ACTIVE DRY HEATING FOR BED BUG ERADICATION WITHOUT AIR FILTRATION IS DANGEROUS AND NEGLIGENT

By: Michael Geyer, PE, CIH, CSP

Heating structures, or areas within structures, is fast becoming the most effective method for bed bug eradication. Active structural heating relies on aggressive air mixing in order to be effective. However, aggressive air mixing generates significant, potentially harmful, aerosols of particulate matter. Methods exist to control the aerosols and they should be judiciously implemented when using heated air to treat for bed bugs, or any other insect or microorganism. Failing to control the aerosol generated during aggressive air mixing may be negligent.

Why Actively Heat Structures

Structures can be actively heated to kill bed bugs, termites, cockroaches and other insects, as well as to dry-out wet materials, accelerate off-gassing VOCs, and kill and/or reduce the concentration (load) of biological organisms within the structure. Active heating of structures constitutes a “green” approach to insect and organism eradication – it is not a chemical pesticide! In fact, structural heating has been prescribed for the treatment of residences for asthma patients.

Killing Insects and/reducing other biological organisms

Bed bugs specifically, and other biologicals, (e.g., fungi, bacteria, other insects, etc.), enjoy the creature comforts of our buildings and enjoy similar temperatures that us humans enjoy, (i.e., room temperature – 70F (21C)). Particularly, bed bugs gravitate to the warmth of the human body, carbon dioxide that humans exhale, tiny cracks and crevices, and darkness. Like most biological organisms, they suffer when heated to temperatures that are extreme. Most biological organisms do not survive temperatures above 135F (57C) and when structures are actively heated to temperatures of 145F (63C), or more, most biological organisms cease to survive – they die. Therefore, actively heating structures to elevated, lethal, temperatures is an effective method of bed bug control – it kills them.

Effectively Heating Structures

Effective structural heating requires a combination of elevated temperatures, temperature duration, and equal distribution uniformity of the elevated temperature coupled with controlled air movement using fans, pressure differences inside heated areas (relative to outside), and the capacity of the air-delivery and heater system. Effective structural heating is an active methodology; it is not passive.

Elevated Temperature and Duration

In order to increase temperatures within a structure, it is accomplished by delivering hot and relatively dry air into a treatment area. There are several methods of structural heating with hot, dry air. For example the heat source may provide electrically-generated heat using infrared heaters, or burning a fuel-gas via forced-air burners or boilers, and the heat can be delivered directly or indirectly, or both. The method of heat generation and the delivery method are somewhat irrelevant to this discussion regarding why actively heating structures without air filtration is dangerous. Consequently, the means and methods of heating structures will be limited in this narrative. However, suffice it to say that active structural heating involves elevated temperatures and requires holding the target temperature for a duration that is sufficient to achieve the intended goal, e.g., kill bed bugs.

Distribution uniformity

To achieve the goal of eradicating bed bugs or other insects, just as with drying, off-gassing chemical vapors, and/or reducing biological loads, the distribution of heat must be uniform and equal. If materials, buildings, rooms, furnishing, etc., are not heated uniformly and equally, and if lethal temperatures are not achieved, the result is a “no kill”. If too high of temperatures are delivered into a treatment area, then damage to heat sensitive items may occur. Also, moisture and chemical vapors can be liberated from hot materials only to be reabsorbed into cool materials. Insects have legs and wings (i.e., they are motile) and they may move from hot, uncomfortable areas into areas that are less stressful. Moreover, materials that are only slightly heated, to a temperature of 90F to 100F (32C to 38C), may exhibit ideal conditions for some microorganisms (e.g., fungi, bacteria, protozoa, etc.) to flourish; as if they were in an incubator and their concentrations may actually increase due to (raised) temperatures that are less than lethal. Thus, effective structural heating must achieve a uniform and equal temperature increase to a target, lethal temperature.

