# BENEFITS OF DRY HEAT TO CLEAN STRUCTURES OF BIOLOGICAL CONTAMINATION AND IMPROVE INDOOR AIR QUALITY (IAQ)

Michael D. Geyer, PE, CIH, CSP

SCS Engineers, Long Beach, California, USA

**ABSTRACT**
Structures once compromised by biological contamination, e.g. toxic mold, can show significantly improved indoor air quality (IAQ) following heat treatment. Dry heat of 150°C for 10 minutes effectively sterilizes most items of active biological agents, e.g., bacteria, fungi, etc. At 63°C most insects, protozoa, bacteria, and fungi cease to function. Heat also neutralizes and oxidizes harmful chemicals produce by biological organisms. While 150°C may be difficult to achieve when heating an entire structure, at least not without adversely affecting some architectural elements, heating a structure and its contents to 80°C has its merits and is possible with today's technology. Moreover, holding a structure at 80°C for 60 minutes not only kills most active biological agents, it accelerates the neutralization of many harmful toxins, accelerates vaporization of water vapor and chemicals, and oxidizes odors.

**INDEX TERMS**
Heat, IAQ, Biological Contamination of Structures, Toxic Mold, VOCs

**INTRODUCTION**
Heat kills living organisms. While thermophilic organisms tolerate higher temperatures, most respiring organisms do not live above 63 ºC for any appreciable period of time. This is because temperature has a predominant influence on the rate of chemical kinetic reactions in cellular functions/organelles. At extreme temperatures, cellular function is disrupted. Even spores and viruses, which do not actively respire, are affected by temperature.

With increased temperature, metabolic rates of most organisms increase. The volatilization rate of chemicals also increases, chemical oxidation reactions increase, evaporation rates increase, moist materials become desiccated, and proteins denature. Heat can be used to detoxify harmful chemicals produced by organisms. Milk is pasteurized at 75 ºC for 15 seconds to kill organisms that may spoil the milk or be harmful themselves. If the food industry uses heat to process food, why can't heat be used to treat inedible items?

This paper presents findings and observations related to the use of heat in controlling harmful or annoying chemical and/or biological contamination in structures. Problematic organisms include toxic molds, wood-destroying fungi and insects, dust mites, cockroaches, fleas, bacteria, etc. Many organisms are associated with offensive odors, which typically consist of volatile and semi-volatile organic compounds (VOCs); some of these organisms may be pathogenic or vectors. In theory, if heat could be applied uniformly, consistently, and of sufficient duration to saturate structures and reach an organism's threshold temperature, structures would be "free" of viable organisms. A similar approach could be applied to chemical contamination, since the higher the temperature, the more chemicals will volatilize.

## HOW HOT IS HOT?

Two parameters are important in reaching the threshold of organisms: temperature and time. The higher the temperature, the less time needed to destroy organisms. This fact is well established in sterilization studies. Anthrax spores, for instance, can be rendered nonviable if heated to 150 ºC for 480 minutes. To effectively heat-treat a building, constituent materials must be assessed to determine the heating cycle, including thermal mass, volume, thermal conductivity, heat stability, and heat sensitivity.

One area of study not yet well established involves temperature and viability of specific organisms. Temperature and duration curves necessary to achieve 90-80-70 percent mortality rates are unclear, especially for organisms most typical in the environment and problematic in structures (e.g., aspergillus). Heating a structure to "sterilization" temperatures is not always practical (and will not be discussed here). If an anthrax-contaminated structure is heated such that architectural components are 150 ºC for 480 minutes, it should not only be free of viable anthrax spores, but some of the components may be damaged from the high temperature. Most biological organisms don't produce heat-tolerant spores, aren't thermophilic, and can be effectively controlled using lower temperatures and shorter durations.

Prior to heating structures, therefore, the clearance criteria (concentration of the target agent, either chemical or biological) that would be considered acceptable (safe or tolerable) must be determined, keeping in mind that higher temperatures and durations increase the likelihood that a building's materials and contents could be damaged.

## BENEFITS OF HEATING STRUCTURES

Heating structures has the following principle benefits:

- Harmful or annoying organisms (animals, insects, protozoa, fungi, bacteria, etc.) can be killed and/or rendered nonviable.
- Moist building materials can be desiccated (Building "Dry-out"). In addition, reducing the moisture content in cellulose-based building materials inhibits or prevents the growth of harmful fungi.
- Off-gassing chemical VOCs from composite and/or synthetic building materials can be accelerated (Building "Bake-out").
- Offensive odors can be oxidized to concentrations below odor thresholds.

In addition to structures, heating technology can benefit other biologically compromised items such as automobiles, shipping containers, boats, planes, pallets of materials, etc.

