I. Introduction

ThermaPureHeat®, a Process of Structural Pasteurization

ThermaPureHeat® (ThermaPure®) is a process that applies the theories of pasteurization to structures. Pasteurization dates back to the mid-1800s with the concepts applied by Louis Pasteur. Pasteur determined that by heating food products to a temperature of approximately 60ºC for several minutes, bacteria, viruses, protozoa, molds and yeasts in the food would be reduced to levels that would no longer cause spoilage to the food or be harmful to the health of the consumer. Pasteurization improved shelf-life of food products and more importantly, provided reduced levels of contamination allowing for safe consumption without damaging the food product. Today, ThermaPure® uses the same principles for structures. Structural Pasteurization™ is a process in which the temperature of a building or portion of a building is increased to a level that will reduce the targeted organisms to acceptable levels while minimizing damage to the structure. This is the basis for ThermaPure®.

Since Pasteur's experiments with heat and food products in the 1860's, many scientists have applied heat to a variety of organisms. Studies in soil science, compost treatments, waste management, pest control and other disciplines have determined thermal death rates for various species of pests and human pathogens. All organisms have a thermal death point. Some combination of temperature and duration of exposure will be effective with every organism. Human pathogens, which must be able to grow at the approximately 37ºC body temperature, are considered mesophiles. In general, organisms that affect indoor air quality, the primary target of ThermaPure®, are mesophilic. Although there are exceptions to this, generally, ThermaPure® will target mesophilic pathogens and temperatures within pasteurization boundaries (50ºC - 70ºC) are sufficient to achieve logarithmic reductions with these organisms. As mentioned earlier, the primary goal of ThermaPure® is to reduce the targeted organisms to acceptable levels.

