bed bugs.

Value-Added Comparison. As expected, the Pearson's chi-square test of homogeneity revealed correlations between the responses from the initial survey and the post-seminar survey. There were no significant differences (positive correlations) among the response proportions between initial and post-seminar surveys for the question about respondents' bed bug infestation history ($P = 0.2531$), as well as, for the demographics of gender ($P = 0.0586$), number of adults per household ($P = 0.146$), and annual household income ($P = 0.5715$), age ($P = 0.0831$), number of children under 5 years old ($P = 0.5555$), and number of children 5-18 years old ($P = 0.4317$) indicating that similar proportions of these demographics participated in both the initial and post-seminar survey (Table 5-13). For all bed bug knowledge questions, there were negative correlations among response proportions between surveys with $P < 0.0001$, indicating that the proportions of correct responses from the post-seminar survey was significantly higher than the proportions correct responses from the initial survey (Table 5-14). These results suggest that respondents knew more about bed bugs after the educational seminar than they did prior to attending the seminar.

Discussion

Educating low-income, multi-unit housing residents about urban pests and pest control is crucial for effectively preventing and managing insect pest infestations. Throughout the United

States, researchers have evaluated the implementation of integrated pest management (IPM) programs in public housing. Researchers have determined that the education of apartment residents is not only important for the success of IPM programs, but can also help reduce pest populations and improve program efficacy (Campbell et al. 1999, Brenner et al. 2003, Morgan et al. 2004, McConnell et al. 2005). In one study, Wang and Bennett (2006) compared a multi-faceted IPM program to a bait-only treatment for cockroach control in an apartment community in Gary, IN. Wang and Bennett (2006) reported that the IPM program provided a significant decrease in cockroach populations and the cost of cockroach control. Wang and Bennett (2006) offered educational materials to residents in test apartment units, and determined that, while the residents used and understood educational materials when they were provided, continuous efforts to deliver pertinent IPM information would help the adoption and efficacy of a community-wide IPM program. Crider (2010) evaluated the implementation of an IPM program for cockroaches in a multi-story public housing facility for elderly residents in Houston, TX. After educating residents about IPM and implementing IPM principles, Crider (2010) found a significant decrease in the average number of cockroaches per unit ($P < 0.0003$). Crider (2010) reported that residents and operational staff members were more willing and prepared to maintain IPM methods in the facility, after being educated about IPM goals.

Educational efforts focused on bed bug management and control are increasing in the United States. Aultman (2013) described a model for a bed bug education initiative that stresses bed bug awareness, the use of preventative measures, and efficient treatment of infestations among renters and homeowners, particularly those who are most commonly victimized by bed bugs (i.e. the elderly, mentally ill, and socio-economically disadvantaged). Aultman (2013) outlines several simple bed bug prevention methods that everyone should be aware of, including not buying used mattresses, bedding, or furniture; being aware of what bed bugs look like; and, inspecting hotels and other dwellings to reduce both active and passive bed bug dispersal. In 2011, the New York State IPM Program provided bed bug management education to nearly 2,000 people, including pest management professionals, health care professionals, school environmental safety staff, students, property managers, housing inspectors, members of the media, school nurses, canine inspection teams, municipal officials, and other members of the general public (Gangloff-Kaufmann 2011). In 2013, the Virginia Apartment Management Association (VAMA) presented the "Bed Bug Guidance Course" for apartment managers, which communicates specific resident-based bed bug prevention steps aimed at alerting residents to the existence of bed bugs (McCloud 2013). These steps include informing residents about bed bug control and about their responsibility in reporting new infestations (McCloud 2013).

Rossi and Jennings (2010) suggest that community education is necessary for the successful implementation of any bed bug management program within a housing community. In a publication by the National Center for Healthy Housing (NCHH), Taisey and Neltner (2010) described a case study of an elderly and disabled (Section 8) property in Oregon, where one third of the apartment units had bed bug infestations. These infestations were not being controlled because the residents were unable to prepare their apartment units for treatment. Therefore, the pest management professionals (PMPs) were unable to treat them. In working with the NCHH, the property management developed building-wide bed bug policies, which specified that apartment staff would assist in unit preparation, and provided written educational materials, group education, and one-on-one education to the residents and staff. The bed bug education increased communication and got everyone invested in building-wide bed bug management and prevention (Taisey and Neltner 2010).

In our study, a bed bug education seminar was presented to 118 residents of four apartment communities in three cities. Overall, only 11.5% of a potential 1030 residents attended the seminar. Residents who did attend were interested in learning about bed bugs. These individuals were also actively engaged in the presentation and were grateful for the opportunity to learn how to avoid bringing bed bugs into their homes. However, two of the apartment communities in the study (Lineweaver Apartments and Annunciation Inn) had a much greater percentage of seminar attendance than the overall contact percentage. The greater contact percentages at Lineweaver Apartments (31.4%) and at Annunciation Inn (32.1%) were not surprising. At Lineweaver Apartments, we had been consistently working in the facility, for the previous five months, applying a preventative diatomaceous earth barrier in each unit as part of an overall bed bug suppression program. Thus, the Lineweaver residents were very familiar with us and were especially interested in attending our presentation. At Annunciation Inn, there were no current bed bug infestations, but there had been bed bug infestations in the past. We assume that the greater seminar attendance percentage was due to residents wanting to learn more about bed bugs because they were aware of how difficult infestations were to eradicate. It was particularly interesting that the seminar attendance at the largest apartment community in the study (Essex Village Apartments) was so low (0.8%), because the managers indicated that there were multiple bed bug infestations in the community and that the residents had specifically asked for bed bug education.

The purpose of our study was not only to educate low-income, multi-unit apartment residents about bed bugs, but also to assess the bed bug knowledge base and to determine if the residents' bed bug knowledge could be improved if they were exposed to basic bed bug education. Several studies have been conducted to determine public opinion, perceptions, misconceptions, and general knowledge of urban pests in the United States. Butterworth et al. (2010) surveyed residents of southwest Virginia to determine their knowledge, perceptions, and practices concerning mosquito-borne disease transmission. Wood et al. (1981) surveyed public housing residents in Roanoke and Norfolk, VA; and Baltimore, MD, to assess their knowledge of German cockroaches control. Interestingly, Wood et al. (1981) reported that 51% of respondents thought the major cause of cockroach infestations was the presence of food and/or filth, but only 14% thought cleanliness was the best control measure. The results of the Wood et al. (1981) study suggest a disconnect in the residents' knowledge between cause and effect of cockroach infestations and their control. In another study, Dingha et al. (2013) conducted a face-to-face survey of 100 participants in three rural North Carolina counties. The results of the surveys suggested that organized educational programs would increase cockroach awareness among residents, and make integrated pest management programs more likely to succeed.

Few studies have been conducted to assess peoples' knowledge about bed bugs, and most studies have focused on whether or not respondents can recognize a bed bug. Reinhardt et al. (2008) determined that out of a survey population of 351 people from three counties in Great Britain, only 10% of respondents (n=351) were able to recognize a bed bug, by looking at an insect in a test tube. Interestingly, as respondents' age increased, bed bug recognition also increased, indicating that older people were more familiar with bed bugs (Reinhardt et al. 2008). Seidel and Reinhardt (2013) questioned 391 people from four large cities in Germany, and determined that only 13% of respondents recognized a bed bug when one was presented to them. Similarly, only 15% of respondents said they would call a pest management professional if they found a bed bug in their homes. Based on these results, Seidel and Reinhardt (2013) estimated that approximately 97% of all early-stage infestations would go untreated. Seidel and Reinhardt

(2013) also suggested that many respondents had strong misconceptions about bed bugs, regarding both their identification and control. These misconceptions would most likely make infestation problems more challenging to resolve.

In our study, we determined that a large portion (69%) of the low-income multi-unit facility residents who participated in the initial survey were unable to correctly identify the approximate size of an adult bed bug. Also, most of these residents did not know that bed bugs were obligate blood feeders. Results like these were not uncommon. In our study, we found that, for most of the survey questions (5 out of 7) about bed bug biology and behavior, respondents were so unsure of the correct answer, that the majority of responses were "don't know/no answer." While being unable to correctly answer questions about bed bug feeding habits, life span, host searching behavior, and disease transmission does not necessarily mean that a person would be ill-prepared to handle a bed bug infestation, we were surprised to find similar proportions of "don't know/no answer" responses for the questions about what a bed bug bite looks like, or whether a respondent had heard of common non-chemical bed bug control methods. Forty percent of initial survey respondents had never heard of mattress encasements, monitoring devices, diatomaceous earth, or heat treatments for bed bug control. This was in spite of the fact that most, if not all, of these common control methods had been employed or were currently being applied in their apartment buildings.

Another particularly interesting observation from the initial survey was that less than half (49%) of respondents who had previously had bed bugs, and only 38% of respondents who had never had bed bugs, were actively doing something to avoid bringing bed bugs into their homes. These responses indicated that, even if all bed bugs were eradicated from each of the apartment communities, there would be a strong likelihood that new bed bugs would be introduced in the buildings. Overall, based on the findings of our initial survey, we were surprised by (1) the substantial numbers of incorrect responses to basic bed bug questions, (2) that there were widespread misconceptions about bed bug biology and behavior, and (3) the apathetic attitudes and behaviors of residents towards bed bug prevention.

Several studies have assessed changes in people's knowledge about insect pests as the result of education efforts. In one study, German cockroach infestation levels were evaluated in Boston Public Housing before and after the implementation of an IPM Educator pilot program. In this program, an IPM specialist taught residents about German cockroach biology and habits, how to prepare their unit for cockroach treatment, and the role of sanitation in cockroach control (Condon et al. 2007). Condon et al. (2007) observed that, after instruction from an IPM educator, the number of unit preparations prior to pest control treatments had increased and, subsequently, the number of cockroaches had decreased after treatments, when compared with the preparation rates (and infestation levels) prior to the education.

