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EFFICACY OF THERMAL REMEDIATION FOR BED BUG (HEMIPTERA: CIMICIDAE) CONTROL IN APARTMENTS OF DIFFERENT CLUTTER LEVELS

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Abstract Whole-home thermal remediation for bed bug control was conducted in fourteen apartment units in Lynchburg, Virginia. Apartment units were divided into categories of low, medium, or high levels of clutter to determine if the time to bed bug lethal temperature (55°C), and treatment efficacy were influenced by household clutter level. For each apartment unit, clutter was quantified, and a clutter ratio was determined by dividing the volume of clutter by the volume of apartment space. The Temp-Air Thermal Remediation System was used for all treatments. In preparation for treatment, four heating units and 10 fans were placed in each apartment, and all furniture drawers and closet doors were opened. Remote temperature sensors were placed in hard-to-heat locations. Sentinel adult bed bugs, nymphs, and eggs were hidden next to sensors. Heaters and fans were turned on, and sensor temperatures were monitored from outside the unit every 15-30 minutes. The average times for sensors to reach the bed bug thermal death point was 2 hours 51 minutes (low clutter); 3 h 4 min (medium clutter); and 3 h 32 min (high clutter). These times were not significantly different ($P > 0.05$). It was discovered that even with manipulation of the heaters, fans and belongings, certain locations ("cold spots") never made it up to lethal temperature. In some of these locations, sentinel bed bugs were able to survive treatment. Overall, we concluded that clutter was not a major contributor to the time or efficacy of whole home thermal remediation. Instead the presence of "cold spots" was the greatest challenge to treatment success.

Key words Heat treatment, *Cimex lectularius*, cold spots

INTRODUCTION

In the United States, the use of whole-home thermal remediation for bed bug (*Cimex lectularius* L.) control is on the rise. In 2015, the University of Kentucky bed bug survey reported that 40% of PMPs use thermal remediation in some form, and that number of PMPs using heat is increasing (Potter et al., 2015). Bed bugs and their eggs cannot survive temperatures above 48.3°C (118.94°F) and 54.8 °C (130.64°F), respectively (Kells and Goblirsch 2011). Thus, pest management professionals (PMP) can use large heat chambers, steam applications, or whole-home thermal remediation systems for bed bug control. According to Kells and Goblirsch (2011), whole-unit heat treatments are effective if ≥50 °C (instant thermal death point) is reached in all locations where bed bugs may be harboring, *or* if all locations reach 48°C as long as the heat is held at that temperature for 71.5 min (Kells and Goblirsch 2011).

One of the pre-existing conditions that is known to hinder bed bug control in housing units is clutter. Household clutter (personal items, books, shoes, appliances furniture etc.) provides numerous location for bed bugs to hide, and increases the time it takes for the pest control technician to treat infested locations. Clutter makes bed bug treatment using chemical applications particularly time consuming. It is for this reason that many pest management companies require residents to prepare their apartments units prior to treatment. These pretreatment preparations often include moving furniture away from the walls, clearing out all closets and drawers, bagging up clothing and other personal belongings.

The purpose of this preparation is to get household items that cannot be treated with insecticide out of the way, allowing the technician to treat the unit faster. However, many residents are physically or mentally incapable of preparing their units for treatment. One of the distinct advantages of whole-home thermal remediation is that it requires little preparation, and allows items that cannot be treated with insecticides to be exposed to heat, killing the bed bugs on those items. Yet, many heat treatment technicians still require residents to do some preparation of their units. This is because most believe that clutter takes longer to heat, and allows bed bugs to find more hiding locations where they may be insulated from the heat treatment. While this argument sounds logical, the effect of clutter on whole-home thermal remediation has never been determined. Using one of the most widely marketed and efficacious thermal remediation systems (Temp-Air Inc., Burnsville, Minnesota; Kells and Goblirsch 2011), together with trained heat treatment technicians from Virginia Tech University, we attempted to quantify the specific effects that household clutter have on whole-home thermal remediation. Specifically, we quantified the time it took to reach the bed bug thermal death point in apartment units containing different levels of clutter, and used sentinel bed bugs to determine treatment efficacy.

