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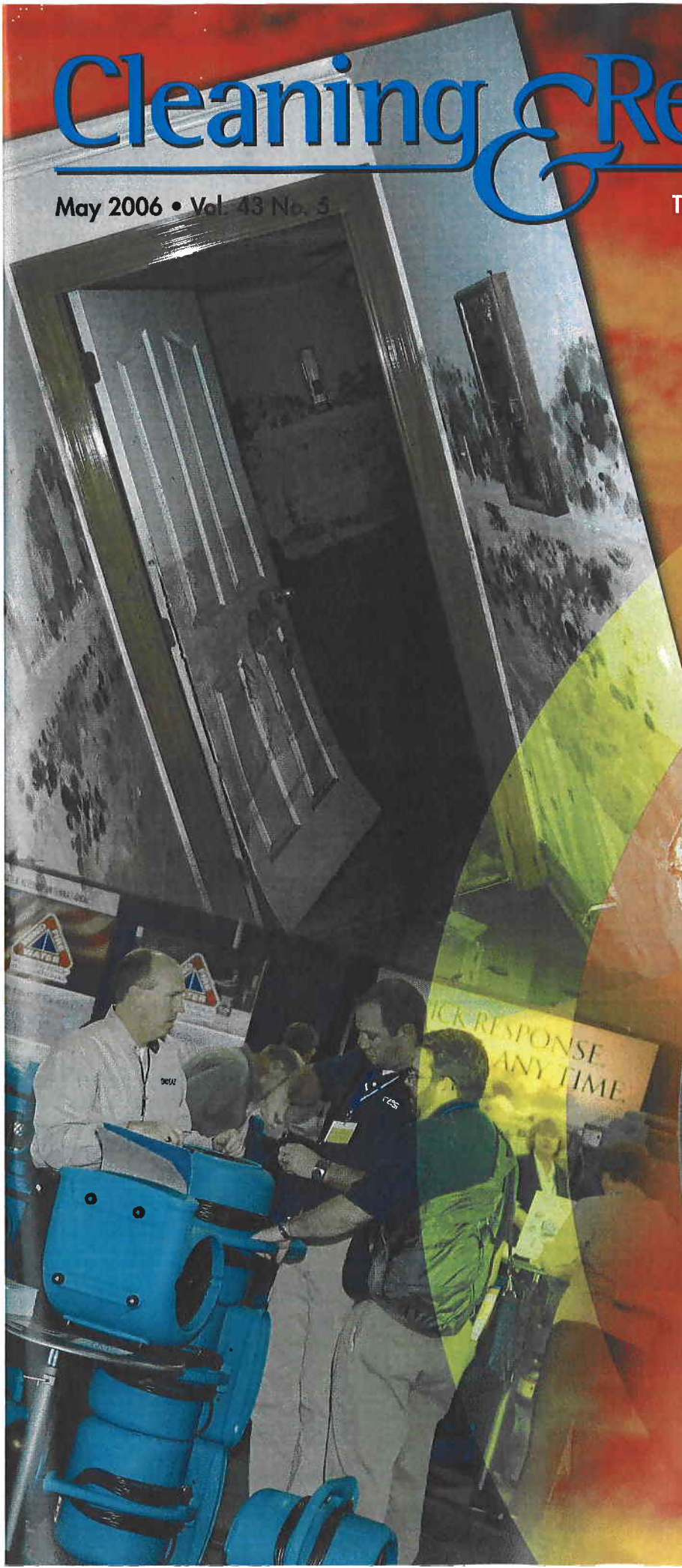