Our post-seminar survey data verified that respondents had increased their knowledge of bed bug identification, behavior, signs of infestations, and common non-chemical bed bug control methods, as the result of attending an educational seminar. For all of the seven survey questions regarding bed bug biology and behavior, the proportion of correct post-seminar responses increased significantly when compared with the proportions of correct initial survey responses. However, post-seminar survey questions asking about when bed bugs are active, or the bed bug life span, or host searching behavior, the proportions of "don't know/no answer" responses were still greater than those proportions of the correct responses. However, in each of these three questions, the proportion of "don't know/no answer" responses from the post-seminar surveys was significantly less than the proportion of the initial surveys. Also, there were significantly more responses to the multiple response questions about where a bed bug might be found in a home and signs of bed bug presence in a home in the post-seminar survey than there had been in the initial survey. When respondents were asked if they had heard of the use of common non-chemical bed bug control methods, post-seminar survey respondents were able to recognize significantly more methods than initial survey respondents. Overall, our initial and post-seminar survey data indicated an increase in the bed bug knowledge base, indicating that respondents had learned a lot about bed bugs from the educational seminar.

Price (2001) suggested that a comparison of pre- and post-education knowledge could be useful for evaluating the impact of educational efforts. Polivka et al. (2011) evaluated the impact of an Urban Healthy Homes initiative aimed at educating low-income children (less than 18 years old) about asthma. Polivka et al. (2011) reported that a comparison of pre- and post-education survey data indicated that respondents' general asthma knowledge increased significantly between the initial questionnaire and the post-education questionnaire. In fact, respondents were able to correctly identify 92% of the listed asthma triggers after the educational intervention, as compared with 83% of triggers prior to the intervention (Polivka et al. 2011).

Because there were significant improvements in the bed bug knowledge base of survey respondents after attending our educational seminar, we assume that the seminar had a positive impact on the seminar attendees. While the "impact" of the educational program was defined as "an improvement in bed bug knowledge among survey respondents," we were unable to measure the true impact of the program on the entirety of each apartment community in the study. For example, we have no data regarding knowledge transferred from residents who attended the seminar to residents who did not attend. In our experience, information and rumors about resident issues quickly disseminate through apartment communities, and particularly elderly and disabled communities. Therefore, the bed bug education seminar, no doubt, had a greater impact (albeit slight) than our post-seminar survey data suggests.

As with many survey-based social studies, several sources of error contributed to the results of this study. A major threat to the validity in this study was the low rate of seminar attendance (25%) as compared with the number of initial survey participants. Those who attended the educational seminar may have been inclined to attend, not because they wanted to learn about bed bugs, but because they had friends who were attending. Attendees may have been paranoid about bed bugs, or simply may have been looking for something interesting to do. The fact that multiple people administered the initial and post-seminar surveys also contributed error to this study. While all surveyors were trained on the design and administration of the survey, we cannot assume that all surveys were administered or recorded without bias.

In spite of potential error, the results of this study indicate that there is a low baseline level of bed bug knowledge among low-income, multi-unit facility residents. However, if educational efforts are directed towards these residents, bed bug knowledge can be improved. While this study focused on residents of public housing communities, educational efforts, including print materials and educational seminars, should be made available to all multi-unit housing residents, whether privately owned or government supported. More studies should, and undoubtedly will, be conducted in other housing communities in order to assess the scope of bed bug knowledge among apartment residents.

Table 5-1. Survey profiles, locations, and contact rates for four different apartment communities.

Apartment Communities	Number of Apartment Units	Initial Surveys n	Initial Surveys %	Seminar Attendees n	Seminar Attendees %	Post-Seminar Surveys n	Post-Seminar Surveys %
Lineweaver Apartments Harrisonburg, VA	121	108	89.3%	38	31.4% † 35.2%	37	30.6% ‡ 97.4%
Annunciation Inn New Orleans, LA	106	68	64.2%	34	32.1% † 50.0%	34	32.1% ‡ 100.0%
Renaissance Place New Orleans, LA	307	181	59.0%	42	13.7% † 23.3%	41	13.4% ‡ 97.6%
Essex Village Apartments Richmond, VA	496	122	24.6%	4	0.8% † 3.3%	3	0.6% ‡ 0.75%
Overall	1030	479	46.5%	118	11.5% † 24.6%	115	11.2% ‡ 97.5%

† Percentages indicate contact rate as compared with the number of initial surveys.

‡ Percentages indicate contact rate as compared with the number of seminar attendees.

Table 5-2. Demographic profile of the total 479 respondents in the initial bed bug information survey of four apartment communities.

Demographic	N	% of Respondents
Gender		
Male	182	38.0
Female	297	62.0
Age		
18-25	37	7.7
26-30	30	6.3
30-39	29	6.1
40-49	36	7.5
50-59	73	15.2
60-69	137	28.6
70-79	88	18.4
Over 80	36	7.5
No answer	13	3.0
Number of Adults per Household		
1	412	86.0
2	52	10.9
3	4	0.8
No answer	11	2.3

Table 5-2. Continued

Demographic	N	% of Respondents
Number of Children per household (< 5 years old)		
0	386	80.6
1	33	6.9
2	19	4.0
3	2	0.4
No answer	39	8.1
Number of Children per household (5-18 years old)		
0	383	79.9
1	23	4.8
2	20	4.2
3	10	2.1
4	5	1.0
5	1	0.2
No answer	37	7.7
Annual Household Income		
Less than $10,000	291	60.8
$10,001-$19,999	75	15.7
$20,000-$29,999	5	1.0
$30,000-$39,999	2	0.4
No answer	106	22.1

Table 5-3. Response differences by apartment community for the question, "Are you currently living with bed bugs?"

		% Response					
	N	Yes	No, but I have had bed bugs in the past	No, and I have never had bed bugs	x^2	df	*P*
Total Population	473	7.7 A	11.5 A	79.5 B	-	-	-
Apartment Community							
Lineweaver Apartments	108	5.6	15.7	78.7	-	-	-
Annunciation Inn	68	0.0	11.8	88.2	-	-	-
Renaissance Place	178	10.5	4.9	82.9	-	-	-
Essex Village Apartments	119	9.8	17.2	70.5	22.4	6	0.001

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)
2. Overall proportions that are not followed by the same letter are significantly different.

Table 5-4. Responses to "Bed Bug History" survey questions about current or past bed bug infestations.

	% Response	
	Currently living with bed bugs	Had bed bugs in the past
Questions	N = 37	N = 55
How did you determine that the pest infestation was bed bugs?		
Information from neighbors	8.1	14.6
Information from property management	8.1	18.2
Information from pest management professionals	10.8	12.7
Information from a university or extension service	5.4	0.0
Information from the internet	10.8	25.5
A medical professional advised me based on bite marks	10.8	0.0
We are not completely sure that the pests are bed bugs	24.3	9.1
No answer	21.6	20.0
What is your reaction to bed bug bites?		
Swollen, itchy bumps or sores	37.8	40.0
Swollen, itchy bumps or sores that require medical attention	8.1	5.5
Very mild rash or irritation	16.2	14.6
I have no noticeable reaction to bed bug bites.	32.4	29.1
No answer	5.4	10.9

Table 5-4. Continued

Questions	% Response Currently living with bed bugs N = 37	Had bed bugs in the past N = 55
What effects would you say the bed bugs have had on your quality of life?		
Loss of sleep	40.5	45.5
Could not relax	54.1	47.3
Feelings of isolation	2.7	18.2
Loss of family or friend connections	5.4	12.7
Increase in smoking/alcohol consumption	2.7	1.8
Loss of job	2.7	0.0
Feelings of depression or desperation	0.0	16.4
Decline in physical health	5.4	5.5
Increase in mental health problems	5.4	3.6
I think I may have transferred the bed bugs to another home or location	0.0	12.7
No impact on quality of life	48.7	36.4
No answer	0.0	18.2
What has been/was done to get rid of the bed bugs?		
I applied a single pesticide that was purchased from a retail store	13.5	14.6
I applied multiple pesticides that were purchased from retail stores	0.0	14.6
Professional heat treatment was applied	16.2	34.6
A single professional pesticide application	16.2	0.0
Multiple professional pesticide applications	13.5	10.9
No remediation attempts have been/were made.	40.5	16.4
No answer	0.0	9.1

Table 5-5. Overall responses to survey questions about the habits of respondents.

Questions	% Response Currently living with bed bugs N = 37	Had bed bugs in the past N = 55	Had never had bed bugs N = 381
How many times have you moved in the last 5 years?			
Once	37.8	29.1	42.8
2-3 times	21.6	18.2	19.4
More than 3 times	0.0	5.5	4.7
None	40.5	47.3	32.6
How often do you or people that live with you travel (with overnight stays) for work or personal reasons?			
Once a year	21.6	23.6	21.5
Several times a year	8.1	25.5	16.0
Never	65.6	50.9	62.5
How often do you or people that live with you have guests stay overnight?			
Once a year	8.1	7.3	10.2
Several times a year	59.5	34.6	23.1
Never	32.4	58.2	66.1
How often do you or people that live with you buy or receive second-hand items?			
Once a year	23.5	14.6	11.0
Several times a year	14.7	9.1	16.0
Never	58.8	76.4	73.0
Do you take any precautions to avoid bringing bed bugs into your home?			
Yes	-	56.3	44.6
No	-	43.8	55.4

Table 5-6. Overall response differences by apartment community for the question, "What size is an adult bed bug?"

		% Response								
	N	So small that you cannot see it	About the size of a pin head	About the size of an apple seed	About the size of a pea	About the size of a penny	No answer	x^2	df	*P*
Total Population	479	6.3	14.8	30.7	8.1	5.4	34.7	-	-	-
Apartment Community										
Lineweaver Apartments	108	11.1	10.2	38.0	16.7	5.6	18.5	-	-	-
Annunciation Inn	68	0.0	41.2	41.2	8.8	7.3	1.5	-	-	-
Renaissance Place	181	7.2	10.5	18.2	3.9	2.2	58.0	-	-	-
Essex Village Apartments	122	4.1	10.7	36.9	6.6	9.0	32.8	41.8	12	<0.0001

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-7. Overall response differences by apartment community for the question, "What does a bed bug eat?"

	N	% Response: Blood	Skin	Other	No answer	x^2	df	*P*
Total Population	479	37.6	12.3	15.0	35.1	-	-	-
Apartment Community								
Lineweaver Apartments	108	29.6	12.0	26.9	31.5	-	-	-
Annunciation Inn	68	47.1	11.8	10.3	30.9	-	-	-
Renaissance Place	181	39.8	11.6	7.7	40.9	-	-	-
Essex Village Apartments	122	36.1	13.9	18.0	31.9	20.6	6	0.0022

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-8. Overall response differences by apartment community for the question, "When are bed bugs active?"

