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CASE STUDY

Development and Evaluation of a Proactive Bed Bug (Hemiptera: Cimicidae) Suppression Program for Low-Income Multi-Unit Housing Facilities

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ABSTRACT. In 2012, a proactive bed bug (*Cimex lectularius* L.) suppression program was implemented in a 121-unit low-income housing facility in Harrisonburg, VA. The program consisted of common minimally toxic and inexpensive integrated bed bug management methods including a novel strategy for applying a perimeter barrier of diatomaceous earth in apartment units. The program was evaluated over the course of 1 yr, after which, mean treatment time, amount of product used, and application cost were calculated for each unit. In 2013, both the number of initial infestations and the costs associated with bed bug treatments were reduced. The apartment residents' perceptions of the bed bug suppression program were assessed using face-to-face surveys, in which many expressed relief that proactive bed bug management measures had been put in place.

Key Words: *Cimex lectularius* L., diatomaceous earth, integrated pest management

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 nonchemical methods (Kells 2006, Romero 2011). Nonchemical 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 ≈US$500. Moreover, the National Pest Management Association's (NPMA) bed bug treatment guidelines recommend three treatments be applied at 2-wk 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 US$800 to US$1,200. 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 (Fig. 1). 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 because of 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 (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 US$8,000 and US$500,000 in a single year for bed bug treatments (D.M.M., unpublished data). 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 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 to 2 oz/100 square feet. Diatomaceous earth 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 toward 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 1), including interior perimeter

Fig. 1. Bed bug adults, nymphs, and eggs in an aggregation on a piece of wooden furniture.

diatomaceous earth applications, heat and other proven nonchemical 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 used 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 facility's management and maintenance staff 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 such as diatomaceous earth applications in each unit.

Program Evaluation Site. The J. R. "Polly" Lineweaver Apartments and the Lineweaver Annex are intersecting apartment buildings that form a single community in Harrisonburg, VA (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. 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 yr old or disabled and have an annual income $<$80% of the local median. Rent is subsidized by the Harrisonburg Redevelopment and Housing Authority, 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 yr old and have an annual income $<$60% of the local median. The Annex is not fully subsidized so some tenants are required to pay the entire rent amount (US$476 per month including all utilities).

At the Lineweaver facility, the first three reported bed bug infestations occurred in December 2010. Before these reported infestations, there had been no bed bug incidence for the previous 9 yr (duration of the current director's tenure; M. Wong, personal communication). 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

Table 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 ≈30 min 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 (118° F) and eggs (122° 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, ON, 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 diatomaceous earth. 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 diatomaceous earth. 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, a one-page brochure explaining the construction and supplies needed for the "do-it-yourself" heat chamber, and a one-page supplies list for diatomaceous earth applications.

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

treatments would cost US$625 for efficiency units and US$825 for one-bedroom units, and included a no-cost retreatment warranty if bed bugs were found in a unit within 30 d 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 US$4,975.

In 2011, the number of infestations in the Lineweaver facility increased to 13. Lineweaver management paid US$8,525 for heat treatments and the inspection of the units surrounding the infested units. It was in 2011 when the HHRA director contacted the Dodson Urban Pest Management Laboratory (DUPML; Virginia Tech, Blacksburg, VA) for advice about how to control the growing bed bug population at Lineweaver. The director was concerned about pesticide use at Lineweaver, as the community was a sensitive environment because of the elderly and disabled residents. The director 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 has found a way to prevent bed bugs from entering your home." 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 (Fig. 2). This was done before the application of the diatomaceous earth perimeter barrier 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 (Fig. 3). 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 the 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 (Fig. 4). All plumbing penetrations, electrical outlets, and light switch plates were also treated with diatomaceous earth using a hand-held bulb duster.