## HOW TO HEAT A STRUCTURE

Heat can be generated using thermal solar radiation, a building's heating ventilation and air conditioning (HVAC) system, portable electric-inductive heaters, lamps, etc. Portable fuel-fired heaters (burning natural gas, propane, or kerosene) can also generate heat. There are advantages and disadvantages of each technology, and flexibility and costs differ. Considerations related to choosing a heat source include:

- Target temperature and duration goals.
- Btu's necessary to bring the volume of thermal mass up to the target temperature and hold it for the anticipated duration, including system inefficiencies (referred to as the Heating Cycle).
- Site source availability (e.g., electrical system capacity).

- Flexibility and scalability (i.e., large/small, accessible/inaccessible areas).
- Safety.
- Cost.

Heaters should be located and controlled in such a manner that they can be turned up or down to regulate heat output, or air flow in the case of forced air heaters. Differing site conditions usually dictate a need for flexible delivery systems.

**SURFACE HEAT OR PENETRATING HEAT**

The type of contamination helps to determine the degree of necessary heat penetration. If contamination occurs from airborne spores, it may be safe to assume that spores are surficial and not deep within walls, dimensional timber, or masonry units. The heating process can therefore be surficial in design. Where materials have become moist and promote fungal growth and amplification, heating should be of sufficient duration to achieve the saturation temperature required to kill organisms deep within affected materials.

**Heat Distribution**

Key to the efficacy of the process is even heat distribution (distribution uniformity). When using electric heaters, a large number of small heaters may be more effective than a single large heater to achieve uniformity. Portable fuel-fired forced air heaters can easily be distributed via flexible Mylar ducting to multiple locations, while keeping the burner-fan assembly safely out of the contained area. Materials of high thermal mass need more heat than those of low thermal mass to even the heating cycle among materials. Portable fans placed in the contained area will assist in distributing heat. Items of low thermal mass, or heat-sensitive items, can also be covered with thermal blankets to slow the heating process.

**Heat Monitoring**

To effectively mitigate the target agent(s), a target temperature and duration must be achieved. Temperature monitoring is therefore important during the entire heating cycle to identify when the target temperature or duration has been reached, and to minimize damage to materials being heated. Sending technicians into a heated space with a temperature probe is unsafe. Remote sensing equipment, including thermocouples, thermistors, or open-path detectors, is necessary to measure temperature within a heated area. The more numerous the monitoring points established, the more evenly a heating cycle can be attained and maintained. Monitoring points should be determined based on the volume of the area and the type of materials being heated. Materials of high thermal mass and/or density may need monitoring points imbedded into the center of the material to ensure temperature saturation.

**Heat-Sensitive Items**

Inside structures, certain items (film and photos, paintings, candles, cosmetics, plastics) are more heat-sensitive than others. Heating finishes on some furnishings may cause softening. Most electronic components can withstand temperatures of 70 ºC with little or no ill effect, however, computer media, cassettes, and videotapes may be damaged.

Materials to be heated thus dictate, to an extent, the target temperature and degree of contaminant control to be anticipated. For instance, toxic fungi have been effectively mitigated in residences whose structures were heated to 80 ºC for 60 minutes. If, however, the contents of these structures include heat-sensitive items, either the items should be covered with insulating blankets, treated (heated) in a separate enclosure at lower temperatures, or not heat-treated at all.

## Heat Hazards

Besides hazards to architectural components, building systems, and building contents, conditions endangering technicians inside heated areas must be considered. Such hazards may include fire, fire suppression system initiation, and the generation and release of particulates.

Chemical kinetic principles show that pyrolytic reaction rates increase rapidly with increasing temperature; for some organic solids, this may be as low as 250 ºC. Wood against a radiant heater may ignite at 300 ºC, and spontaneously ignite at 600 ºC. Other cellulose-based materials with high surface area (such as cotton) will char and possibly ignite at lower temperatures. Typical fire suppression systems activate at temperatures as low as 80 ºC. These systems must be deactivated, de-energized, and often protected from heat, which often warrants a fire watch being established during the heating cycle.

Generation and release of aerosols often accompanies desiccation of moist building materials. Moreover, the turbulent air flow dynamics necessary to achieve even heat distribution enhances the aerosolization of small particulates. Uncontrolled, these particulates may represent a significant and harmful concentration of allergens to sensitive individuals.

Where allergens must be controlled, air filtration with heat-tolerant high-efficiency particulate air (HEPA) fan units is used. Depending on the site, HEPA units could be used to filter *and* circulate air within the heated area, assisting in heat distribution; it may also be necessary to place HEPA units outside of the heated area and duct the air to the unit.