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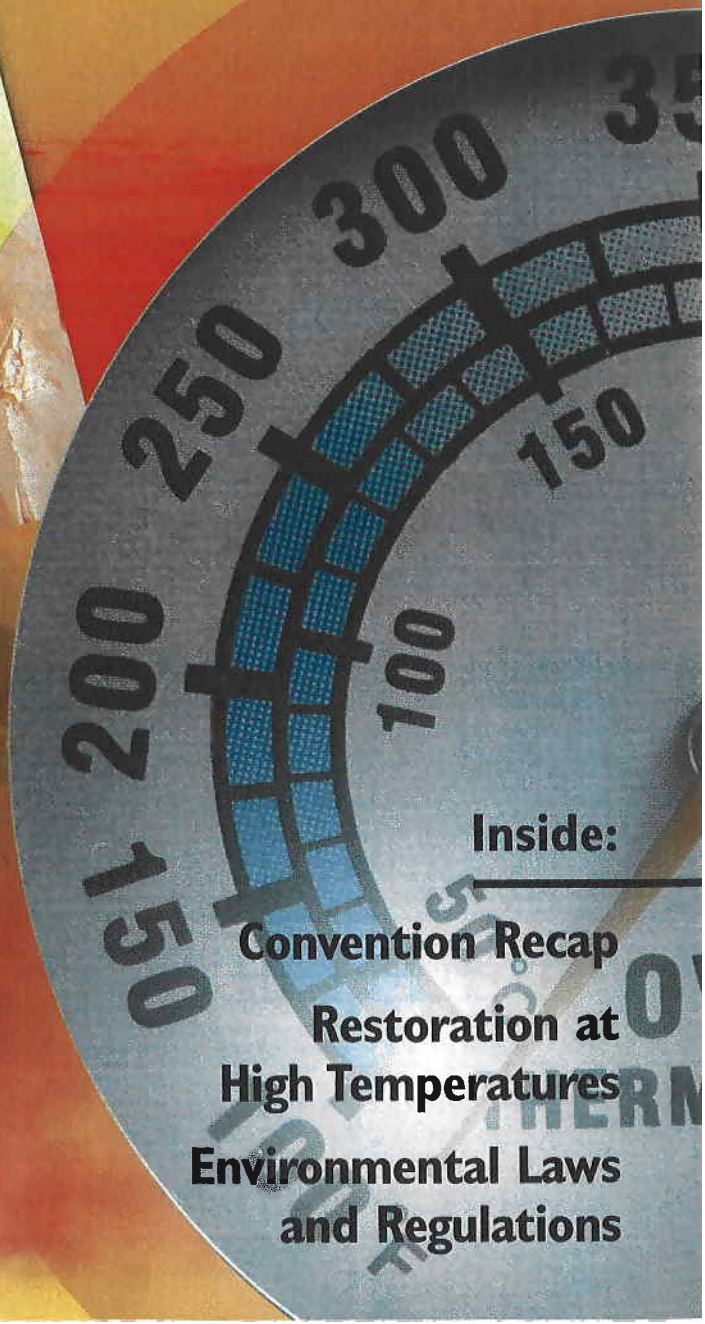

Inside:

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HIGH TEMPERATU

EFFECTS ON MICRO

By Ralph E. Moon, Ph.D., CHMM, CIAQP

Editor's Note: This is the first of three articles on the use of high temperature restoration techniques.

Man has recognized the importance of heat to cook, dry and sanitize objects since the invention of fire. Within the professional restoration community, higher temperatures are an asset, increasing the ability of air to hold moisture and facilitate drying. There are several successful drying methods available to the restoration professional; a few of the more common ones are discussed in this article. Desiccant, refrigerant and convective systems offer practical solutions for the variety of drying situations encountered following water losses and catastrophic events. Though these methods differ in operation and philosophy, they share the underlying principles of lowering the relative humidity and elevating temperature. The temperatures attained by these methods vary depending on the method and the ambient conditions.

Most drying methods generate interior temperatures that range between 90 and120 F. When supplemental heat is added to attain temperatures of 120 to 160 F or more, the objective is to reduce the level of harmful bio-organisms and reduce the potential allergens in addition to drying and desiccating. This "high temperature" procedure is intended to lessen occupant exposure to allergenic components (i.e., mold spores, mycotoxins, fungal mycelia, bacteria and pests) and odors.

Some restoration contractors who use high temperature methods refer to their allergen removal process as "pasteurization." Pasteurization is a process of heating food for the purpose of killing harmful organisms such as bacteria, viruses, protozoa, molds and yeasts (Wikipedia, 2006). The definition goes on to explain that, "Pasteurization is not intended to kill all microorganisms in the food, as compared to appertization, invented by Nicolas Francious Appert. Instead, pasteurization aims to achieve a 'log reduction' in the number of viable organisms, reducing their number so they are unlikely to cause disease." In the treatment of milk, the temperature is raised to 140 F (63 C) for 30 minutes or 161 F (72 C) for 15

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seconds. The various temperature regimes of living organisms, thermal death points and a description of the high temperature heating process is described in this series of articles.