Monitors and Encasements. Because HHRA could not afford to supply 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. Because of 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. 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

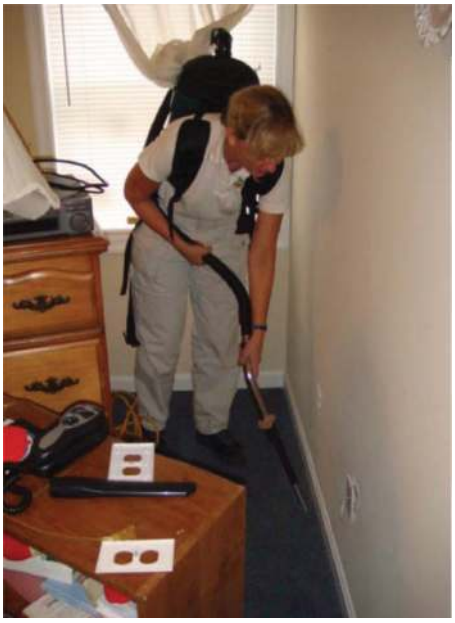

Fig. 2. The floor-wall junctions around each apartment unit were vacuumed with a commercial grade backpack vacuum to remove clutter, live and dead bed bugs, eggs, and exuvia.

Fig. 3. A blind, elderly man was present while the diatomaceous earth perimeter barrier was applied in his unit. Many residents were physically unable to prepare their units before the application.

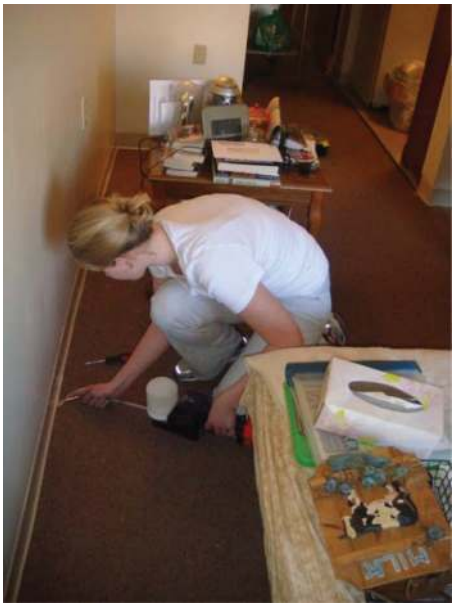

Fig. 4. A diatomaceous earth barrier was applied underneath the vinyl baseboard around the perimeter of each apartment unit using a power duster. Pictured is the Exacticide Power Duster.

Fig. 6. The HHRA staff and administration attended a hands-on seminar where they were taught how to apply the perimeter diatomaceous earth barrier using a Cyclone Power Duster.

Table 1. However, as of December 2013, neither the recommended heat chamber nor the proposed heat trailer had been constructed.

Education. Two 45-min bed bug education seminars were offered to the Lineweaver residents. 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 (Fig. 5). A 2-h 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 diatomaceous earth and implement the other bed bug suppression program components (Fig. 6).

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.

Fig. 5. Lineweaver residents attended an educational seminar about basic bed bug biology, identification, and control.

In each apartment unit, the amount of time spent on preparation and diatomaceous earth application was recorded, as well as the number of laborers, unit size, and amount of diatomaceous earth applied (g). To determine the potential cost of implementing the proactive diatomaceous earth perimeter barrier, the combined labor and supply costs were calculated. The cost of the diatomaceous earth (MotherEarth D Pest Control Dust, BASF, St. Louis, MO) was US$15.42 per 1,000 g applied. Labor cost for implementing the program at Lineweaver was calculated at a rate of US$1 per minute per laborer (break-even cost for the pest management industry).

Data Analysis. Mean application times and amounts of diatomaceous earth applied were calculated for different sized units and number of laborers. Tukey's honestly significant difference test (JMP Pro 10, SAS Institute Inc., 2012, Cary, NC) 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 3-yr 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 (n = 108) 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 before the perimeter application. Approximately 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 either by the Lineweaver staff, DUPML staff, or other residents. While, ≈14%