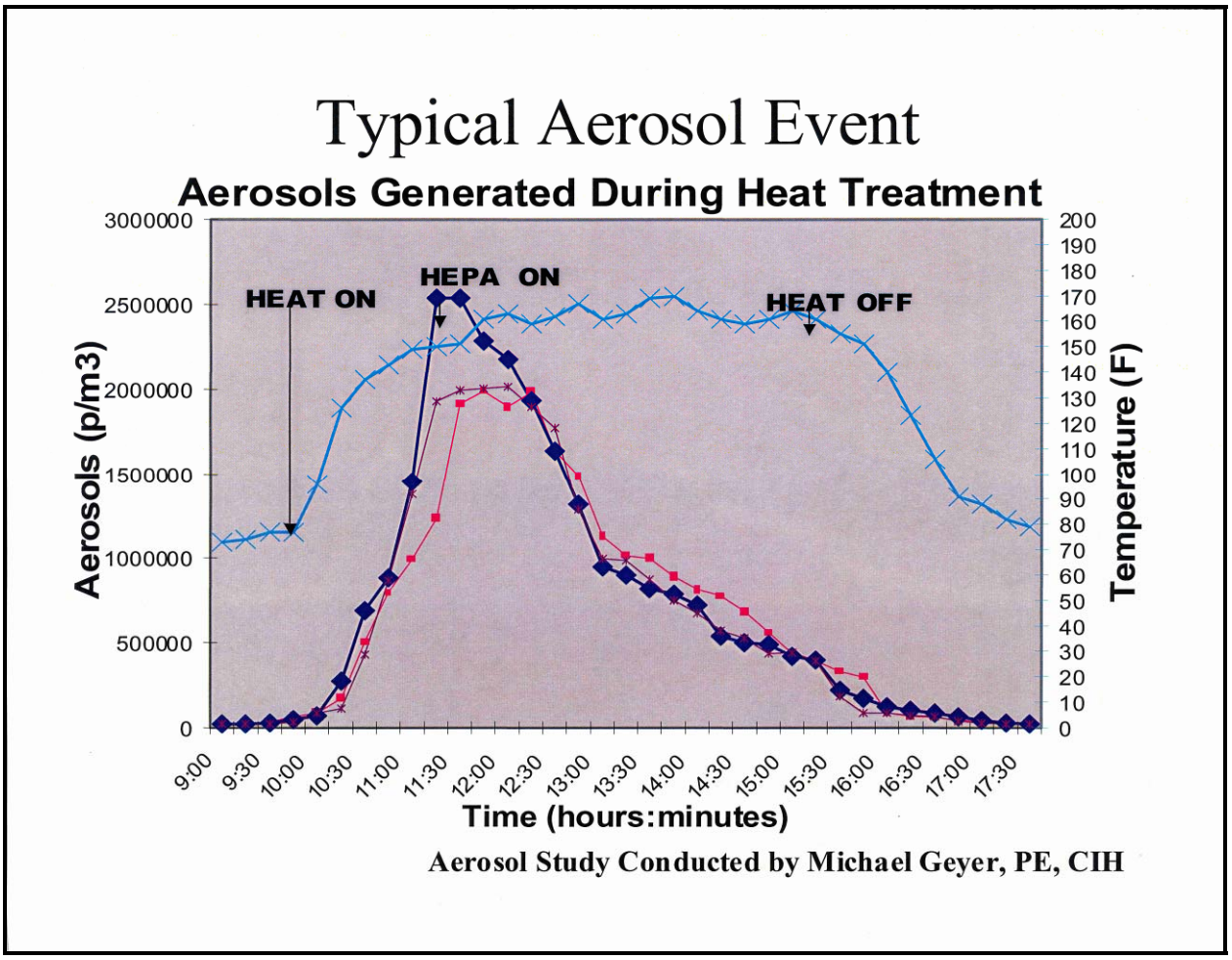
The concept of pasteurization is easily understood and application to a food product is not difficult to accomplish. Heating a container of milk to 60ºC for the duration of 30 minutes to achieve pasteurization is relatively simple. However, the same application to a structure is much more complex. Efficacy, defined as a logarithmic reduction of the target organism, is achieved through uniform distribution of the target temperature and appropriate duration applied to the structure. Buildings are complex and consist of a variety of materials resulting in various thermal conditions and requirements. For example, a wall system may consist of a finish coating such as paint, gypsum board or plaster, air space, timber or steel framing, electrical wiring, steel or plastic conduit, and often an insulating material. Each of these materials has different thermal properties. Additionally, the wall system may be reinforced as a sheer wall or may have windows or other openings. There may be architectural features that make uniform distribution of heat difficult. Attaining the target 60ºC for the duration of 30 minutes in this wall system is complex and requires appropriate training and the correct equipment.

Convection for Heat Distribution and Aerosol Generation

The primary heat transfer process used for structural pasteurization is convection. Because of the various conditions of a structure, temperature efficacy is determined by a combination of heat transfer processes, including convection, heat conduction and thermal radiation. Structural pasteurization occurs from two primary actions occurring in the structure. The first action,

thermal death, is accomplished by exceeding the thermal death point of the targeted organism by elevating and maintaining the temperature of the structure. This component of the process results in the reduction of viability of the organism. The second action, aerosolization, occurs from a combination of thermal dynamics and primarily by the strong convective currents that are forced into the space. As important as the heat generation is to the process for reducing target viability, filtration is important to the capture of aerosol. It is the successful combination of reduced target viability and aerosol capture that results in structural pasteurization. ThermaPure® needs temperatures and distribution appropriate to meet the thermal death requirements of the targeted organism and filtration adequate to capture the abundance of aerosol that is generated by the convective processes. Together, these combine to create target efficacy and improved indoor air quality.

It is this combination of effects that is important to understand. The following graph was generated from data taken from a ThermaPure® project. The data demonstrates both temperature and aerosol capture requirements. This particular graph is only showing one temperature plot, whereas ThermaPure® projects might have as many as one hundred probes or recording devices to assure all core materials have reached the appropriate temperatures. Additionally, this graph is showing the temperature of just the treatment air. This graph is used to demonstrate how aerosol is increased and captured once the heaters are turned on.