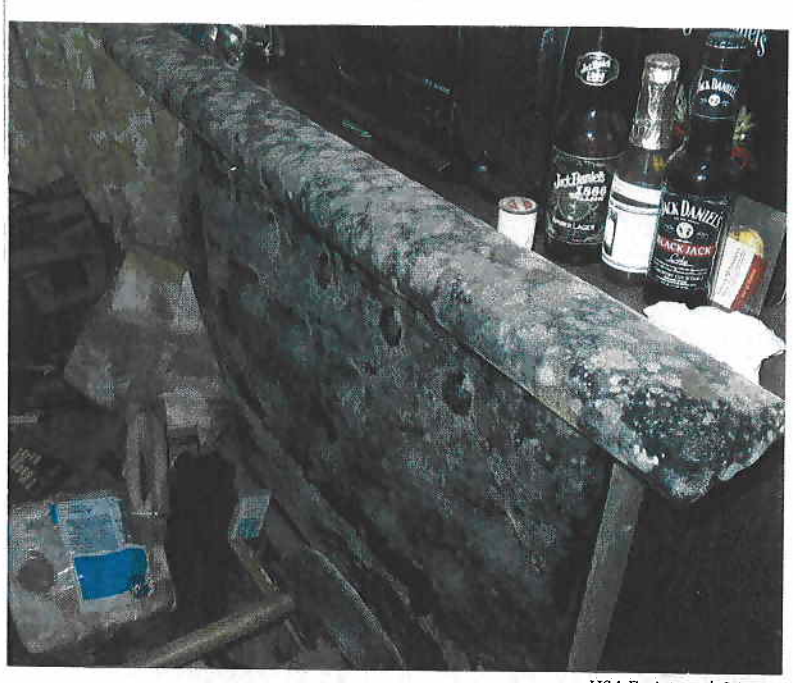
High Temperature Effects on Microorganisms and Toxins

Microorganisms (bacteria) can be divided into four categories of adaptation to temperature regimes: thermophiles, mesophiles, psychrophiles and psychrotrophs (see Table 1).

Within the restoration community, we are primarily concerned with mesophilic organisms because their optimal temperatures lie within the same temperature range as the human body, our homes and workplaces. Remarkably, some organisms actually prosper at temperatures of 160 F and above. Our ability to state unequivocally that high temperatures kill particular target organisms is predicated on the ability to document sustained, uniform temperatures in the thermal kill

Table 1. Temperature ranges for prokaryotic (bacterial) microorganisms (ICMSF, 1980)

	Temperature °F (°C)		
Group	Minimum	Optimum	Maximum
Thermophiles	104-113 (40-45)	131-167 (55-75)	140-194 (60-90)
Mesophiles	41-59 (5-15)	86-113 (30-45)	95-117 (35-47)
Psychrophiles	23-41 (-5 -+5)	54-59 (12-15)	59-68 (15-20)
Psychrotrophs	23-41 (-5 -+5)	77-86 (25-30)	86-95 (30-35)



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zone; this may vary depending on the relative humidity. Fungi react differently than bacteria to moist heat and dry heat; some may be sustained under heat treatment (e.g., the fungus *Aspergillus fumigatus* and the bacterium *Thermoactinomycetes vulgaris).* Among the thermophilic fungi and bacteria (many of which are found indoors), some fungal spores germinate only *after* heat stimulation treatment (less than 110 F) and then grow (Yang, 2005).

Though restoration companies may not typically encounter thermophilic bacterial species, many bacterial spores, particularly Bacillus species (including Anthrax) are very resistant to environmental stressors, including heat, and can tolerate temperatures higher than those used in high temperature treatment. For example, Anthrax spores can be killed by boiling at 120 C (250 F) or dry heat at 159 C (318 F) for one to two hours (BioPort Corporation, 2006). The most extensive studies on the effects of heat on bacteria were conducted in the late 1800s when great scien-

Table 2. Thermal Death Points of Bacteria and Spores: An Historical Survey

Author's Note: This table provides the reader with an historical perspective on research to determine the thermal death point of microorganisms. Some genus and species names have changed over time; however, the temperature regimes are accurate.