	N	% Response				x^2	df	P
		Night	Day	Anytime	No answer			
Total Population	479	49.9	7.9	9.8	32.4	-	-	-
Apartment Community								
Lineweaver Apartments	108	10.2	37.9	16.7	18.5	-	-	-
Annunciation Inn	68	41.2	41.2	8.8	1.5	-	-	-
Renaissance Place	181	10.5	18.2	3.9	58.0	-	-	-
Essex Village Apartments	122	10.7	36.9	6.6	32.8	40.4	6	<0.0001

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-9. Questions where "not sure/no answer" had the highest frequency of response out of the 479 respondents surveyed in a study of four apartment communities.

Questions Asked	N	% Response "not sure/no answer"
What size is an adult bed bug?	166	34.7
How long can an adult bed bug live?	379	79.1
How often does an adult bed bug feed?	342	72.0
How does a bed bug find a host?	389	81.2
What does a bed bug bite look like?	192	40.1
Do bed bugs transmit disease?	198	41.3

Table 5-10. Overall response to the question, "What would be some indicators of bed bug presence in a home?"

	N	% Response: Bites on the skin	Exuvia (cast skin)	Fecal spotting on furniture/walls	Live bed bugs	No answer	x^2	df	*P*
Total Population	638	40.0	0.6	28.1	13.3	18.0	-	-	-
Apartment Community									
Lineweaver Apartments	144	48.6	2.1	11.1	28.5	9.7	-	-	-
Annunciation Inn	78	57.7	1.3	16.7	10.3	14.1	-	-	-
Renaissance Place	264	25.0	0.0	45.1	4.9	25.0	-	-	-
Essex Village Apartments	152	48.7	0.0	20.4	15.1	15.8	120.3	9	<0.0001

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-11. Overall response to the question, "Where might you find a bed bug in a home?"

	N	% Response: On beds and mattresses	On furniture near beds and mattresses	In/on walls and baseboards	In closets and clothes-containing furniture	In a kitchen	In a bathroom	No answer	x^2	df	*P*
Total Population	686	46.9	14.7	7.0	5.8	2.8	3.5	19.2	-	-	-
Apartment Community											
Lineweaver Apartments	226	31.0	15.0	14.2	7.5	6.6	9.3	16.4	-	-	-
Annunciation Inn	88	69.3	11.4	5.7	6.8	1.1	0.0	5.7	-	-	-
Renaissance Place	188	51.1	9.6	0.0	4.8	1.1	0.0	33.5	-	-	-
Essex Village Apartments	184	51.6	21.2	5.9	4.4	0.5	1.6	14.7	109.1	15	<0.0001

1. Response similarities among apartment complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-12. Overall response to the question, "Have you heard of using any of the following methods of bed bug control?"

		% Response							
	N	Mattress encasements	Monitoring devices	Heat treatments	Diatomaceous earth	No answer	x^2	df	*P*
Total Population	644	20.2	3.3	29.4	6.4	40.4	-	-	-
Apartment Community									
Lineweaver Apartments	192	24.5	4.2	38.0	15.6	17.7	-	-	-
Annunciation Inn	70	17.1	4.3	12.9	4.3	61.4	-	-	-
Renaissance Place	201	5.9	1.9	15.9	2.9	73.1	-	-	-
Essex Village Apartments	181	32.6	3.3	41.4	2.8	19.9	27.2	9	0.0013

1. Response similarities among apartent complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.)

Table 5-13. Comparison of demographic profiles of the initial and post-seminar survey responses. Response similarities among apartment complex were tested using Pearson's chi-square test of homogeneity ($P \leq 0.05$; JMP, SAS Institute Inc.).

	% Responses				
Demographic	Initial Survey	Post-Seminar Survey	x^2	df	P
Gender	N = 357	N = 112			
Male	46.4	33.9	5.4	1	0.0586
Female	53.6	66.1			
Age	N = 347	N = 112			
18-25	0.3	0.9	12.6	7	0.0831
26-30	1.1	0.9			
30-39	2.0	0.9			
40-49	9.2	10.7			
50-59	16.8	13.4			
60-69	35.3	29.5			
70-79	27.2	38.4			
Over 80	8.1	5.4			
Number of Adults per Household	N = 349	N = 112			
1	94.8	91.1	2.1	1	0.146
2	5.2	8.9			
3	0.0	0.0			

Table 5-13. Continued

Demographic	% Responses Initial Survey	Post-Seminar Survey	x^2	df	P
Number of Children per household (< 5 years old)	N = 323	N = 112			
0	99.7	100.0			
1	0.3	0.0	0.35	1	0.5555
2	0.0	0.0			
3	0.0	0.0			
Number of Children per household (5-18 years old)	N = 323	N = 112			
0	99.7	99.1			
1	0.3	0.9			
2	0.0	0.0	0.62	1	0.4317
3	0.0	0.0			
4	0.0	0.0			
5	0.0	0.0			
Annual Household Income	N = 357	N = 112			
Less than $10,000	63.6	56.3			
$10,001-$19,999	17.1	20.5			
$20,000-$29,999	0.6	0.9	2.0	3	0.5715
$30,000-$39,999	0/0	0.0			
No answer	18.8	22.3			

Table 5-14. Comparison of initial survey and post-seminar survey questions, where significant differences between response proportions were determined by Pearson's chi-square test of homogeneity ($P \leq 0.05$).

Questions	% Response: Initial Survey	% Response: Post-Seminar Survey	x^2	df	P
What size is an adult bed bug?	N = 357	N = 112			
About the size of an apple seed	28.6	53.6			
Others	36.1	33.9	33.9	5	<0.0001
No answer	35.3	12.5			
What do bed bugs eat?	N = 357	N = 112			
Blood	38.1	86.6			
Others	27.8	8.0	83.6	3	<0.0001
No answer	36.1	5.4			
How often does an adult bed bug need to eat?	N = 353	N = 112			
Weekly	1.9	33.9			
Others	24.4	35.7	121.3	5	<0.0001
No answer	73.7	30.4			
When are bed bugs active?	N = 357	N = 112			
They can bed active at anytime	8.7	38.4			
Others	52.9	53.6	79.8	3	<0.0001
No answer	38.4	8.0			

Table 5-14. Continued

Questions	% Response: Initial Survey	% Response: Post-Seminar Survey	x^2	df	*P*
How long does an adult bed bug live?	N = 357	N = 112			
2-3 months	2.8	16.9			
Others	17.4	28.6	49.7	6	<0.0001
No answer	79.8	54.5			
How does a bed bug find a host?	N = 357	N = 112			
Attracted by exhaling (CO_2) and body heat	3.9	29.5			
Others	7.3	38.4	152.3	4	<0.0001
No answer	88.8	32.1			
Where would you expect to find a bed bug in a home?	N = 502	N = 238			
On beds/mattresses	45.2	37.4			
On furniture near beds/mattresses	12.4	27.3	60.8	6	<0.0001
In/on walls and baseboards	7.4	18.1			
No answer	20.9	7.9			
What would be some indicators of bed bug presence in a home?	N = 486	N = 195			
Bites on the skin	37.2	41.5			
Exuvia (cast skin)	0.8	7.2			
Fecal spotting on furniture/walls	30.5	25.1	37.3	4	<0.0001
Live bed bugs	12.8	18.5			
No answer	18.7	7.7			

Table 5-14. Continued

Questions	% Response		x^2	df	*P*
	Initial Survey	Post-Seminar Survey			
What does a bed bug bite look like?	N = 357	N = 112			
Everyone reacts differently to bed bug bites	1.1	37.5			
Others	56.3	53.6	148.8	5	<0.0001
No answer	42.6	8.9			
Do bed bugs transmit diseases?	N = 357	N = 112			
Yes	31.7	14.3			
No	27.5	66.9	57.2	2	<0.0001
No answer	40.9	18.8			
Have you heard of using any of the following products for bed bug control?	N = 463	N = 314			
Mattress encasements	15.3	28.9			
Monitoring devices	3.2	19.1			
Heat treatments	24.6	32.5	141.3	4	<0.0001
Diatomaceous earth	8.4	18.2			
No answer	48.4	1.3			

Conclusions

In 2010, U. S. Congressmen George K. Butterfield (D-N.C) and Donald E. Young (R-A.K) established a Congressional Bed Bug Forum concerning the rapidly growing bed bug population. The forum's intent was to determine the appropriate federal role in helping to more effectively respond to and manage bed bugs in the United States. In a letter addressing Nancy Pelosi (Speaker of the House of Representatives), the congressmen specifically indicated that insecticide resistance, the high cost of bed bug treatment, and the lack of bed bug knowledge among citizens were all contributing to the increase in bed bug infestations in the United States (Butterfield and Young 2010).

Efforts to research and learn more about the management, prevention, and control of bed bug infestations are ongoing. At this time, many universities have bed bug research groups and most pesticide manufacturers are producing and distributing bed bug control products. As part of this effort, we have conducted three studies evaluating different aspects of bed bug management.

In one study, we evaluated bed bug response to diatomaceous earth applications in the laboratory. We evaluated five diatomaceous earth insecticide products and one amorphous silica insecticide product. We also evaluated bed bug response to different application rates of diatomaceous earth and whether or not the bed bug feeding status influenced the efficacy of diatomaceous earth treatments. We determined that diatomaceous earth was successful at producing 100% bed bug mortality in all assays. One of our most interesting results was that 100% mortality was achieved for all bed bugs evaluated at different diatomaceous earth application rates. These results indicated that diatomaceous earth applied at rates as low as one-tenth of the label rate would eventually result in bed bug desiccation after constant exposure.

Our second objective was to develop a proactive bed bug suppression and management program for low-income, multi-unit housing facilities, and to implement the program in a facility. The program included vacuuming, a proactive diatomaceous earth barrier application, mattress encasements, monitoring devices, heat treatments, and resident education. Our assessment of the program indicated that it was economical, easy and relatively quick to implement, and, in particular, it showed promise in reducing bed bug infestations. While the true efficacy of the proactive bed bug suppression program will only be revealed over the next few years, we consider the installation of the program to be a success. Our data indicate a downward trend in new bed bug infestations (26.3%) and a slight reduction in bed bug treatment costs (2%), over the course of two years.