In this example the heaters were turned on at about 10:00 and the three particulate plot lines show an immediate increase in aerosol generation parallel to the increase in temperature. The heat process was started prior to turning on the HEPA filtration to demonstrate how rapidly aerosol is generated in a treatment space. Normally, HEPA filtration is on both before and after the heat generation begins. The significance of this graph is to demonstrate the amount of aerosol generated by the ThermaPure® process and the necessity for filtration to capture the aerosol and scrub the air. Improved air quality occurs when both the combination of reduced viability of targeted organisms and bulk removal of aerosol generated by the process is achieved. It is important to understand both aspects of structural pasteurization and the differences with the process as applied to food products. While food pasteurization strictly targets reducing viable populations of microorganisms, structural pasteurization also includes the significant element of bulk contaminant removal with the process.

The successful application of ThermaPure® occurs when structural temperatures have increased to levels exceeding the thermal death rate of the targeted organism(s) and filtration has removed the bulk aerosol generated by the source contamination and the convective heating process. With appropriate training and equipment, structural pasteurization can be accomplished and the vast benefits of ThermaPure® realized. Structural pasteurization can significantly improve indoor air quality when appropriately applied.

Training - A Necessity for Successful Implementation

E-Therm offers new and existing licensees various levels of training to assure they are able to accomplish structural pasteurization. The Ventura training facility has both classroom and a mock structure for hands-on application. The classroom training provides an understanding of the technology including target goals and capacity, equipment and materials, appropriate applications, physics and thermal dynamics, worker health and safety, building materials, and measuring results. The field training is the hands-on application of the classroom. Differing types of equipment are demonstrated in the mock structure to illustrate advantages and disadvantages based on a variety of differing conditions. Temperature monitoring equipment is used to demonstrate effectiveness of the various equipment and impact on different materials. Materials that are susceptible to high temperatures are included so trainees can learn how to prevent damage or protect these items.

Licensee training continues in the field as E-Therm recommends that all projects the licensees perform be overseen by a certified heat technician. It is recommended that a Heat Technician 3 provide oversight for all whole structure projects. Partial structure projects should have at a minimum a review of the Operations Help Sheet by E-Therm until the licensee's technicians have received an appropriate number of project experiences. Many licensees continue to use the Operations Help Sheet to assist them in estimating and planning heat projects. Quality control is required and typically performed by the licensee.

Successful licensees have insisted that all involved personnel receive technical training. This oftentimes includes sales persons, estimators, operations managers, and senior managers in addition to the technicians. This provides a corporate understanding of the process and capabilities. Training is a key element to the successful deployment of ThermaPure®.

II. Review of Literature

19th and 20th Century Bacteria and Virus Studies of Food Borne Pathogens

One hundred years before Louis Pasteur discovered the process to be named after him, Nicolas Appert discovered a method to keep foods from spoiling. Appert found that by placing foods in a sealed container and soaking the container in hot water for a few hours the food would be preserved. Today, we know this process as "canning". The history of using heat to reduce the growth of pathogens had begun.

There are many other examples of using high temperatures to manage the presence of pathogens in food products. During the 1850s to 1880s when Pasteur was conducting his research, he along with Joseph Lister, Robert Koch, and a medical minority were advancing what would be known as the "germ theory of disease."[1] Koch determined that specific bacteria caused certain diseases. The relationship between bacteria and human health continued to be explored and better understood. By 1900 the germ theory of disease was accepted and physicians had begun using disinfectants for surgical tools and preparations. They began experimenting with chemicals for treatment of infectious diseases. During these formative years, research in human pathogens was generally performed to resolve disease rather than to prevent it. However, in their quest to understand the biology of bacteria, scientists researched the thermal death of known human pathogens. Studies of tuberculosis and anthrax developed a better understanding of the thermal resistance of the affecting pathogens.