Aggressive air mixing/currents

In order to achieve uniform and equal distribution of elevated temperatures within a structure or area being actively heated, aggressive air mixing must be employed. Hot air is more buoyant than cool air, and if not aggressively mixed, a heated room will have a hot ceiling and a cool floor, with varying degrees of temperature in between. When aggressive air mixing is employed, which is necessary for heating uniformly and equally, particulate aerosols will be generated – lots of aerosols! Experts have measured, via hand-held, direct-read laser particle counters, significant increases in particulate concentrations in contained structures when aggressive air mixing is employed, with or without heating. Increases in particulate concentrations have been measured 5 to 10 orders of magnitude above that of ambient and/or passive conditions, i.e., conditions prior to activating the fan units to create the aggressive air-mixing environment.

Aggressive air mixing is necessary to uniformly and equally distribute hot air when actively heating an area, to raise temperatures of target locations and materials. It should be anticipated that the aggressive air mixing will also create significant aerosols and distribute those aerosols far and wide; even into areas not targeted for the heat treatment effort. If not controlled, it is likely that surfaces (be it floors, furniture, counters, etc.) within the treatment area, post aggressive air mixing, are covered with a layer of fine particulate matter. This matter, having been released and distributed during the active heating process, may be extremely harmful to building occupants if not mitigated. In the case of bed bugs, pillows, blankets, sheets and the like are covered with particulate matter. Occupants’ head and nose are placed in direct contact with this particulate matter.

Controlled exhaust air

When structures are actively heated, the air within the treatment area may quickly saturate with vapors that need to be removed, and particulates that need to be filtered. Moreover, aggressive air mixing will distribute these out-gassed vapors similar to aerosol distribution. Vapor concentration can be controlled via controlled exhaust. Effective filtration will reduce particulates inside the treatment to safe levels and also within the exhaust air. Consequently, filtration will mitigate particulates released into the environment; where they may harm sensitive receptors downwind.

Aerosols Form When Structures Are Actively Heated

A known effect of active heating is the generation of significant concentration of aerosols. There are several mechanisms involved that contribute to the generation of aerosols and the mixing of particulates when structures are purposefully heated with hot air. As mentioned above, aggressive air mixing is substantive in the liberation and distribution of particulates. Aggressive air mixing also breaks-up matrixes and bundles of particles (i.e., large aggregate particles are broken into many smaller particles.) Also significant is the drying aspects of hot air. Many hydrophilic organic particles have hydroscopic water molecules adsorbed onto them, thus increasing their weight. Heating increases the vapor pressure exhibited on these water molecules, liberating some of them, and this phenomenon makes the hydrophilic particle lighter in weight and more easily made airborne. Water molecules are also polar and small particles may be held together due to the attraction with polar water molecules. These small particles may be released when water molecules are no longer present. Fungi, when pressured with aggressive air currents and/or drying air, are known to sporulate (release spores). Even small quantities of fungal biomass can be anticipated to release millions of mold spores when stressed by hot, dry air in an aggressive air mixing environment. Moreover, as the fungal biomass dries it can be anticipated to break apart and fracture in small particles, thus releasing many small mold products. Lastly, hot mixing air currents generate static electrical potentials along with the movement of particulates in the hot air. Static electrical potentials in the mixing air will affect particulates that are polar (i.e., have electrical potentials on their surface) and some will become airborne that may not necessarily do so. Bottom line...in a hot, aggressive, air mixing environment, significant concentrations of aerosols must be expected. Moreover, they must be mitigated. Otherwise a potentially harmful concentration of aerosols will be present in the air during treatment and residue (post-heat) on surfaces.

What Makes Airborne Particulates Dangerous

Large and small particulates – PM10's, PM2.5's, nano-particles

It is well known that it is the small particulates that cause the most damage to lung tissues when inhaled deep into the gas exchange region of the lungs, and very small particles can cross cell membranes. Large particles are typically trapped by impaction on mucous surfaces of the nose and throat, impingement on bronchi, and entrapment within cilia. Small inert particles, those much less than a micron, are thought to move in and out of the lungs with minimal affect, but this is not true of chemically reactive or sensitizing particles. Many atmospheric studies have confirmed that aerosols of an aerodynamic diameter of 10-microns or less, or PM10's, are dangerous. More recent studies have looked at the damaging affects of smaller particulates, those that are near 2.5 microns in size, or PM2.5's. There is current concern for engineered products referred to as nano-particles that are far smaller than 1 micron; yet their health affects are not fully understood at this time.