The final study was conducted to assess and improve the bed bug knowledge base of low-income apartment residents. We were able to travel to three cities and teach public housing residents about bed bugs, their biology and behavior, and common control methods. Initially, we went door-to-door to survey the apartment residents of four apartment communities. After contacting as many residents as possible, we held several educational seminars that were designed to teach the apartment residents about bed bug biology, behavior, identification, and control. After the seminar, we again surveyed those residents who attended the seminar, so that we could assess any change in their bed bug knowledge. While we were encouraged by the initial participation of the apartment residents, we did not have a very high level of participation in our educational seminars. However, those residents who attended an educational seminar did leave the seminar with increased bed bug knowledge. We hope that these residents are better prepared to deal with bed bugs and will know how to avoid bringing them into their homes in the future.

While the results of these three studies contribute to the bed bug research efforts in the United States, the number of questions regarding the factors influencing bed bug control continues to grow. Research in the areas of bed bug biology, behavior, physiology, insecticide resistance mechanisms, effective chemical and non-chemical control methods, and prevention measures must be further studied increase our chances of controlling bed bugs in the future. In addition, we believe that a greater nationwide effort should be made, nationwide, to relay new, beneficial, and relatable bed bug prevention information to those who need it.

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Appendix 4A. Printable booklet, "Bed Bugs: How to Protect Yourself and Your Home"

BED BUGS How to Protect Yourself and Your Home

Virginia Cooperative Extension
Virginia Tech • Virginia State University
www.ext.vt.edu

Virginia Department of Agriculture and Consumer Services

BED BUGS How to Protect Yourself and Your Home

Bed bugs have been a pest of humans throughout history and were a common pest in the United States at the turn of the previous century. They were essentially eradicated in the U.S. in the 1940s and 1950s largely because of the use of the insecticide DDT, which was readily available to consumers and was broadly applied with little regulation. Since the 1990s, we have seen an increase in bed bug infestations in the United States. There are many theories about why bed bug infestations have returned including increases in international travel, the transfer of secondhand furniture and clothing, a higher turnover of occupants in multi-unit housing, widespread resistance to insecticides (including DDT); and a lack of bed bug awareness and precautions worldwide. While these factors all contribute to the rise in infestations, we need to remember that bed bugs are natural ectoparasites of humans. When we consider the billions of people living on earth today compared to 100 years ago, it should be no surprise that there are more bed bugs.

This book will give you information that you need to identify a bed bug, and the signs of a potential infestation. You will also learn about how bed bugs can get into your home. Use this guide to learn how to check yourself and your home for bed bugs, and what management tools should and should not be used in your home.

For more information, please visit:

Bed Bug Outreach and Education Program
http://www.vdacs.virginia.gov/pesticides/bedbugs.shtml

VDACS Office of Pesticide Services
http://www.vdacs.virginia.gov/pesticides/

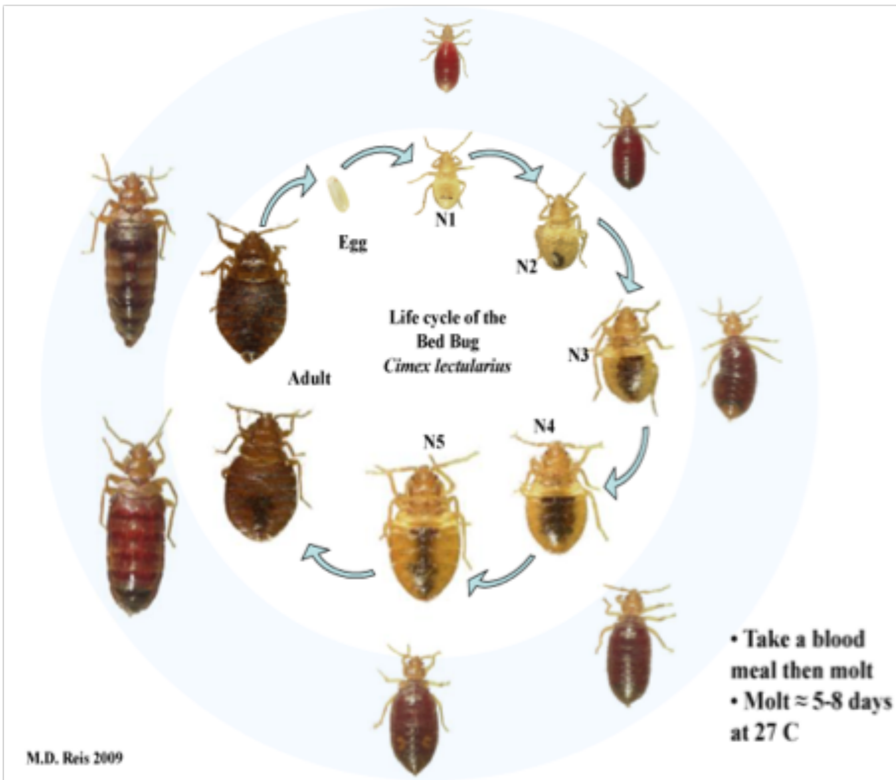
Virginia Department of Agriculture and Consumer Services
http://www.vdacs.virginia.gov/

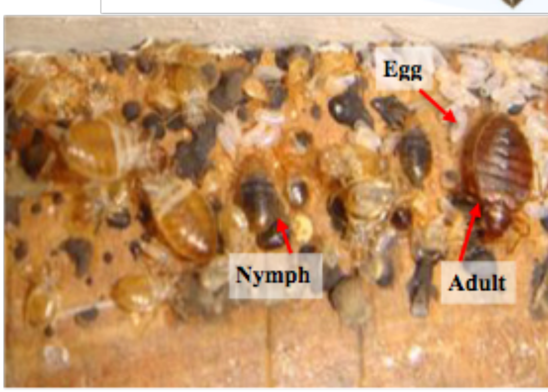
Virginia Tech Department of Entomology
http://web.ento.vt.edu/ento/

Virginia Cooperative Extension
http://www.ext.vt.edu

Bed Bug Identification

Bed bugs have five immature stages. Each stage must consume a blood meal to develop into the next stage. Adult bed bugs must have regular (~7 days) blood meals in order to keep producing eggs.





Adult bed bugs are flat and reddish brown in color. They are the size and color of an apple seed.

Nymphs, or immature bed bugs, are yellowish in color and semi-transparent. Immature bed bugs range from the size of a comma (,) to the size of an adult bed bug.

Eggs are very tiny, pearl white in color and about the size of this comma (,). You can see their red eyes developing at age 5 days.

3

The Life of a Bed Bug

When bed bugs are not feeding (typically during the daylight hours) they gather together in groups or aggregations.

Bed bugs feed only on blood. They may probe your skin several times with their mouthparts before settling in to feed.

Female bed bugs will begin laying eggs within a day or two of feeding and mating. Eggs will hatch in 6 to 9 days and, with access to regular blood meals, nymphs will continue to develop.

Adult bed bugs will mate very soon after feeding.

Bed Bug Indicators

Seeing and identifying live bugs is the most obvious indicator of a bed bug problem.

Each person reacts differently to bed bug bites. Skin reactions are not the best way to identify bed bugs.

Immature bed bugs have to shed their skin in order to grow. Sometimes the shed skins are the only bed bug evidence you will find, not the bugs themselves.

Bed bugs feed on blood and then excrete it as feces (bed bug poop). These black poops are common indicators of bed bug presence.

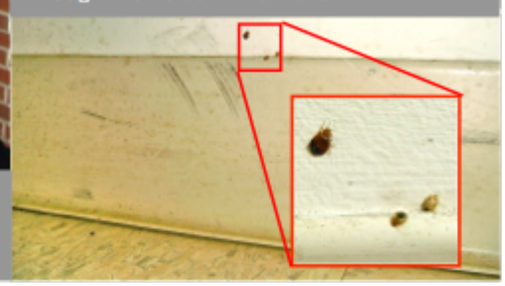
How Do Bed Bugs Get Into Your Home?

Storing furniture or bringing used furniture into your home is a common way to get bed bugs. Inspect any used furniture before bringing it inside.

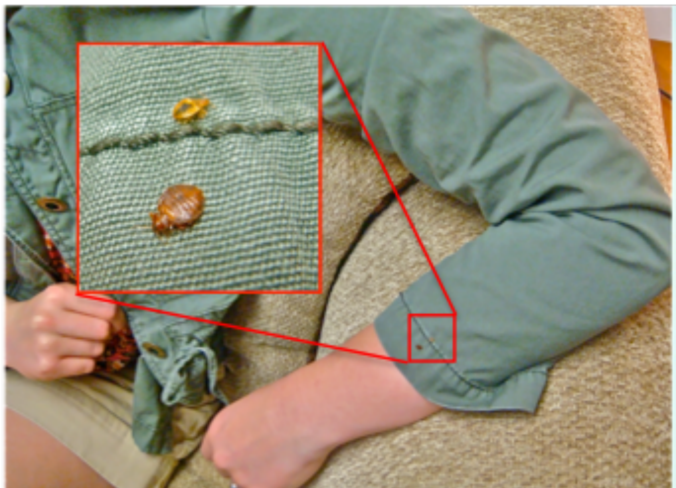
Bed bugs can get into your home by hitchhiking on your belongings.

Friends and family coming to visit may also have hitch-hiking bed bugs on their belongings, even without them knowing it.

In some cases, bed bugs can get from your neighbor's home to your home by climbing through the voids in the walls.