There was considerable research during the late 19th century regarding the thermal death rate of bacterial species in food products. In the 20th century much of this research was to reach better understanding of food borne pathogens. The following is a review of early studies which list thermal death rates for a selection of pathogenic bacteria. Note that the thermal death rates of the listed species fall easily within ThermaPure® temperature ranges:

	Thermal Studies of Bacteria,	**Taken from: Hampil (1932)[2]**
Species[3]	**Temperature and Duration**	**Author/Scientist**
Bacillus coli (E. coli)	10 min @ 60ºC (140ºF)	Loeffler, 1886
Bacillus typhosus (Salmonella)	10 min @ 56ºC (131ºF)	Sternburg, 1887
Paratyphoid bacilli	20 min @ 60ºC (140ºF)	Krumwiede & Noble, 1921
Dysentery bacilli *(Shigella)*	10 min@58-60ºC (140ºF)	Runge & O'Brien, 1924
Hemophilus influenzae	2 min @62ºC (144ºF)	Onorato, 1902
Vibrio cholerae	15 min @ 55ºC (130ºF)	Kitasato, 1889
Bacillus pestis (Yersinia)	2 min @60ºC (140ºF)	Gladin, 1898
Staphylococci	10 min @ 62ºC (144ºF)	Sternburg, 1887
Streptococci	30 min @60ºC (140ºF)	Ayers & Johnson, 1918
Mycobacterium tuberculosis	3 min @63ºC (146ºF)	North & Park, 1925

[1] Auyang, S. (2006). "Reality and politics in the war on infectious diseases." Unpublished article. http://www.creatingtechnology.org/biomed/germs.htm.

[2] Hampil, B. (1932). "The Influence of Temperature on the Life Processes and Death of Bacteria", *The Quarterly Review of Biology*, Vol 7. No. 2 (172-196)

[3] Note: Many of the originally designated names of these bacterial species have changed over time; current terminology is provided in parentheses.

By the 1990's many standards existed for preparation of food products. The pasteurization process was further defined by the USDA with requirements that the thermal process regime require a 4 to 7D kill of microorganisms as a prerequisite of process control (USDA 1990). Many of the thermal studies performed express the results in log reduction of the target species. The question the researchers were attempting to answer was how many log reductions would be achieved at a specific temperature and duration. What changes would occur at increased temperatures? Specific pathogens are expected to exist in certain food products so pasteurization temperatures and durations could be set for the target and associated product.

Today, traditional food pasteurization would seek an approximate 60ºC temperature and duration of 15 to 17 minutes. They have found high-temperature, short time (HTST) pasteurization schedules to be as effective with less harm to the food product. This process is often done at 70-72ºC for 10 to 15 seconds. It is imperative that the same log reductions occur with either method, therefore, significant numbers of tests have been performed with various food borne pathogens to determine efficacy. ThermaPure® can follow the same regimes utilizing lower temperatures at longer durations or higher temperatures with short durations. However, there is risk of potential damage to the structure at the higher temperatures.

Waste Management and Pasteurization

Other studies of the thermal death of micro-organisms have occurred in waste management. Human excreta are the principle vehicle for the transmission and spread of a wide range of communicable diseases. Some of these diseases are the leading causes of sickness and death in many of our third world countries. It has been estimated that several hundred diseases may be transmitted from animal to animal and more than one hundred and fifty may be transmitted from animal to man.[4] Pathogens found in human excreta include bacteria, viruses, cysts of protozoa, and eggs of helminthes. All of these may cause disease in a new host.

One of the processes used to manage the spread of these pathogens is to induce inactivation through the deployment of high temperature sludge treatment or composting. Temperature is a more thorough intervention process in the inactivation of enteric pathogens. According to the World Health Organization, "…heating to pasteurization temperatures (generally 60ºC) for periods of minutes to tens of minutes will destroy most waterborne pathogens of concern."[5] Typically, temperatures reached in a compost operation range from 50 to 65ºC. Such temperatures are generally above the thermal death points of mesophilic pathogens. The survival of bacteria is variable but most viruses are killed in about 20 minutes at 70ºC.[6] It is important to learn from these studies the thermal sensitivity of pathogens found in human excreta. These studies are directly applicable to ThermaPure® both for the data and especially for flood impacted structures. Floodwaters may carry both animal and human excreta that will continue to colonize in a structure if conditions are appropriate. The temperatures reached by ThermaPure® can be very effective in reducing these pathogens.