## HEATING PROTOCOLS

Several case studies are presented in Table 1. General protocols being used for four typical building-compromised situations include:

- Typical biological heat treatment: 75 to 85 ºC for 60 minutes.
- Heat-sensitive treatment: 60 to 70 ºC for 60 minutes.
- Accelerate VOC off-gassing: 35 to 55 ºC for hours or days.
- Desiccate building materials: 50 to 75 ºC for hours or days.

## Equipment

Propane-fired burner-fan units have been demonstrated to be the most flexible, scalable, and cost-effective heat generators. These units are often placed outside the heated (contained) area, typically in a group, where they can be easily monitored and adjusted. Adjustments are based on thermocouples placed into representative materials, and read from multi-channel readout devices. Hot air is ducted into the contained area with Mylar ducting and kept distributed via additional fan units (inside the contained area), if necessary. Canvas tarps, similar to those used on structural fumigation projects, are used to cover the structure, contents, or items being heated in order to create a contained area/space. If a limited area or moveable contents are to be heated, portable containments are constructed and erected using nonflammable or flame-retardant materials, or a portable heat chamber is used.

In order to achieve efficacy on projects involving VOC off gassing or desiccation, sufficient air exchanges are necessary to mitigate re-adsorption of the chemicals and/or water vapor. Air flow dynamics must be considered to optimize exchange of hot air in, and VOC/moisture-laden air out of the contained space (i.e., cross-flushing). To reduce harmful effects of allergens released during the heating process, heat-tolerant HEPA fan units are used.

**TABLE NO. 1 – CASE STUDIES**

| **YEAR:** Built / Heat treated | **Building:** Type & Function | **Contaminants:** | **Heat:** Method & Heat Cycle | **Results:** |
|---|---|---|---|---|
| | | | | |
| 1960s / 1998 | 2,200-$m^2$ Industrial warehouse with 660 sq.m. of office space. | Odors and VOCs from re-construction effort, and elevated viable mold spore aerosol in office space. | Existing bldg. HVAC system (elec.), portable elec. heaters & interior fans. Approx 45°C for 3 days, then 1 day air circulation with no heat. | Reduced VOCs by U.S. EPA method TO-14. Reduced viable mold spore aerosol. |
| 1950s / 1999 | 330-$m^2$ Detached, single family dwelling. | Fungi growth and amplification from poor drainage, water seepage into bottom level, and moist buildings materials. | Typical gross removal and detailed cleaning efforts, then heated with 12-1,500 watt halogen lamps for 2 days. Temp. not measured. | Clearance not obtained after typical abatement efforts. After heating, viable mold spore aerosol was less than 50% of outdoor concentration. |
| 1950s / 2000 | Two 90-$m^2$ classrooms. | Moist building materials due to roof system leaks. | Typical removal and cleaning efforts. Heated classrooms to 80°C for 60 minutes. | Air monitoring results: pre-heat 2K to 10K cfu/$m^3$, post-heat 200 to 700 cfu/$m^3$, outdoor aerosol approx. 700 cfu/$m^3$ |
| 1950's / 2000 | 165-$m^2$ Detached, single family dwelling. | Offensive odor from deceased person, insects, visible fungi. | Heated prior to abatement, 90°C for 120 minutes. | Odor gone, insects dead, and bacterial cultures were below 2 cfu/sample. |
| 1999 / 2001 | 183-unit Multi-family apartment complex consisting of 11 two and three story structures. | Fungi growth and amplification near windows from condensation on glass during cold weather. | Typical removal and cleaning efforts. Heated apartment 80°C for 60 min., contents 70°C for 60 min. | Most swab samples had no detectible colony forming units (cfu) remaining samples (30%) showed one cfu. |

Depending on site characteristics, these may be placed inside or outside the containment. HEPA units and cross-flushing the treatment area have proven to be very effective in developing an even heating cycle while removing and mitigating released particulates.

**WHAT HEATING DOES NOT ACCOMPLISH**
Heating contaminated materials will not take the place of removing gross levels of contamination. This technology complements traditional remediation methods after gross removal is complete, and reduces most labor-intensive, detailed cleaning efforts currently performed to achieve clearance criteria. Traditional (non-heat) remediation techniques often have difficulty in achieving clearance.

**SUMMARY**
Heat is an effective, non-toxic form of biological control in structures, and substantially improves IAQ where it has been compromised. Variable results can be achieved depending on anticipated goals, without destroying materials or contents. Moreover, propane-fired burner-fan units, when combined with heat-tolerant HEPA fans, appear to be the most flexible, scalable, portable, and cost-effective equipment in mitigating biological contamination and improving building IAQ.

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