Species	Duration & Temperature	Author
Common Bacteria		
Bacillus coli (E. coli)	10 min @ 60°C (140°F) 30 min@ 65-67°C (153°F) 35 min @ 73-75°C (167°F) 15 min @ 68°C (155°F) 45 min@ 60°C (140°F)	Loeffler, 1886 Escherich and Pfaundler, 1903 De Jong and DeGraef, 1914 Shippen, 1915 Padyhe & Doyle, 1992
Bacillus thermophilus	5-6 hrs @ 100°C (212°F)	Rabinowitsch, 1895
Bacillus typhosus	10 min @ 56°C (131°F) 5 min @ 60°C (140°F) 4 min @ 63°C (146°F)	Sternberg, 1887 Bassenge, Mienicke & Friedel, Kolle, Kutscher, 1905 Orskov, 1926
Paratypoid bacilli	20 min @ 60°C (140°F) 3 min @ 63°C (146°F)	Krumwiede & Noble, 1921 Orskov, 1926
Dysentery bacilli	1 hr @ 56°C (131°F) 10 min @ 58-60°C (140°F)	Thomson, 1916 Runge & O'Brien, 1924
Brucelli organisms	10 min @ 57.5°C (135°F) 5-10 min @ 65°C (149°F)	Eyre, 1912 Zwick & Wedeman, 1913
Bacterium tularense	10 min @ 56°C (133°F)	McCoy, 1912
Hemophilus influenzae	2 min @ 62°C (144°F)	Onorato, 1902
Vibrio cholerae	5 min@ 80°C (176°F) 15 min @ 55°C (131°F)	Koch Kitasato, 1889
Bacillus pestis	30min @ 80°C (176°F) 2 min @ 60°C (140°F) 1 hr @ 65°C (149°F)	Kitasato, 1894 Gladin, 1898 Kolle, 1912
Staphylococci	10 min @ 62°C (144°F) 35-60 min @ 75°C (167°F) 45 min @ 60°C (140°F)	Sternberg, 1887. Samter, 1908 Neisser, 1921
Meningococci	1min @ 60°C (140°F)	Bettencourt and Franca, 1904
Pneumococci	15 min @ 60°C (140°F) 30min @ 60°C (140°F)	Wirth, 1916 Baggar, 1926

tific interest was created by disease-producing organisms as noted by their original authors (see Table 2).

Heat resistance was studied and reviewed historically by several authors (Robertson, 1927; Magoon, *et. al.*, 1926) and produced conclusions that we recognize today as founding principals, such as, "The subject of heat resistance in microorganisms, in general, recognizes that young cells are more easily destroyed than old cells" (Hampil, 1932). The cause of death for bacteria can be divided into four portions: dry heat and moist heat at both low and high temperatures (Hampil, 1932.). At low temperatures, dry heat causes the formation of oxidation proteins which destroy bacteria (Paul, Birstein and Reusz, 1910). At high temperatures, two processes may occur. Protein coagulation takes place (Rubner, 1899) and scorching or carbonization of the outside which interferes with nutritive processes.

The complete destruction of bacteria by heat was first studied by Koch (Koch *et al.*, 1881). These carefully designed experiments formed the fundamental principles of heat sterilization used today. His early experimentation showed that Anthrax required a temperature of 284 F (140 C) for three hours to kill the spores, whereas they could be killed in a few minutes when boiled. His experiments demonstrated that steam placed under pressure at an elevated temperature sterilized surfaces much more rapidly. Comparisons between the thermal tolerance of different organisms show that complex (animal, protozoa, fungi) organisms will not survive at higher temperatures as compared to simpler organisms like blue-green algae and bacteria (see Table 3).

The lethal temperature varies among microorganisms. The time required to kill depends on the number of organisms, the species, pH, duration and temperature (Todar, 2002). Laboratory research shows that the thermal death point for selected pathogenic bacteria and spores range from 131 F and 212 F (see Table 2). In a building, the ability to substantiate attaining a lethal temperature is predicated on