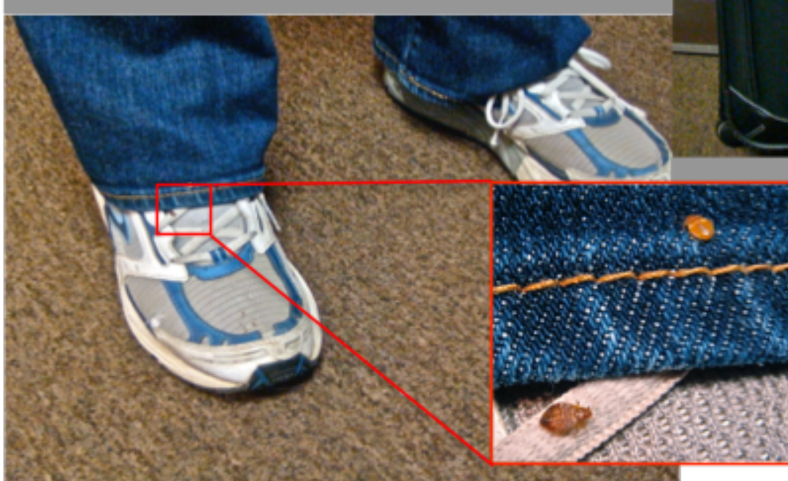


How to Check Yourself For Bed Bugs



You can also pick up bed bugs on the seams, surfaces or cuffs of shirts and blouses when sitting on infested furniture.

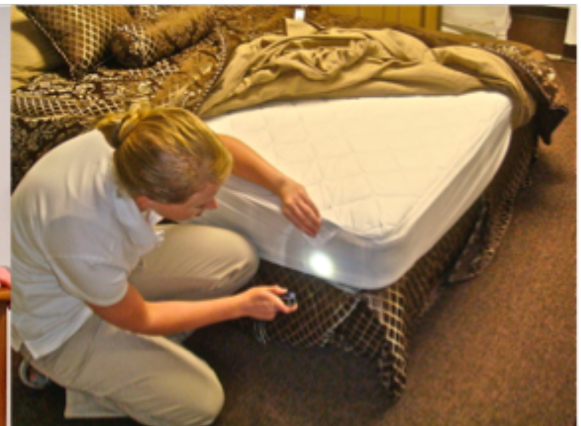
Inspect your purses, computer bags, gym bags and other items for bed bugs before bringing them back into your home each day.



Examine your pants for bed bugs by carefully inspecting seams, surfaces, and cuffs. Inspect the tread of your shoes and the laces for clinging bugs.

How to Check Your Home For Bed Bugs

Inspect the nightstands and furniture next to the bed using a flashlight to see inside drawers, set-in screw holes, cracks and wood seams.



If you think you may have bed bugs at home, inspect locations where you (the food source) like to rest. Check the bed seams and mattress tags for bed bug evidence.

Inspect upholstered furniture, like couches. Using a flashlight, carefully look over surfaces, seams, cracks and crevices and cushions for bed bug evidence.

Make sure to have a flashlight with a strong and bright beam!

What Can You Do in Your Home?

You can see bed bugs and their eggs. Simply inspecting your personal items can protect you from infesting your home.

Bed bug monitors, like these, capture any bed bugs that try to find their way to a blood meal (you). The bugs fall into the trap and cannot escape.

Protect your bed from becoming a home for bed bugs by placing both the mattress, and especially the box springs, in a "bite proof," "escape proof" encasement.

The heat from a hot clothes dryer will kill all bed bugs and their eggs. Many types of items can go in the dryer, including clothes, shoes, and bed linens.

What Can Your Housing Management Do?

Items that may contain bed bugs can be sealed and cooked inside a heat box. The heat will kill all bed bugs and their eggs in furniture and personal items.

A desiccant dust can be applied in wall voids, behind faceplates, and in drop ceilings to prevent bed bugs from moving from one apartment unit to another.

When a bed bug infestation occurs, trained bed bug exterminators will be needed to get the population under control. Trained bed bug-sniffing dogs may be brought in periodically for inspections.

What NOT To Do For Bed Bugs In Your Home

Bed bugs will not walk through piles of dust. If a pile of dust is higher than their eye why would they get in it? This dust is a potential inhalation hazard, a mess, and bed bugs will just avoid it.

Never attempt to control a bed bug infestation yourself with insecticides. If spraying insecticides worked we would have no bed bug problems in the United States. Insecticide exposure is dangerous for you, and will not control bed bugs.

Do not put insecticides or repellents on your skin or bedding to stop bed bugs from biting. These products pose more danger to you than the bed bugs, and do not prevent bed bug bites.

Bug bomb vapors ignited to cause explosion in Lebanon row home

By BARBARA MILLER, The Patriot-News

House fires and explosions have been caused by people over-using bug bombs to control bed bugs. Studies have shown that bug bombs do not control infestations.

11

BED BUGS How to Protect Yourself and Your Home

Presented by the Urban Pest Management Laboratory at Virginia Tech in cooperation with the Virginia Department of Agriculture and Consumer Services, Office of Pesticide Services and Virginia Cooperative Extension.

For more information, please visit:

Bed Bug Outreach and Education Program
http://www.vdacs.virginia.gov/pesticides/bedbugs.shtml

VDACS Office of Pesticide Services
http://www.vdacs.virginia.gov/pesticides/

Virginia Department of Agriculture and Consumer Services
http://www.vdacs.virginia.gov/

Virginia Tech Department of Entomology
http://www.ento.vt.edu

Virginia Cooperative Extension
http://www.ext.vt.edu

Created by Molly Stedfast and Dini Miller

Virginia Tech Entomology
Urban Pest Management Laboratory
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Blacksburg, VA 24061

Appendix 4B. Print material about the construction of the 'Do-It-Yourself' Heat Chamber.

Do-It-Yourself Heat Chamber

For Bed Bug Prevention and Management

At the University of Florida, Drs. Philip Koehler and Roberto Pereira developed a protocol for building an 8′ x 8′ Polystyrene heat chamber that is designed to reach the thermal death point for bed bugs and eggs (122° F) using electric oil-filled heaters and fans. The heat chamber can be used to treat infested household items and furniture or as a precaution before moving potentially infested items. This heat chamber can be put together easily, taken down, and re-used in different locations.

- Fact Sheet: Using Heat to Kill Bed Bugs
  http://www.vdacs.virginia.gov/pesticides/pdffiles/bb-heat1.pdf
- Video: Bed Bug Heat Treatment
  http://entnemdept.ifas.ufl.edu/sepmc/bedbug_heat_treatment/Bed_Bug_Heat_Treatment.html

Supplies:

- **16 2′x2′ interlocking rubber mats**

  Mats are sold in sets of four 2′x2′ sections, so four sets must be purchased. Each set of four should be pieced together. Once the four sets are arranged in a square, seams should be sealed with duct tape. See **Images 1** and **2**.
- **6 8′x4′x2″ polystyrene foam boards**

  The four walls must overlap according to the diagram in **Figure 1**. Each intersection should be sealed with duct tape. The remaining two boards will become the roof.
- **2 oil-filled, electric radiator heaters**

  Heaters must be able to heat to 140° F; models with internal temperature and time cut-offs are not appropriate for use in the heat chamber.
- **2 commercial box fans**
- **1 oscillating fan**

  Metal fans are preferred because their motors are more likely to be able to withstand the high heat of the chamber. Make sure to keep the warranty in case there are any malfunctions. The fans are critical for keeping the hot air circulating within the sealed chamber. See **Figure 2**.
- **2+ surge protectors**
- **2+ extension cords**
- **5 rolls of duct tape**

  Duct tape should be used to seal the chamber along the edges of the polystyrene walls, ceiling, and floor.
- **4 digital indoor/outdoor thermometers**

  Choose a wired model with a minimum probe cable length of 6′ and be sure to buy the appropriate batteries. The outdoor sensors of the thermometers will serve as the thermo-probes and should be placed in the most difficult areas to heat, i.e. between mattresses, beneath seat cushions, or inside items where airflow would be low. Thermometers should be monitored until each unit reads higher than the thermal death point (approx. 130° F; may take more than 6 hours). See **Image 3**.

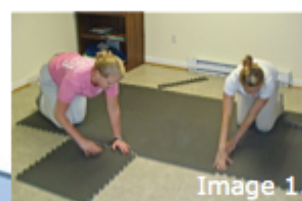


Image 1.

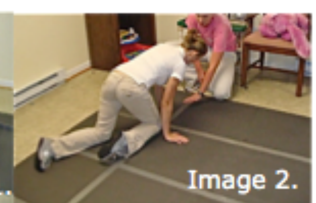


Image 2.

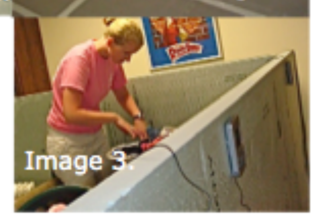


Image 3.

Figure 1.

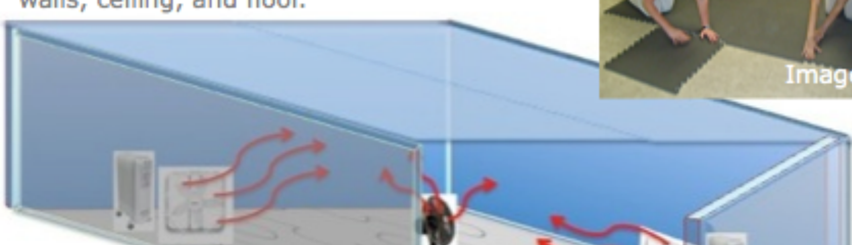


Figure 2.

Molly Stedfast, August 2012
Virginia Tech, Department of Entomology
Virginia Tech

Appendix 4C. Print material about proactive diatomaceous earth treatment supplies.

Bed Bug Management and Prevention: Diatomaceous Earth Applications SUPPLIES

Molly Stedfast, Virginia Tech, Department of Entomology
August 2012

1. Diatomaceous Earth

There are several brands of diatomaceous earth. We recommend MotherEarth® D Pest Control Dust, a BASF product. A 10 lb. pail is available from www.doyourownpestcontrol.com

2. Cyclone Power Duster™

The Cyclone Power Duster™ uses compressed carbon dioxide to apply dust at pressures up to 250 psi. The unit comes with two CO_2 canisters and a 24" wand. A 12" wand is available from the manufacturer. We recommend purchasing the shorter wand because it is easier to maneuver in crowded and cluttered spaces. To refill your CO_2 canisters, you will need a CO_2 supplier. The manufacturer provides more information and offers discounts when purchasing multiple units. Available from http://cyclone-duster.com/.

3. Hand Duster

We recommend one hand duster to accompany each Cyclone Power Duster™. Choose a hand duster with which you are comfortable but make sure that it has a plastic nozzle tip for safety, as it will be used to treat electrical outlets.