Of some relevance in this study of lung-damaging particulates is the difference between particles that are organic versus inorganic. Organic particles, in general, have a much lower density and less mass than most inorganic particles, and larger organic particles are more buoyant than most inorganic particles of similar size. In structures that are aggressively treated with hot air, both organic and inorganic particulates must be anticipated. In situations where biological particulates are of concern (e.g., water-damaged buildings with mold spores, mold fragments, dust mites, bacteria, etc.) the hazard of bio-aerosols cannot be underestimated because of their potential to be bio-reactive, toxigenic, and/or infectious. Moreover, inert airborne particles have been shown to contain microorganisms...essentially hitching a ride on the inert particle. Moreover, particulates cannot be thought of as unique, pure, or isolated. More often, airborne particles are clusters, bundles, and matrixes of a combination of several sub-particles, organic and inorganic, active and inert. A sampling of airborne particles generated during aggressive air mixing will detect major and minor fractions of fibrous and non-fibrous elements; inerts such as quartz, feldspars, and silicates; chemical sensitizers such as zinc and related corrosion products; organic sensitizers such as mold spores, pollen, and insect feces; and a host of other stuff.

Recent studies show inhaled particulates are dangerous

Studies have shown that the inhalation of small particulates, especially those less than 10- microns in size, may increase respiratory disease, cause lung damage, and induce asthma, allergic reactions, cancer, and premature death. Most affected by the inhalation of small particulates are children with young and developing lung tissue, people with respiratory dysfunction and/or sensitivity, and people with compromised immune systems. It is speculated that some bio-aerosols may trigger hypersensitivity in compromised individuals. Moreover, there are claims by some indicating that an acute exposure to bio-aerosols may also trigger hypersensitivity. This said, and given that hot, dry, aggressive air mixing environments have all the attributes to generate and distribute significant concentrations of aerosols, aerosol control is essential. Given that structural heating often occurs in buildings that are water-damaged, exhibit uncontrolled growth of fungi and bacteria, or excessive and uncontrolled growth of insects (e.g., bed bugs, fleas, termites, etc.), the control of harmful bio-aerosols generated when actively heating a structure for bed bugs or other insects or for biological remediation is a necessity. Not controlling aerosols generated within an aggressive air mixing treatment area is negligent; especially when given the fact that there are effective controls that can mitigate aerosols.

Engineering Controls - Air Filtering to Remove Aerosols

Exhaust alone is not effective or prudent to mitigate aerosols generated in an aggressive air mixing environment. Solely exhausting air from an area subject to aggressive air mixing will assist in diluting the concentration of aerosols within the treatment area, however, a significant portion of the aerosol will remain and settle-out, and the rest is emitted with the exhaust air. If not controlled, even the particulate-laden exhaust air may be dangerous to receptors downwind from the point of exhaust. The most effective and practical method of capturing and removing the aerosol is through the prodigious use of fan units equipped with high efficiency particulate air (HEPA) filter media. HEPA-filtered fan units have a proven ability to mitigate particulate aerosols and where enhanced filtration is warranted, ultra-HEPA filter media is available. Moreover, when HEPA-filtered fan units are incorporated into remediation projects where biological control is warranted and where biologicals may become airborne (e.g., mold spores), capturing the bio-mass on a filter media is similar to other methods of physical, gross removal, i.e., the filter is a physical removal method. HEPA air filtration is effective and warranted to control particulate aerosols, but several elements must be designed into the use of HEPA-filtered fan units to achieve efficacy.

Sized for rate of air exchange

To control aerosols, HEPA-filtered fan units must be adequately sized, in number and in capacity (i.e., flow rate), to cycle sufficient air through the treatment area being subjected to aggressive air mixing. In some circumstances, a rate of 4 to 6 air exchanges per hour (AE/hr) may be adequate to control the aerosol generated. In other circumstances 10 to 20-AE/hr, or more, may be necessary to achieve control in soiled (dirty) locations. If the area to be heat-treated is very clean, 1-AE/hr may be adequate to maintain ambient conditions (i.e., pre-mixing particulate concentrations). Only through the use of direct read aerosol monitors can the immediate concentration of airborne particulates be measured in areas subjected to aggressive air mixing and, subsequently, the capacity of filtration and air exchange rates thus determined; to mitigate aerosol concentrations to ambient conditions or less.