Species	Duration & Temperature	Author
Pathological Origin		
Salmonella	1 hr@ 60°C (140°F)	Feachem, 1983
Shigella	1hr @ 55°C (131°F)	Feachem, 1983
Streptococci	30 min@ 60°C (140°F) 15 min @ 60°C (140°F) 24 hr @ 60°C (140°F)	Ayers & Johnson, 1918 Wirth, 1926 Bagger, 1926
Non-pathogenic Mesophiles		
Str. Lactis	15 min @ 70°C (158°F)	Orla-Jensen, 1919
B. tuberculosis	6 min @ 63°C (145°F)	North and Park, 1917
Clostridium botulinum (Meyer, 1928)		
C. botulinum (Type B)	20min @ 80°C (176°F)	Van Ermengem, 1897
Type A	60 min @ 100°C (212°F)	Thom, Edmondson and Gilener, 1919
Types A and B	240 to 255 min @ 100°C (212°F) 300 min @ 100°C (212°F)	Dickson and co-workers, 1922 & 1925 Tanner and McCrae, 1923
Type B	10 min @ 100°C (212°F)	Starin, 1926.
Anaerobic Spores Clostridium botulinum (Meyer, 1928)		
Cl. welchii	8 - 90 min in steam (>100°C)	Becker, 1920
Cl .nouyii	8 - 90 min in steam(>100°C)	Becker, 1920
Vibrion septique	2 - 15 min in steam(>100°C)	Becker, 1920
Cl.bifermentans	90 - 150 min in steam (>100°C)	Becker, 1920
Other Anaerobic Spores		
Bacillus thermophilus	5-6 hrs @ 100 °C (212°F)	Rabinowitsch, 1895
Bacillus Illidzensis	4 min @ 100 °C (212°F)	Karlinski, 1895
Thermophilic Cladothrix	4 min @ 100 °C (212°F)	Kedzoir, 1896
Cl. gelatinosum	75 min @ 100 °C (212°F)	Laxa, 1898
Micrococcus form	10 min @ 76 °C (169°F)	Russel and Hastings, 1902
Bacille	Resisted hours of boiling	Tsilinsky, 1902

Sources:

Hampil, Bettylee, 1932. The Influence of Temperature on the Life Processes and Death of Bacteria, *The Quarterly Review of Biology*, Vol. 7. No. 2, pages 172-196.
Morrison, Lethe E. and Tanner, Fred W. 1924. Studies on Thermophilic Bacteria, *Botanical Gazette*, Vol. 77, No. 2, pages 171-185.

the completeness of the drying effort, performance measurements and microbial sampling. Even after the living organism is dead, fungal spores, mycelia and mycotoxins still pose an allergenic concern.

High temperature regimes do not destroy mycotoxins (Yang, 2005). The varieties of toxins produced by fungi depend on the species, growth substrate and the presence or absence of competing organisms (Burge and Ammann, 1999). The vast majority of mycotoxins have not been identified; therefore, claims of complete removal following any restoration procedure cannot be substantiated.

How Does High Temperature Work?

High temperature drying in this article is defined as 120 F and above; these conditions require specific technical instructions. Recognizing that every project must consider site-specific criteria, we can gain insight into the high temperature procedures in the specifications prepared for the Fresno Housing Authorities (SCS Engineers, 2003). The following is an abbreviated scope of work describing the technical requirements:

1. Purpose

- Drying out moist architectural components
- Killing viable biological organisms (e.g., insects, fungi and bacteria)
- Oxidizing odors

2. Site Superintendent

The contractor will employ a site superintendent as the responsible person to act as an OSHA-Competent Person who can recognize hazards and direct others. The superintendent is required to record/log all job-site work progress. The superintendent shall be fully qualified through education, training and experience to perform the work.

3. General Pre-start Inspection

The superintendent must perform an inspection of the structure before assembling heat generators or distribution equipment. The inspection will verify if the structure is safe and sound, will not be compromised when heated, and whether the structure is devoid of personal belongings. These observations will be recorded.

4. Site Set-up

The superintendent shall layout the heat generators and distribution equipment to ensure that the heat can be equally distributed within the designated area. The layout of the heating equipment shall be recorded on a drawing. All salient features of the structure shall be recorded on a drawing. The superintendent shall ensure that the heat generators are sufficiently sized to bring the structure up to specified target temperatures and will maintain those temperatures for the specified duration.

5. Establishing Temperature Monitoring Points

To be effective, a threshold temperature must be maintained for a specified duration of time. Temperatures must be measured and recorded during the entire heat treatment process. Temperatures must be measured in real time in the air space and within various architectural components.

6. Threshold Temperature

The threshold temperature shall meet or exceed 160 F or 71 C in the majority of probes. All probes in the designated heat treatment area shall reach a minimum temperature of 155 F or 68 C. However, temperatures in the structure shall not exceed 175 F or 80 C.

7. Temperature Duration

The duration with which most temperature probes shall be maintained above the threshold temperature (160 F) is 60 minutes. The duration may vary depending on specific target organisms and/or VOCs. All probes in the designated treatment area shall be maintained at or above the threshold temperature for a minimum of 60 minutes.

8. Cool-down Period

Upon meeting temperature and duration goals, a 60-minute cool down period shall be initiated. During the cool-down period, all heat sources are turned off and the structure is to remain sealed while temperature monitoring continues.