4. Backpack Vacuum

We recommend one backpack vacuum per Cyclone Power Duster™. Choose a lightweight, pest control-quality vacuum with a HEPA filtration system, like the Atrix BugSucker, available from www.doyourownpestcontrol.com.

Other Supplies:

5. Phillips-head screwdriver
6. Flat-head screwdriver
7. Extension cord
8. Mini pry bar or 501-knife
9. Shoe covers
10. Dust masks

Virginia Tech 1872

Appendix 5A. Survey and education program introduction script.

Survey Script

BEFORE THE SURVEY

Good Morning / Afternoon,

My name is ____________________ and I am with Virginia Tech / The City of New Orleans Mosquito, Termite, and Rodent Control Board. We are working with the management here at Lineweaver Apartments / Annunciation Inn / Renaissance Place / Essex Village Apartments doing survey research. The purpose of this research is to learn about bed bugs in apartments in Harrisonburg, VA / New Orleans, LA / Richmond, VA.

I would like to ask you a few questions about bed bugs. This survey should only take a few minutes. We would appreciate your participation. All we need you to do is answer some questions to the best of your ability. Your participation in this research will be completely anonymous and is voluntary. You may choose not to participate. If you decide to participate in this survey, you may withdraw at any time.

Would you like to participate?

YES – Indicates consent, Thank them, begin survey
(Consent is documented by a completed survey)

NO – indicates no consent, Thank them for their time

AFTER THE SURVEY

Thank you for your time and participating in this survey. We hope to see you at one of our three bed bug information meetings on ________________________. We will have information about how to protect yourself and your home from bed bugs. (Refer them to the posted flyers)

Do you have any questions?

Thank you.

Appendix 5B. Initial bed bug survey.

RESIDENTS - Bed Bug Educational Survey

Bed Bug History

1) Are you currently living with bed bugs?

□ Yes (Track 1)

□ No, but I have experienced bed bugs in the past (Track 2)

□ No, and I have never experienced bed bugs. (Track 3)

TRACK 1

2) How have you determined that the pest infestation is bed bugs?

□ We have determined they are bed bugs based on information given to us by neighbors.

□ We have determined they are bed bugs based on information given to us by our landlord or property manager.

□ We have determined they are bed bugs based on information given to us by pest management professionals.

□ We have determined they are bed bugs based on information given to us by local extension agent, or university entomologist.

□ We have determined they are bed bugs based on information found on the Internet or in literature.

□ We are not sure if they are bed bugs.

Comments:____

3) Do you recall how long ago you first noticed bites?

□ Less than a week ago

□ Between one week and one month ago

□ Between one month and 6 months ago

□ Between 6 months and a year ago

□ More than a year ago

Comments:____

4) Are you or is anyone living with you showing any of the following reactions to the bites? (All that apply)

□ Bites result in swollen, itchy bumps or sores.

□ Bites result in swollen, itchy lesions that require medical attention.

□ Bites result in mild irritation or rash.

□ Bites do not cause a noticeable reaction.

□ No noticeable reaction

Comments:____

5) How many times have you moved in the last 5 years?

□ None. I have resided in the same location for the last 5 years

□ Once

□ 2-3 times

□ More than 4 times

Comments:____

6) How frequently do you or people that live with you travel for work or personal reasons (including vacation stays in hotels/motels, and/or medical facility stays)?

□ Never

□ Once a year

□ Several times a year

Comments:____

7) How often do you have visitors staying with you (include friends, family, students returning home, etc.)?

□ Never

□ Once a year

□ Several times a year

Comments:____

8) How often do you purchase or receive second hand furniture or clothing (check all that apply to yourself and /or anyone residing with you, include donations from friends and family)?
□ Never
□ Once a year
□ Several times a year
Comments:____

9) What effects have the bed bugs had on the quality of life (check all that apply to you/anyone residing with you)?
□ Loss of sleep
□ Cannot eat properly
□ Not able to fulfill work duties as well as usual
□ Not able to care for dependents as well as usual
□ Cannot relax
□ Financial loss (approximately? _____________)
□ Loss of or troubled personal relationships
□ Feeling isolated
□ Loss of friends and family connections
□ Increase in alcohol consumption
□ Increase in smoking
□ Increase in prescription drug use
□ Increase in recreational drug use
□ Loss of job
□ Loss of home
□ Significant weight gain or loss
□ Decline in health or increase in health problems
□ Loss of self esteem
□ Feels of depression and / or desperation
□ Increase in mental health problems
□ I think I may have transferred the bed bugs to another home or location
Comments:____

10) What has been done, so far, to get rid of the bed bugs (select all that apply)?
□ Application of a single pesticide purchased from a retail store
□ Application of 2-3 different pesticides purchased from retail stores
□ Application of more than 3 different pesticides purchased from stores
□ "Bombed" place of residence with bug bombs purchased from a retail store
□ A professional pest management company applied pesticides
□ We have worked with more than 1 professional company in an attempt to get rid of bed bugs
□ A professional pest management company applied a heat or cold treatment
□ A professional bed bug detection dog was used to locate bed bugs

Comments:____

11) If you applied pesticides or chemicals yourself please select all the statements that apply to your situation
□ I applied pesticides once
□ I applied pesticides two or three times
□ I applied pesticides four to eight times
□ I applied pesticides more than eight times
□ I used other substances to kill the bugs e.g. gasoline, cleaning agents, insect repellents, (please list the substances in the text box)
Comments:____

12) Do you still have bed bugs?
□ Yes
□ No
□ Not sure
Comments:____

TRACK 2

2) How did you determine that the pest infestation was bed bugs?
□ We determined they were bed bugs based on information given to us by neighbors.
□ We determined they were bed bugs based on information given to us by our landlord or property manager.
□ We determined they were bed bugs based on information given to us by pest management professionals.
□ We determined they were bed bugs based on information given to us by a local extension agent or university entomologist.
□ We determined they were bed bugs based on information found on the Internet or in literature.
□ We were never completely sure if they were bed bugs.
Comments:____

3) How long did the infestation exist before it was resolved?
□ Less than a week
□ Between one week and one month
□ Between one month and 6 months
□ Between 6 months and a year
□ More than a year
□ It was never resolved, we moved out after ___________ (indicate months/years)
Comments:____

4) Did you or did anyone you are living with have a reaction to the bites?
□ Bites resulted in swollen, itchy bumps or sores.
□ Bites resulted in swollen, itchy lesions that required medical attention.
□ Bites resulted in mild irritation or rash.
□ Bites did not cause a noticeable reaction.
□ No noticeable reaction
Comments:____

5) How many times have you moved in the last 5 years?
□ None. I have been in the same home for the last 5 years
□ Once
□ Moved 2-3 times
□ More than 4 times
Comments:____

6) How frequently do you or people that live with you travel for work or personal reasons (including vacation stays in hotels/motels, and/or medical facility stays)?
□ Never
□ Once a year
□ Several times a year
Comments:____

7) How often do you have visitors staying with you (include friends, family, students returning home, etc.)?
□ Never
□ Once a year
□ Several times a year
Comments:____

8) How often do you purchase or receive second hand furniture or clothing (check all that apply to yourself and /or anyone in your family, include donations from friends and family)?
□ Never
□ Once a year
□ Several times a year
Comments:____

9) What effects did the bed bugs have on the quality of your life (check all that apply to you and/or your family)?

□ Loss of sleep
□ Cannot eat properly
□ Not able to fulfill work duties as well as usual
□ Not able to care for dependents as well as usual
□ Cannot relax
□ Financial loss (approximately? ____________)
□ Loss of or troubled personal relationships
□ Feeling isolated
□ Loss of friends and family connections
□ Increase in alcohol consumption
□ Increase in smoking
□ Increase in prescription drug use
□ Increase in recreational drug use
□ Loss of job
□ Loss of home
□ Significant weight gain or loss
□ Decline in health or increase in health problems
□ Loss of self esteem
□ Feels of depression and / or desperation
□ Increase in mental health problems
□ I think I may have transferred the bed bugs to another home or location

Comments:____

10) What was done to get rid of the bed bugs (select all that apply)?

□ Application of a single pesticide purchased from a retail store
□ Application of 2-3 different pesticides purchased from retail stores
□ Application of more than 3 different pesticides purchased from stores
□ "Bombed" place of residence with bug bombs purchased from a retail store
□ A professional pest management company applied pesticides
□ We have worked with more than 1 professional company in an attempt to get rid of bed bugs
□ A professional pest management company applied a heat or cold treatment
□ A professional bed bug detection dog was used to locate bed bugs

Comments:____

11) If you applied pesticides or chemicals yourself please select all the statements that apply to your situation.
□ I applied pesticides once (1)
□ I applied pesticides two or three times (2-3)
□ I applied pesticides four to eight times (4-8)
□ I applied pesticides more than eight times (8+)
□ I used other substances to kill the bugs e.g. gasoline, cleaning agents, insect repellents, etc. (list below)
Comments:____

12) Do you do certain things differently now, in an attempt to avoid acquiring bed bugs again (tell us what you do differently to avoid bed bugs)?
□ Yes
□ No
□ Not sure
Comments:____

TRACK 3

2) How many times have you moved in the last 5 years?
□ None. I have resided in the same location for the last 5 years
□ Once
□ 2-3 times
□ More than 4 times
Comments:____

3) How frequently do you or people that live with you travel for work or personal reasons (including vacation stays in hotels/motels, and/or medical facility stays)?
□ Never
□ Once a year
□ Several times a year
Comments:____

4) How often do you have visitors staying with you (include friends, family, students returning home, etc.)?
□ Never
□ Once a year
□ Several times a year
Comments:____

5) How often do you purchase or receive second hand furniture or clothing (check all that apply to yourself and /or anyone residing with you, include donations from friends and family)?
□ Never
□ Once a year
□ Several times a year
Comments:____

6) Do you apply pesticides inside your residence (select all that apply)?

□ Application of pesticides purchased from a retail store for specific problems (e.g. ants, cockroaches, etc.) not more than once a year.
□ Application of 2-3 different pesticides purchased from retail stores per year.
□ Application of more than 3 different pesticides purchased from stores per year.
□ Bomb place of residence with bug bombs purchased from a retail store
□ A professional pest management company (exterminator) applies pesticides every month
□ A professional pest management company applies pesticides only when needed (not every month, unless they are needed every month).