of the residents were interested and curious about the diatomaceous earth application, 7.4% stated that the pending diatomaceous earth application made them nervous, upset, or afraid. The second question asked residents if they noticed anything about the diatomaceous earth 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 diatomaceous earth in the air for ≤1 h; diatomaceous earth on the carpet around the edge of the rooms; or a slight smell for 1 h after treatment. The last question asked residents if they had any further concerns (living conditions, retreatments, and 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 diatomaceous earth barrier was applied in all 121 unit (U) within 5 mo. The time spent applying the diatomaceous earth barrier and the amount of diatomaceous earth 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 diatomaceous earth barrier, mean application time (assuming two laborers) and mean amount of diatomaceous earth applied per unit were calculated (Table 2). The cumulative application time spent at Lineweaver Apartments was 189 h and 15 min, or a mean of 47.3 min per unit with two laborers. If labor is to be calculated at US$1 per minute, the cost per unit would be US$47.31 per laborer (2) or US$94.62 per unit. The theoretical labor cost for the 121 U in the Lineweaver facility would have been US$11,355. The total amount of diatomaceous earth applied in the units was 7,139.9 g, or ≈60 g per unit. The total cost of the diatomaceous earth applied was US$110.10 or US$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 diatomaceous earth perimeter barrier in all 121 U would have been US$11,465.10.

Reduction in Treatments and Expenses. Between January 2011 and December 2013, there were 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 retreatments (Table 3). In 2012, there were 171% more initial treatments and 383% more retreatments than there were in 2011. In 2013, there were 26.3% fewer initial treatments and 8.3% 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 307.9% 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 2.0%, when compared with the costs from 2012. Over the 3 yr of the study, the annual heat treatment cost changed from US$8,525.00 (2011) to US$34,075.00 (2013), an increase of 299.7%. Lineweaver's total expenditure for the 3 yr of the study was US$77,375.00.

Table 3. In 2011, 2012, and 2013, 105 whole-unit heat treatments were applied in Lineweaver Apartments for bed bug remediation: 40 initial treatments and 65 retreatments

Year	Initial treatments	Retreatments	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%↓)

Percent increase (↑) and decrease (↓) were calculated from year to year and are reported in parentheses.

Discussion

The use of nonchemical 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 nonchemical, chemical, and integrated management 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 nonchemical 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 diatomaceous earth barrier in the building was US$11,465.10, the overall cost of its implementation would be a one-time expense. The mean cost per unit was between US$67 and US$149, depending on unit size and power duster used. These data suggests that a small per unit financial investment may reduce the

Table 2. Mean application time in minutes (±SE) for two laborers and mean amount of diatomaceous earth applied per unit in grams (±SE) based on unit size and duster used

	Efficiency unit		One-bedroom unit	
	Exacticide	Cyclone	Exacticide	Cyclone
Mean treatment time with two laborers (min)	60.5AB (±6.45)	33.37C (±2.46)	73.44A (±9.32)	45.28BC (±2.97)
Cost per laborer (US$)	60.50	33.37	73.44	45.28
Mean diatomaceous earth applied (g)	54.33a (±8.07)	48.54b (±1.84)	74.13b (±6.79)	67.83a (±2.29)
Cost (US$)	0.84	0.75	1.14	1.05
Mean cost per unit (US$)	121.84	67.49	148.02	91.61

These data were used to determine the potential financial investment for a multi-unit facility to apply the proactive perimeter diatomaceous earth barrier. Means not followed by the same letter are significantly different.

number of whole-unit heat treatments (US$625–825) 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 min per unit, actual times ranged between 9 and 80 min 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 diatomaceous earth perimeter barrier as part of the regularly scheduled maintenance routine or at unit turnover.

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 Power Duster required constant agitation to maintain the flow of the diatomaceous earth. 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 U, a rubber gasket inside the Exacticide Power Duster eroded because of constant abrasion by the diatomaceous earth. This allowed the diatomaceous earth to be sucked into the body of the duster, causing the motor to break. At that point, we began using the Cyclone Power Duster, which used pressurized carbon dioxide (from a portable 2.5-pound 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 Power 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 diatomaceous earth 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 Power Duster often resulted in the appliance getting shocked.

Because we were concerned about the diatomaceous earth 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, survey responses revealed the opposite of our expectations. 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 (26.3%) 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 ≈300% between 2011 and 2013.

It should be noted that while we were implementing the program, we were not inspecting for live infestations. In June 2012, a researcher conducting simultaneous study in the Lineweaver Apartment complex inspected each unit in the building for bed bugs (Vaidyanathan et al. 2013). Vaidyanathan et al. (2013) intended to collect different bed bug populations 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 identified. 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 before the infestation becomes 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. To evaluate the cost-effectiveness of this IPM program, this community will be monitored over the next 3 yr 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 been trained to implement this proactive bed bug suppression program. 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.

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