Insight provided by high temperature drying practitioners offers practical perspectives. The difficulty of achieving lethal temperatures within the core of structural materials increases exponentially with the degree of moisture control within those materials. It is important to remember that "you can't achieve high temperatures until the wood is dry" (Vyrostek, 2006).

Moisture content can vary widely in a flooded home where some wood members may be saturated while other materials may contain sufficient water content to support microbial growth (approximately 20 percent or greater moisture). Both types of materials, saturated or elevated moisture, can be dried at temperatures less than 120 F. Proper drying, however, must consider the wide range of moisture content.

The duration of drying is critical and should be carried out slowly and uniformly over the period of time that is needed to complete the objective. As in kiln drying, differential temperatures and rapid temperature changes increase the possibility of damage as wood dries. Crawl spaces with

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exposed soil, heat sinks (i.e., concrete and brick structures) and building envelope breaches pose restrictions to achieving temperature uniformity.

Is High Temperature Necessary?

This is perhaps the most important question of all. The answer depends on whether the use of high temperature is the most practical, efficient and safe method to meet the client's needs. Sewage-flooded structures, schools and medical facilities compromised by pathogenic microorganisms, insect-infestations, time-sensitive businesses, nuisance odors and individuals with multiple chemical sensitivities may benefit from the high temperature process; however, the public's understanding of a "unique" or "innovative" restoration strategy may be clouded by their perception that it is also the "most appropriate."

The public's perception of mold is influenced by their health, personal observations and the media. When water damage and resulting microbial growth occur, some consumers seek comfort in absolute remedies, "I don't want a single *Stachybotrys* spore in my house," or "the indoor air quality should pose no health risks from mold." Though satisfying, these expectations are always short-lived, if not impossible to achieve, but business development efforts are sometimes driven to satisfy the loftiest expectations. In some circumstances the risks associated with remediation may exceed the benefits.

A recent indoor air quality article examined whether microbial growth can be left inside walls based on the relative risk (Burge, 2005). Some fungal species (e.g., *Penicillium chrysogenum*), though prevalent after a water loss, pose no risk when enclosed in the wall cavity of a school. Though inconsistent with parent and teacher expectations, the practical aspects of removal (*i.e.*, school closings, restoration costs, loss of salary and expenses) offer a sobering perspective of mold's presence and its priority for removal. The most appropriate remediation technology should be elected wisely by considering the inherent risks.

Table 3. Approximate upper thermal limits for survival in different groups of organisms

Organism	Upper Limit (°F)
Animals including protozoa	113-123 (45-51°C)
Fungi and algae	132-140 (156-60°C)
Blue-green algae	163-176 (73-75°C)
Bacteria	>194 (>90°C)

Source: Brock, T.D. 1967. Life at High Temperatures, *Science*, Vol. 158, p.1012.

How do We Know it Worked?

Performance measurements collected before, during and after any restoration procedure are necessary to confirm that the restoration process met the design intent or intended outcome. Fungi and bacteria are present on the entire earth's surface; determinations of effective thermal kill and removal must be documented in periods measured in minutes and hours after project completion. Once the structure returns to ambient temperature, moisture will return the construction materials and contents to their equilibrium moisture content; ventilation and infiltration will inoculate

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a host of fungal and bacterial species into the interior spaces within a few days.

In the end, the most effective way to reduce future microbial proliferation is to keep the interior dry. A detailed logbook describing the moisture content at multiple sampling locations, temperature and relative humidity measurements, microbial sampling of air and surfaces and infrared analysis of the structure will support a successful project, substantiate payment and lessen claims of misrepresentation.

Elevated temperatures not only desiccate microbes, they can also accelerate aging and change the performance of selected materials and contents. The potential effects on building materials are described in Parts 2 and 3 of this series.

High temperature or "pasteurization" restoration techniques pose both creative restoration opportunities and elevated risks. Structures that are contaminated with pathogens or support extensive microbial contaminants may benefit from desiccation and the capture of microbial mass.

Client expectations are bound to soar if "high temperature restoration" is marketed as a sanitation technique. Historical studies on thermal death in bacteria and spores range as high as 212 F, making sanitation an unachievable goal.

No restoration process is permanent. High temperature is clearly a benefit in the short-term; however, structures where the moisture content is poorly regulated will return to their previous condition. Client training and orientation to the importance of maintaining building performance and moisture controls may help lessen claims of misrepresentation. ■

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