Comments:____

7) Do you do certain things differently in an attempt to avoid acquiring bed bugs.Tell us what you do differently now you know bed bugs are an increasing problem, e.g. avoid renting furniture, avoid second hand clothes or furniture, etc.
□ Yes
□ No
□ Not sure
Comments:____

Bed Bug Information

These questions are about basic bed bug biology, behavior, identification, and control methods. Please have the respondent answer as freely as possible but provide prompts if needed. Please indicate the closest response listed, or write in the response in the "other" space.

1. Have you seen a live bed bug?

☐ Yes
☐ No
☐ Not sure
☐ No Answer

2. In your opinion, why is the world experiencing a resurgence of bed bugs?

☐ Increased international travel and immigration?
☐ Military presence in the middle east
☐ Unregulated transfer of second-hand clothing, and furniture?
☐ Change in control methods?
☐ Higher turnover of occupants in apartments and public housing?
☐ Global health officials have been focusing efforts on disease vectors other than bed bugs?
☐ Lack of societal awareness and precautions, worldwide?
☐ Insecticide Resistance
☐ Dirty people
☐ Biblical Plague
☐ Not sure
☐ No answer
☐ Other: ____

3. How large is an adult bed bug?

☐ So small you can't see it
☐ About the size of an apple seed
☐ About the size of a pea
☐ About the size of a penny
☐ Not sure
☐ No answer
☐ Other: ____

4. What do bed bugs eat?

☐ Trash
☐ Skin
☐ Hair
☐ Blood
☐ Fabric
☐ Debris
☐ Not sure
☐ No answer
☐ Other: ____

5. How often does an adult bed bug need to eat?

☐ Several times a day
☐ Once a day
☐ Several times a week
☐ Once a week
☐ Once month
☐ Once in their lives
☐ Not sure
☐ No answer
☐ Other: ____

6. How often does an immature bed bug (nymph) need to eat?

☐ Once per life stage
☐ Several times a day
☐ Once a day
☐ Several times a week
☐ Once a week
☐ Once month
☐ Once in their lives
☐ Not sure
☐ No answer
☐ Other: ____

7. What time of day are bed bugs active?

☐ Day
☐ Night
☐ All day
☐ Not sure
☐ No answer
☐ Other: ____

8. How does a bed bug find a host (person) to feed on?

☐ They are attracted by body heat
☐ They are attracted by breathing (CO_2 expulsion)
☐ They walk and search randomly
☐ They fly and land on the host
☐ They drop from the ceiling onto the host
☐ Not sure
☐ No answer
☐ Other: ____

9. How long can an adult bed bug live?

☐ One day
☐ 2-7 days
☐ One week to one month
☐ 2-3 months
☐ 4-6 months
☐ 7-12 months
☐ 1-2 years
☐ More than 2 years
☐ Not sure
☐ No answer

☐ Other: ____

10. Where would you expect to find a bed bug in a home?

☐ On a bed/mattress
☐ On furniture near a bed/mattress
☐ On/in the walls near a bed/mattress
☐ In a bathroom
☐ In a kitchen
☐ In a closet/clothes-containing furniture
☐ Not Sure
☐ No answer
☐ Other: ____

11. What would be some indicators of bed bug presence in a home?

☐ Bites on the skin
☐ Fecal spotting on the mattress
☐ Fecal spotting on the walls/outlets
☐ Exuvia or cast skin
☐ Live bed bugs
☐ Not sure
☐ No answer
☐ Other: ____

12. What does a bed bug bite look like?

☐ Large red bumps
☐ Small red bumps
☐ A rash
☐ Blisters
☐ Mosquito bites
☐ Nothing
☐ Bed bug bites are different on each person (unable to determine a single reaction)
☐ Not sure
☐ No answer
☐ Other: ____

13. Do bed bugs transmit disease?
☐ Yes
☐ No
☐ Not Sure
☐ No Answer

14. Have you heard of using any of the following for bed bug management or prevention?
□ Heat
□ Diatomaceous Earth
□ Passive Monitors or Climb-up interceptors
□ Mattress Encasements
□ Not Sure
□ No Answer

Demographic Information

4. What is your age? 18-25 26-30 31-40 41-50 51-60 61-70 71-80 Over 81

24) What is your gender? Male Female

25) How many adults live in your household? _______

26) How many children under 5 live in your household? _______

27) How many children between the ages of 5-18 live in your household? _______

28) What is your annual household income?

Less than $10,000	$11,000-$19,000	$20,000-29,000	$30,000-39,000	$40,000-49,000
$50,000-59,000	$60,000-69,000	$70,000-79,000	$80,000-89,000	Over $90,000.

Comments:____

Thank you for your time and for answering my questions. Do you have any questions? If you have any more questions, please contact ____________ in the main office. Thank you.
Further Comments:

Appendix 5C. Resident education seminar.

Virginia Tech
Department of Entomology

Bed Bugs and How to Protect Yourself

Return of the Bed Bugs

- Bed bugs were essentially eradicated in the 1940-50s
- In the 1990s, bed bug infestations began to increase in the United States, Canada, Europe, and Australia.
- As of 2006, bed bug infestations have been reported in each of the 50 states.
- Why are they back?

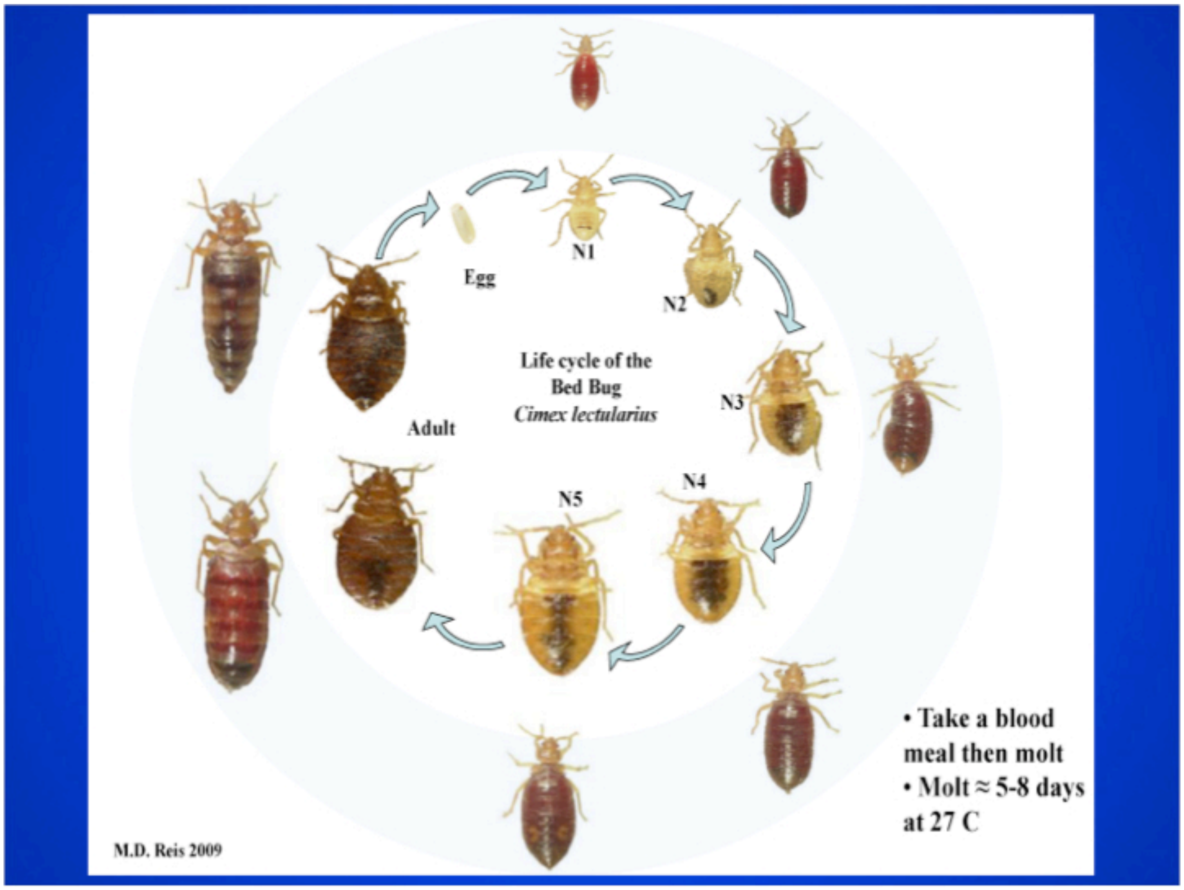
Why are bed bugs back?

- Increased international travel?
- Transfer of second-hand furniture?
- High turnover of occupants in apartments and public housing?
- Lack of societal awareness and precautions, worldwide?
- Bed bugs don't transmit any diseases, so they aren't studied?
- Insecticide resistance?