MATERIALS AND METHODS

This study was conducted in 14 separate apartment units (ranging from 37-61 m^3 located in a four-story apartment building (Lynchburg, Virginia; June 2016). Units were selected for treatment because their residents had either complained of bed bug presence or had seen bed bugs in the previous 12 months. Some of the selected units had been previously treated (some multiple times) with conventional liquid insecticides by a commercial pest management company. Each apartment unit was unique in its size, layout, and contents. The area and volume of each unit was calculated after measuring the room sizes, ceiling heights, window casing and sill depths, and void spaces throughout the unit. The dimensions of all of the contents of each apartment (furniture, appliances, clothing, knick-knacks, housewares, books, DVDs, electronics, etc.) were also measured and the "clutter volume" was quantified (m^3). The amount of clutter in the apartment units ranged from very light, to what would be considered hoarding levels.

Whole-unit heat treatments were conducted in each apartment using the Temp-Air Heat Remediation System (Temp-Air Inc., Burnsville, Minnesota). This system included the use of four (7 KW) generator-powered heaters, 10 high-velocity fans, and a remote monitoring system with 22 wireless sensors. Prior to each unit's heat treatment, heat sensitive belongings (living plants, candles, medications, etc.) were removed from the unit and inspected for bed bug evidence. All air vents, windows, and doors were lined with 5 mm plastic sheeting and sealed with heat-resistant tape. Smoke detectors and overhead sprinkler nozzles on the ceiling were covered with a polystyrene insulating box and secured with heat-resistant tape. Heaters and fans were placed so as to optimize the circulation of hot air throughout the unit. The wireless temperature sensors were placed in hard-to-heat locations within the furniture and clutter, and floor/wall junctions. Sensors were also placed at each heater to monitor temperature output. Nine replicates of sentinel bed bugs (3 replications each of ten adult male bed bugs; ten mixed instar nymphs; and at least ten 3-5 day-old bed bug eggs; contained in a nylon knee-high stocking) were placed alongside nine of the temperature sensors.

The heat treatment protocol used in this study was that provided by the Temp-Air manufacturers. The heat treatments were performed using equipment placed and monitored by the trained Virginia Tech Housing technicians who use this system regularly. During the treatment, the technicians adjusted apartment contents and redirected heaters and the fans until all temperature sensors reached 48.9°C (per manufacturer's instructions). When a treatment concluded, the treatment duration and sentinel bed bug (adult and nymph) mortality was recorded. Bed bug eggs were observed for hatch for five days after the heat treatment was concluded.

Data Analysis. The size (volume in m^3) and the clutter volume (m^3) of each apartment unit were used to calculate a clutter ratio. This ratio allowed us to compare treatment duration across units of different size and clutter levels. Using the clutter ratio, the 14 units were categorized by clutter level: 5 units were low; 4 units were medium; 5 units were high. The average time to for all sensors to reach bed bug lethal temperature in units of different clutter levels was analyzed using ANOVA. Values of $P \leq 0.05$ were used to indicate significance.

RESULTS AND DISCUSSION

The calculated clutter ratios ranged from 0.07 (less than 10% of apartment volume) to 0.31 (over 30% of apartment volume). The five units had low (0.072 – 0.14) levels of clutter and 4 units (data from the 5th unit was lost) had medium (0.15 – 0.18) clutter ratios. None of these low to medium level clutter units looked exceptionally cluttered when inspected prior to treatment. The apartment units that had high clutter levels were easy to identify prior to taking the clutter measurements. In these units the clutter ratios were also much higher (0.20 - 0.31) than those in units ranked as low or medium.

After all heat treatments were completed, there was a trend indicating that the apartment units with the highest levels of clutter took longer to reach lethal temperature than those with lower levels of clutter. What was surprising was that the differences in average time to lethal temperature in units from all three clutter categories were not significantly different (df = 2; F=1.9; P = 0.2; Figure 1). The average time it took for the majority of sensors to reach lethal temperature in a low clutter apartment unit was 2 hours 51 minutes. In units of medium clutter, the average time to reach lethal temperature was 3 hours 4 minutes. In apartments with high levels of clutter, the time to reach lethal temperature was 3 hours 32 minutes.

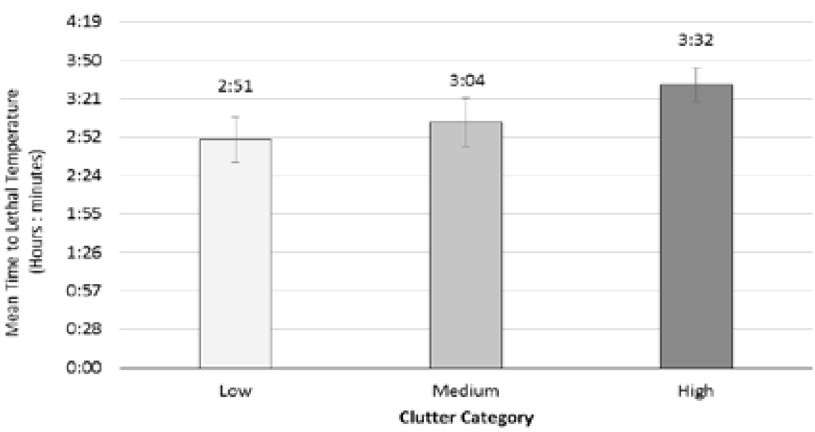

Figure 1. Time for most sensors to reach bed bug lethal temperature (mean ± SE) during whole-unit heat treatments in apartments of varying clutter levels.

The average time to reach bed bug lethal temperature was determined using the Temp-Air protocol coupled with the placement of 22 remote sensors per unit. While the majority of sensors placed in similar locations (in different units) reached temperature at relatively consistent times, sensors placed in certain locations took much longer to get to lethal temperature. We called these locations “cold spots”. In other words, sensors placed in near the heater output consistently took approximately one hour to reach ~55^{o}C. Sensors placed between couch cushions took approximately one hour and 45 minutes (on average) to get to lethal temperature. As expected, sensors placed deep in a dresser drawer full of clothes took an average of 3 hours to reach lethal temperature.

However, some sensors placed in the open (exposed to ambient temperatures), at the floor wall junction on a slab floor, still took 3 hours and 11 minutes to reach bed bug lethal temperature. Sensors placed on the floor of the utility closet took 3 hours and 30 minutes to reach lethal temperature. The sensor locations that took the longest to reach lethal temperature were under piles of clothes. These locations included, under bagged clothes (left from a previous chemical treatment), or clothes piled on the floor, or clothes left in a laundry basket. Sensors under piles of clothes took approximately 4 hours to get to bed bug lethal temperature. Interestingly, the "cold spots" that were identified in this study were the same (with the exception of the utility closet), as those identified by Kells and Goblirsch (2011).

As expected, mortality of the sentinel bed bugs was 100% in those locations that reached lethal temperature. However, some of the sentinels that had been placed in "cold spots" did have survivors. This was true even in some locations where the sensors had reached lethal temperatures. For example, when treating apartment unit 103 (bottom floor; high clutter category) the heat sensor output indicated that all sensors had reached bed bug lethal temperature. Thus, treatment was terminated. However, when the sentinel bed bugs were being collected, researchers observed the adult bed bugs placed in a corner of the kitchen floor (floor wall junction; slab-on-ground construction), near a freezer and under personal belongings, were still moving. The adjacent sensor read 49°C. When the live bed bugs were discovered, a fan and heater were moved and focused on this corner of the kitchen for 15 min (until all sentinels were dead). In addition to the live adults, we did have one bed bug egg hatch from unit 103. This group of eggs had been placed high on a living room closet shelf under many belongings. The sensor in this location reached only 48°C. In apartment unit 108 (0.18 clutter ratio; medium), a replication of eggs that had been placed on the floor of the hot water closet had 6 eggs hatch. At the time of treatment termination the sensor adjacent to this replication of eggs had read 49°C. Also in apartment 310 (0.13 clutter ratio; low), twelve eggs hatched in a replication that had been placed at the kitchen floor-wall junction, but in the corner behind a trash can, in between the cabinet and stove. At the time the treatment had been terminated the adjacent sensor had read 52°C for the previous 15 minutes.

CONCLUSIONS

In this study we had the advantage of being able to use trained technicians (with no time constraints) to run one of the highest quality thermal remediation systems, and use 22 remote sensors to constantly monitor heat treatment temperatures throughout the apartment unit. These were optimal treatment conditions that are not the luxury of every technician in the field. We did not ask apartment residents to prepare their units in any way and therefore, we were able to isolate the effects of clutter on heat treatment duration and efficacy. Our results indicated that clutter was not the major contributing factor to heat treatment time and efficacy. Instead, "cold spots" were the single greatest challenge to thermal remediation. We concluded that even under the most optimal heat treatment conditions, these cold spots must be identified and monitored carefully or you run the risk of having bed bugs survivors, particularly those in the egg stage.

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