The environmental remediation industry's standard of care is based on 4-AE/hr, then modified (based on direct-read measurements) as conditions warrant. In lieu of using direct-read aerosol monitors, areas being heat-treated, when coupled with aggressive air mixing, should use HEPA filtered fan units sized for a minimum air exchange rate of 4 per hour.

Controlled input and output

In situations where it is necessary to exhaust air laden with moisture and/or chemical vapors**, s**ome HEPA-filtered fan units' exhaust can be ducted-out of the treatment area to remove the vapors. In doing so, the exhaust air is clean and filtered of particulates. Other HEPA-filtered fan units can sit inside the treatment area, un-ducted, and cycle air through the filter element - solely to capture particulates and physically remove them. Where exhaust is warranted, it must be controlled and the flow rate of moisture-chemical laden air removed from the treatment area must be measured relative to the flow rate of air (hot or ambient) into the treatment area. Too much or too quickly removed, and the treatment area will not rise in temperature if heating is a goal; this is especially critical when the treatment area is indirectly heated via heat exchangers. Too high an input flow of hot air into a treatment area and the movement of aerosols may be difficult to control; thus air filtration is essential to mitigate the movement of particulates into spaces that are not part of the treatment area when high input flow rates are used. When HEPA-filtered fan units are judiciously used, the movement of "clean" hot air within the treatment area and into other "non-treatment" spaces does not carry the risk of particulate contamination.

Located to mitigate dead-zones

HEPA-filtered fan units must be located in sufficient quantity and capacity to achieve an air exchange rate, and so located to filter air in locations that would otherwise allow particulates to settle-out. Corners, small alcoves, nooks, and enclosed spaces are typical locations where air mixing currents may be limited or reduced, and these are locations where an un-ducted HEPA-filtered fan unit can assist and enhance air mixing currents, as well as capturing particulates (for physical removal) that might otherwise settle-out (in these areas).

Cleaning the Air - Before, During and After Heating

In most circumstances, areas that will be treated with hot air also warrant cleaning, i.e., they are dirty, soiled, and/or contaminated. During the time that equipment is being mobilized and set-up to generate and deliver hot air into a treatment area, HEPA-filtered fan units should be one of the first pieces of equipment placed, put into operation, and activated. They can immediately begin to capture aerosols generated by activities taking place to prep and deliver heat to a treatment area. When hot air is being delivered into a treatment area and being actively distributed therein, HEPA-filtered fan units should be operating continuously and without interruption. Once the target temperature and duration is reached and the cool-down phase begins, HEPA-filtered fan units should still be continuously operating. Moreover, they should continue to operate during the demobilization effort and be one of the last pieces of equipment turned-off and packed out; thus mitigating particulate aerosols the entire event, from beginning to end.

Measuring effectiveness

Where heat treatment is performed, an easy and effective method of measuring the effectiveness (post-treatment) of particulate removal is with a tape lift – similar to the tape lift method used to determine to presence-species of mold on a surface. Particles adhered to the tape lift can be evaluated and identified using a polarized light microscope. In some circumstances it may be useful to compare surfaces within the treatment area to surfaces outside of the treatment area. This said, the tape lift and particle identification should not replace the application and use of direct-read, real-time particle counters – hand-held devices that can provide real-time data on the effectiveness of dust mitigation measures during aggressive air mixing efforts.

Summary

In summary, heating structures or areas within structures is fast becoming the most effective bed bug eradication method and as a remediation technique. Effective structural heating relies on equal and uniform distribution of the hot air and this is best accomplished with aggressive air mixing. However, aggressive air mixing generates significant aerosols. Methods exist to control the aerosols and they should be judiciously implemented to do so – HEPA-filtered fan units are the best available control technology to mitigate aerosols generated during active heat treatment. Failing to control the aerosol generated during an effort that employs aggressive air mixing may be negligent, because studies have indicated that it is very likely to be harmful or injurious to persons exposed to the post-treatment aerosol.