World-wide resurgence: Pest control operators report a 100-500% increase in bed bug jobs in US, Europe, and Singapore

Adult Bed bugs

- Reddish-brown
- Flat
- No wings
- 6 legs
- 4-5 mm long
- Piercing-sucking mouthparts



Immature Bed bugs

- Eggs
- 5 immature stages
- Require a blood meal and shed skin to molt to next stage
- Look like adults but smaller

What Bed Bugs Do

- Live in groups
- If hungry, they become active between midnight and 5 AM
  - Stimulated by an increase in CO_2 from human exhaling
  - Attracted to humans by our body heat
- In a night, bed bugs will travel many yards to get to a host





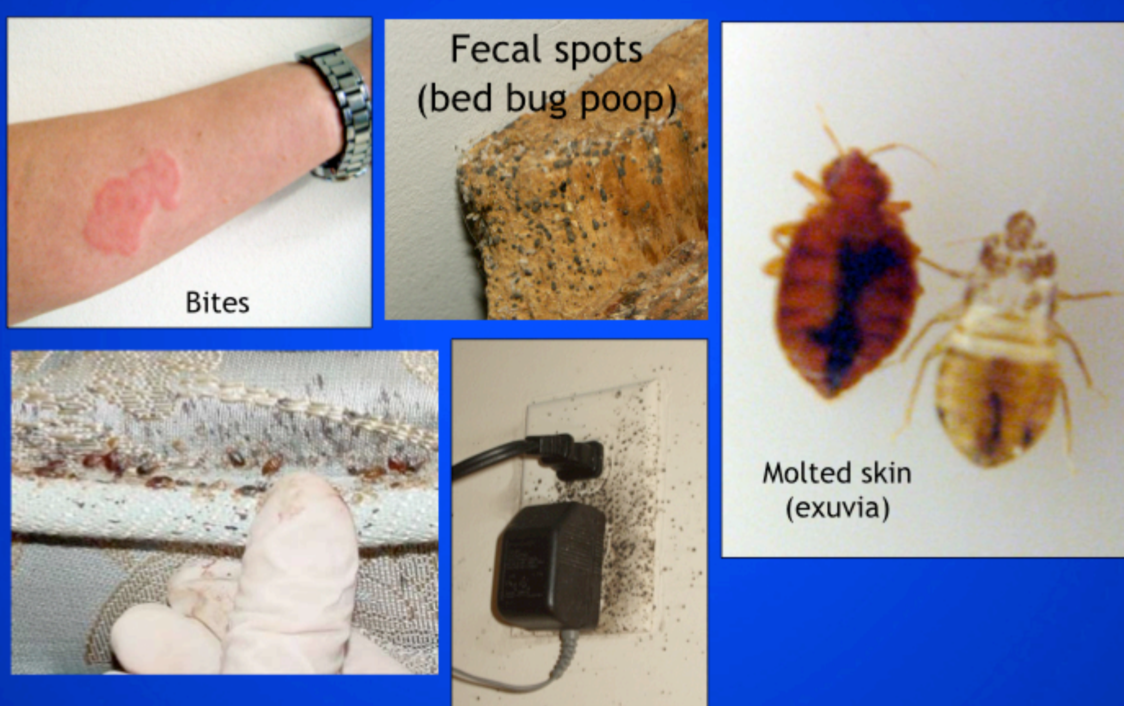
Bed Bug Feeding

- Poke our skin with their straw-like mouthparts
- Feed for 5-10 minutes
- After feeding, leaves the host
- Bed bugs feed every 3-7 days

Use piercing-sucking mouthparts as a straw to suck up the blood

Fed vs.Unfed

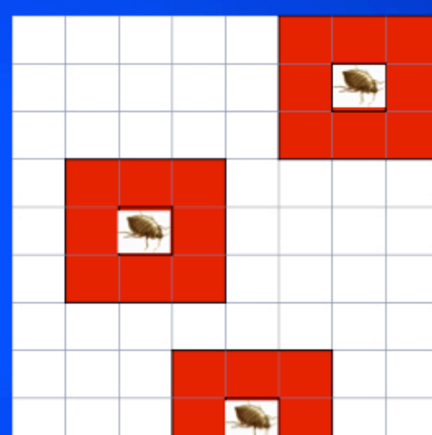
Signs of Bed Bug Presence



Look Closely

Preventing an Infestation in Your Home

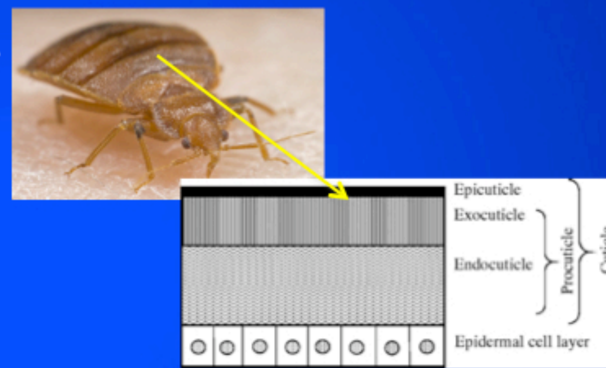
- Diatomaceous Earth
- Heat
- Monitoring devices
- Mattress Encasements



Many multi-unit facilities treat not only the infested apartment but also the eight surrounding units.

Diatomaceous Earth

- Non-toxic desiccant dust
  - Gets imbedded in the wax layer
  - Absorbs the waterproofing components
- Made from fossils of microorganisms that are mined from the ocean
- Can be applied by a trained professional



Heat

- Heat is the most effective method of control.
  - Thermal death point for all life stages including eggs in 118° F.
- Clothes dryer
  - Clothing, bags, and bedding can all be put in a dryer on high heat for about 30 minutes.

Monitoring Devices

– Place under furniture legs to be used as monitors

The Bed Moat™

Climb-Up Interceptor™

Mattress Encasements

- Mattresses
- Box springs
- Crib mattresses

What you can do right now…

- Install monitors and check them regularly
- Install mattress encasements
- Cut down on the clutter in your homes
- Check any furniture you bring in to your home
- Use the clothes dryer for all new clothes and linens
- Check yourself and belongings when returning home
- If you find bed bugs, tell your manager!

Questions?

For more information,
please see the fact sheets
provided by the
Virginia Department of Agriculture and
Consumer Services

http://www.vdacs.virginia.gov/pesticides/bedbugs-gacts.shtml

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Appendix 5D. Post-seminar bed bug survey.

RESIDENTS - Bed Bug Educational POST Survey

Bed Bug History

1. Are you currently living with bed bugs?
- ☐ Yes
- ☐ No, but I have experienced bed bugs in the past
- ☐ No, and I have never experienced bed bugs.

Bed Bug Information

These questions are about basic bed bug biology, behavior, identification, and control methods. Please have the respondent answer as freely as possible but provide prompts if needed. Please indicate the closest response listed, or write in the response in the "other" space.

1. Have you seen a live bed bug?
- ☐ Yes
- ☐ No
- ☐ Not sure
- ☐ No Answer

2. In your opinion, why is the world experiencing a resurgence of bed bugs?
- ☐ Increased international travel and immigration?
- ☐ Military presence in the middle east
- ☐ Unregulated transfer of second-hand clothing, and furniture?
- ☐ Change in control methods?
- ☐ Higher turnover of occupants in apartments and public housing?
- ☐ Global health officials have been focusing efforts on disease vectors other than bed bugs?
- ☐ Other: ____
- ☐ Lack of societal awareness and precautions, worldwide?
- ☐ Insecticide Resistance
- ☐ Dirty people
- ☐ Biblical Plague
- ☐ Not sure
- ☐ No answer

3. How large is an adult bed bug?
- ☐ So small you can't see it
- ☐ About the size of an apple seed
- ☐ About the size of a pea
- ☐ Other: ____
- ☐ About the size of a penny
- ☐ Not sure
- ☐ No answer

4. What do bed bugs eat?
- ☐ Trash
- ☐ Skin
- ☐ Hair
- ☐ Blood
- ☐ Other: ____
- ☐ Fabric
- ☐ Debris
- ☐ Not sure
- ☐ No answer

5. How often does an adult bed bug need to eat?
- ☐ Several times a day
- ☐ Once a day
- ☐ Several times a week
- ☐ Once a week
- ☐ Other: ____
- ☐ Once month
- ☐ Once in their lives
- ☐ Not sure
- ☐ No answer

6. How often does an immature bed bug (nymph) need to eat?

☐ Once per life stage
☐ Several times a day
☐ Once a day
☐ Several times a week
☐ Once a week
☐ Once month
☐ Once in their lives
☐ Not sure
☐ No answer
☐ Other: ____

7. What time of day are bed bugs active?

☐ Day
☐ Night
☐ All day
☐ Not sure
☐ No answer
☐ Other: ____

8. How does a bed bug find a host (person) to feed on?

☐ They are attracted by body heat
☐ They are attracted by breathing (CO_2 expulsion)
☐ They walk and search randomly
☐ They fly and land on the host
☐ They drop from the ceiling onto the host
☐ Not sure
☐ No answer
☐ Other: ____

9. How long can an adult bed bug live?

☐ One day
☐ 2-7 days
☐ One week to one month
☐ 2-3 months
☐ 4-6 months
☐ 7-12 months
☐ 1-2 years
☐ More than 2 years
☐ Not sure
☐ No answer

☐ Other: ____

10. Where would you expect to find a bed bug in a home?

☐ On a bed/mattress
☐ On furniture near a bed/mattress
☐ On/in the walls near a bed/mattress
☐ In a bathroom
☐ In a kitchen
☐ In a closet/clothes-containing furniture
☐ Not Sure
☐ No answer
☐ Other: ____

11. What would be some indicators of bed bug presence in a home?

☐ Bites on the skin
☐ Fecal spotting on the mattress
☐ Fecal spotting on the walls/outlets
☐ Exuvia or cast skin
☐ Live bed bugs
☐ Not sure
☐ No answer
☐ Other: ____

12. What does a bed bug bite look like?
☐ Large red bumps
☐ Small red bumps
☐ A rash
☐ Blisters
☐ Mosquito bites
☐ Nothing
☐ Bed bug bites are different on each person (unable to determine a single reaction)
☐ Not sure
☐ No answer
☐ Other: ____

13. Do bed bugs transmit disease?
☐ Yes
☐ No
☐ Not Sure
☐ No Answer

14. Have you heard of using any of the following for bed bug management or prevention?
□ Heat
□ Diatomaceous Earth
□ Passive Monitors or Climb-up interceptors
□ Mattress Encasements
□ Vacuuming
□ Not Sure
□ No Answer

14. If you have heard of any of these products, please tell me how and why they are used.

5. Mattress encasements ____

   ____

6. Passive monitors or furniture leg traps

   ____

   ____

7. Heat treatments

   ____

   ____

8. Diatomaceous Earth

   ____

   ____

9. Vacuuming

   ____

   ____

Demographic Information

1. What is your age? 18-25 26-30 31-40 41-50 51-60 61-70 71-80 Over 81

2. What is your gender? Male Female

3. How many adults live in your household? _______

4. How many children under 5 live in your household? _______

5. How many children between the ages of 5-18 live in your household? _______

6. What is your annual household income?

Less than $10,000	$11,000-$19,000	$20,000-29,000	$30,000-39,000	$40,000-49,000
$50,000-59,000	$60,000-69,000	$70,000-79,000	$80,000-89,000	Over $90,000.

Comments:____

Thank you for your time and for answering my questions. Do you have any questions?
If you have any more questions, please contact ____________ in the main office. Thank you.
Further Comments: