KEY FINDINGS ON BED BUG BEHAVIOR AT LETHAL & SUB-LETHAL TEMPERATURES
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For the effective use of high temperatures to control bed bug populations, it is essential to know the survival characteristics and behavior of bed bugs at various temperatures and exposure times. Temperature plays a vital role in insect development, growth, and multiplication. Insects grow and multiply at optimum temperatures and, at sub-optimal temperatures, can stop reproducing, hibernate over winter. Beyond the sub-optimal, temperatures become lethal and cause complete kill (100% mortality) of all stages of the insect life cycle. The question is: how high do these temperatures have to be and will the bed bugs respond behaviorally to avoid lethal conditions as temperatures increase? Key findings on the survival and behavior of bed bugs at different temperatures, exposure times and scenarios are presented here. Also presented are the findings on the rate of penetration of lethal temperatures on different types of materials in a household/apartment setting.

1. Time versus Temperature Mortality Studies:

The survival and mortality of adults and life stages of bed bugs was investigated in a controlled environment chamber with a constant rate of temperature increase of 6.5°F/h. The temperatures ranged between 86 and 131°F, with exposure times of 2 - 120 min.

Results: Complete and immediate kill of adult bed bugs occurred when temperatures reached at least 118°F. For failed emergence of eggs, complete and immediate kill occurred at 122°F. Temperatures in the range of 113 - 122°F required a time component, displayed in the table, below:

Temperature	**Time (Minutes)**	
	Adults	Eggs
113	90 minutes	8 hours
118	2 minutes	90 minutes
122	0 minutes	0 minutes

Practical implication: A distinct advantage of heat is that unlike chemical treatments, heat can penetrate cracks and crevices and inaccessible areas where bed bugs reside or harbor. To ensure control, it is important to achieve and maintain temperatures above 118°F for more than 90 min. to effectively kill all life stages of bed bugs. In practice, considering the clutter in the treated space and the need to penetrate cracks and crevices, treatment times are much longer, ranging from 6 to 8 hours, and hence 118°F would be highly effective.

2. Threshold behavior and subsequent movement of bed bugs in response to increasing temperatures delivered through conduction:

Adult bed bug behavior was observed in a conduction arena comprising of 1 m^2 aluminum plate. A ceramic heater placed under the plate heated the plate at the rate of 9.43°F per minute and created a gradient of temperature between 80 to 131°F, with the high temperature in the center. Bed bug behavior was observed from the point when the heater was started until the bed bug died or escaped. (Keep in mind that escapes are expected in this situation because of the relatively small area that was heated.)

Results: Initial movement of bed bugs started at an average temperature of 81°F and feeding behavior was observed at an average temperature of 95°F. Escape behavior was initiated at an average temperature of 106°F. However, post-escape behavior showed many bed bugs returning toward the heat for the purposes of feeding.
Practical implication: Bed bugs tend to forage or feed as temperatures rise, and the narrow temperature differential (13°F) between the escape threshold and lethal temperatures is indicative that they will tend to stay within an area being heated or are contained. Even if escape would initially occur, their tendency to move toward heated zones helps position them closer to areas where they may encounter lethal heat. Also, the use of residual dust insecticides in extreme outlying cracks and crevices areas will help prevent bed bugs returning from any refugia that may be created. Also, this study considered conductive heat only and must be considered

along with convective heat.

3. Threshold behavior and subsequent movement of bed bugs in response to increasing temperatures delivered through convection:

Set up and variables: Adult bed bug behavior and movement was observed in a convection arena comprising of a box (3'x24"x8" high) with aluminum walls, Plexiglas lid, and a plywood floor coated with epoxy paint. The arena was divided into two chambers by inserting an insulated panel in the middle. A 1500W electrical heater delivered heat into the plenum through a duct dispersing the heat into the arena. The behavior of bed bugs placed in a petri-dish was studied with the rise of temperature.

Results: Bed bugs were less responsive to convective heat, compared to conductive heat (shown in part 2). Threshold air temperatures causing escape averaged 118 °F and were above the lethal threshold temperatures of 113°'F. When escape was attempted, more than half of the bed bugs attempted to return to their harborage, and 60% died within the arena. This is despite the thermal refugia only being 3" from the harborage.

Practical implication: In the convection scenario, bed bugs stayed longer in harborage and tended to return to the harborage as air temperatures rose in the peripheral areas. About 37.5% of bed bugs escaped from the harborage to peripheral areas highlighting the need for managing airflow around the perimeter and moving stuff away from the walls. However, these lab studies imply that convective heat shows a better means of containing bed bugs from escaping.

4. Rate of penetration of lethal heat through mattresses, upholstered furniture, exterior walls and other structural elements in two habitat types (apartment, house):

These were the commercial heat treatments to control bed bug populations in a single bedroom apartment and in a larger multi-level house. Direct-fired propane-fueled heaters were used for both the treatments. Temperature profiles were monitored using wireless temperature sensors as well as HOBO data loggers by placing them in the general space (difficult to reach areas), between sofa cushions, mattresses, piles of clothes, closets, etc. Using data loggers, temperatures were scanned every 30-60 seconds, and the wireless temperature sensors reported temperature every five minutes.

Results: The rate of temperature increase was slower for the single multi-level house (5.0 to 11.7°F/hr) compared to a single bedroom apartment (8.3 to 13.2°F/hr). For the apartment, the bagged pile of clothes took longest to come up to the lethal temperatures. With the exception of the pile of clothes, the rate of temperature increase was lowest for baseboards and under the baseboards for the apartment and house, respectively.

Practical implication: The commercial treatment brought forth the importance of managing airflow in the space being heat treated. Achieving lethal temperatures of at least 118°F and above in the air space provides a threshold for kill and enables mass transfer of heat to other articles in the living space for effective control. It is important to manage the airflow around the walls/periphery and also make sure that piles of clothing or any articles allow the air movement through them so that cold pockets are avoided, thus eliminating areas of potential harborage for the bed bugs.

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