About Michael Geyer, PE, CIH, CSP

An expert in mitigating chemical-biological contaminants in buildings, conducting property conditions assessments, improving indoor air quality, mitigating vapor intrusion, characterizing landfill gas, and building off-grid homes.

Michael has 20-years of professional experience in environmental engineering, preceded by 15-years of construction experience working in the trades, building off-grid power systems, and supervising building projects. He has built hundreds of residential homes (both tract developments, custom houses and remote ranch-style homes) and commercial buildings, and many special-use structures, e.g., theater, sport venue and schools. His unique construction experience has been valued by developers/owners building on compromised property (e.g., Brownfields) with known chemical or biological hazards. He specializes in high-hazard construction efforts and those impacted with methane, hydrogen sulfide, VOCs or radon. His experience in the remediation of buildings compromised with biological agents using heat as a remediation technique, is extensive.

Michael’s current work includes: mitigating soil-gas vapor intrusion (VI); assessing outdoor and indoor air quality (IAQ); conducting building envelope and property condition assessments (PCAs); designing engineering controls to enhance occupant safety; and oversight of construction projects impacted by chemical hazards. Michael also designs and builds off-grid and utility inter-tie power systems, super-insulated cabins and high-performance homes for private parties. Michael contracts with all types of clients, including: municipalities, developers, private property owners/managers, and industrial sector clientele, as well as professional practice firms such as engineering, architecture, insurance and law. Michael is often retained by counsel to assist litigation, review case documents, provide expert opinion, and support arbitration. Michael also shares his considerable knowledge with others. He routinely presents case studies at national conferences and seminars and is often requested to provide classes at industry-sponsored professional development courses (PDCs), and for five years he has volunteered his time to the Kern County (California) Solid Waste Management Advisory Committee. He is active with his community, his 4-H club and supports home-education.

REFERENCES

1. U.S. Environmental Protection Agency, Air Quality System, Hazardous Air Pollutants. http://www.epa.gov/oar/data/help/haqshaps.html
2. U.S. Department of Labor, Occupational Safety & Health Administration, OSHA Technical Manual – Section III: Chapter 2, Indoor Air Quality Investigation. http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html
3. California Environmental Protection Agency, Air Resources Board, ARB Fact Sheet: Air Pollution Sources, Effects and Control. http://www.arb.ca.gov/research/health/fs/fs2/fs2.htm
4. American Lung Association: Selected Key Studies on Particulate Matter and Health: 1997 – 2001. http://www.kintera.org/atf/cf/%7B7A8D42C2-FCCA-4604-8ADE-7F5D5E762256%7D/PMSTUDIES.PDF
5. Baron, Paul A, PhD. National Institute of Safety and Health/DART – Measurement of Fibers. http://www.cdc.gov/niosh/nmam/pdfs/chapter-l.pdf
6. Peter J. Adams, Carnegie Mellon University – Medical News Today - Harmful Particulates Blanket East Coast. March 2, 2007
7. Health Impacts of Smog in Toronto – Toronto Environmental Alliance 2008 http://www.torontoenvironment.org/campaigns/climate/smogfacts
8. National Institute of Health and John Hopkins University - Particulate Reduction Education in City Homes (PREACH). May 2008 http://clinicaltrials.gov/ct2/show/NCT00466024
9. National Institute of Environmental Health Sciences (NIEHS) - Fine Particulate Matter Associated with Increase in Hospital Admissions for Cardiovascular Diseases. September 2006 (http://www.niehs.nih.gov/research/supported/sep/2006/pmcardio.cfm)
10. National Institute of Environmental Health Sciences (NIEHS) - Risks of Coarse Particulate Air Pollution. September 2008 http://www.niehs.nih.gov/research/supported/sep/2008/particulate.cfm
11. Nanoparticle Handling Fact Sheet. Environmental Health and Radiation Safety. University of Pennsylvania. May 2003 http://www.ehrs.upenn.edu/resources/docs/labsafety/nanoparticles.pdf
12. Bed Bugs – Biology and Management. Harvard School of Public Health. 2005 http://www.hsph.harvard.edu/bedbugs/