[4] Jones, P. and Martin, M. (2003). "A Review of the Literature on the Occurrence and Survival of Pathogens of Animals and Humans in Green Compost", *The Waste and Resources Action Programme*, Banbury, England.
[5] Sobsey, M., (2002) "Managing water in the home, accelerated health basis of improved water supply", World Health Organization.
[6] Day, M. and Shaw, K. (2000) "Biological, chemical and physical processes of composting". In: Stofella, P.J. and Kahn, B.A. *Compost utilization in horticultural cropping systems*. Lewis Publishers, Boca Raton, FL, 17-50.

The following table lists data from some of the wastewater and compost management resources.

Pathogen Genus, Species	Group	Thermal Death Point	Time Required	Source
Escherichia coli	Bacteria	60ºC/140ºF	45 minutes	Padhye & Doyle, 1992[7]
Salmonella	Bacteria	60ºC/140ºF	1 hour	Feachem, 1983[8]
Salmonella typhi	Bacteria	60ºC/140ºF	30 minutes	Stern, 1974[9]
Shigella sp.	Bacteria	55ºC/131ºF	1 hour	Feachem, 1983
Brucella abortus	Bacteria	61ºC/142ºF	3 minutes	Golueke, 1982[10]
Giardia lamblia	Protozoa	60ºC/140ºF	2-3 minutes	Univ of Utah, 2005[11]
Entamoeba hisolytica	Protozoa	60ºC/140ºF	1 minute	Feachem, 1983
Viruses	Virus	70ºC/158ºF	20 minutes	Day, 2000[12]
Rotovirus	Virus	63ºC/145ºF	30 minutes	G.N. Woode[13]
Poliovirus 1	Virus	55ºC/131ºF	30 minutes	Wiley, 1969[14]
Enteroviruses, reoviruses and adenoviruses (All)	Virus	60ºC/140ºF	2 hours	Feachem, 1983
Ascaris lumbricoides	Helminths	55ºC/131ºF	1 hour	Feachem, 1983
Necator americanus	Helminths	50ºC/122ºF	50 minutes	Stern, 1974
Taenia saginata	Helminths	71ºC/160ºF	5 minutes	Golueke, 1982

Pest Control Studies

For over one hundred years, entomologists have used high temperatures to kill insects. Quarles (2006) reported the earliest application of high temperatures to control insect infestation was in flour mills. Beetles and moths in stored products were killed using "extreme temperatures" rather than using chemical pesticides. Temperatures around 49ºC (120ºF) were used as heat was considered less dangerous than fumigation and caused less operational disruption. This process is still being used in flour mills today. Heat has been used to treat many types of insects, including museum pests, cockroaches, termites, wood boring beetles, carpenter ants, fleas, and bed bugs. Other applications were developed in grain management. Heat can be used to disinfect both the grain and the building in which it is stored.[15] Agriculture and Agri-Food Canada have conducted a number of research studies designed to preserve stored grain products. High temperature is one of the processes evaluated killing insects in stored grains. Although this may not be an ideal process because of the impact high temperatures may have on the stored grain, this group has evaluated thermal death points of stored-product insects. Muir (2000)

[7] Padhye, N.V. and Doyle, M.P. 1992. "*Escherichia coli* 0157:H7: Epidemiology, pathogenesis, and methods for detection in foods". *J. Food Protect*. 55(7):555-565.
[8] Feachem, R. et al, (1983) *Sanitation and Disease Health Aspects of Excreta and Wastewater Management*, Wiley, Dorchester, England, p278.
[9] Stern, G. (1974) "Pasteurisation of liquid digested sludge", In*: Proceedings of the National Conference on Composting Municipal Sludge Management*. Information Transfer, Inc., Silver Spring, MD.
[10] Golueke, C.G. (1982) When is Compost safe? *Biocycle* March/Aprl:28-38.
[11] University of Utah. *Wilderness Medicine*, (2005) University of Utah, School of Medicine.
[12] Day, M. and Shaw, K. (2000). "Biological, Chemical and Physical Processes of Composting." In: Stofella and Kahn. *Compost Utilization in Horticultural Cropping Systems*. Lewis Publishers, Boca Raton, USA, 17-50.
[13] Woode, G.N. Personal Communication. In: Feachem, R. et al, (1983) *Sanitation and Disease Health Aspects of Excreta and Wastewater Management*, Wiley, Dorchester, England, p188.
[14] Wiley, A.A. and Westerberg, S.C. (1969) In: Feachem, et al, (1983) p163.
[15] Quarles, W. (2006) "Thermal Pest Eradication in Structures." *The IPM Practioner*. 28 (5/6), 1-8.

indicated that a temperature equal to or in excess of 62ºC (144ºF) is adequate to kill all stored-product insects in seconds[16]. Insects have no ability to regulate their body temperature; therefore they are extremely sensitive to a process like ThermaPure®.

Considerable testing has been done to determine the thermal death rate of insects. The following tables illustrate the results of some of this research:

Species	Insect Name	Thermal Death Point	Duration	Source: Quarles (2006)
Xenopsylla cheopis	Rat flea larvae	39.4ºC/103ºF	1 hour	Mellanby, 1932
Pediculus humanus	Body louse	46.6ºC/116ºF	1 hour	Mellanby, 1932
Blatella germanica	German cockroach	54.4ºC/130ºF	7 minutes	Forbes, Ebeling, 1987
Incisitermes minor	Western Drywood Termite Nymph	54.4ºC/130ºF	6 minutes	Forbes, Ebeling, 1987
Triboltum confusum	Adult Flour Beetle	54.4ºC/130ºF	4 minutes	Forbes, Ebeling, 1987
Lithepuhema humile	Argentine Ant	54.4ºC/130ºF	1 minute	Forbes, Ebeling, 1987

Species	Insect Name	Thermal Death Point	Duration	Source: Getty (2006)[17]
Cimex lectularius	Bed Bug	39-40ºC/ 111-113ºF		Usinger, 1966
Cimex lectularius	Adults and nymphs	>40ºC/113ºF	15minutes	Gulmahamad, 2002
Cimex lectularius	Eggs	>40ºC/113ºF	1 hour	Gulmahamad, 2002

Other studies have shown that insects are susceptible to high temperatures. Zeichner (1996)[18] reported that heat treatment of food service facilities provided outstanding control of German cockroaches. Considering the chronic history of insecticide resistance of cockroaches, this study indicated that the heat treatment had good value by reducing re-treatment requirements. Additionally, the U.S. Army has a pest management guideline for the application of heat for controlling cockroaches in food service facilities.[19] The U.S. Army specifications call for a minimum temperature of 115ºF (41ºC) for 45 minutes or more. Arthropods such as dust mites are also susceptible to high temperatures. Reaching temperatures of 140ºF (60ºC) and maintaining for one hour will kill dust mites.[20]

Dust mite and cockroach allergens are two primary triggers of asthma. Certain allergens are also susceptible to high temperatures. Although there is minimal research on the topic of allergen

[16] Muir, W.E. and Fields, P.G. (2000), Chapter 13, Thermal Control of Insects and Mites. Muir, W.E. Ed: *Grain Preservation Biosystems*. University of Manitoba, Winnipeg, Manitoba, Canada.
[17] Getty, G. (2006) Email Correspondence citing: Harlan, H. (2004). "Ectoparasites, Part Three: Bed Bugs and Kissing Bugs", *The Mallis Handbook of Pest Control, 9th Edition*, Pest Control Technology.
[18] Zeichner, B.C., A.L. Hock and D.F. Wood, Jr. (1996). "The Use of Heat For Control Of Chronic German Cockroach Infestations In Food Service Facilities – Fresh Start", *The 2nd International Conference on Insect Pests in the Urban Environment*, pp 507-513. Also In: (1998). "Heat and IPM for Cockroach Control". *The IPM Practitioner*. Vol XX, February 1998.
[19] U.S. Army CHPPM. (1999) Procedures for Thermal Control of Cockroaches In Army Food Service Facilities. *USACHPPM Technical Guide No. 208 Supplement.*
[20] Ogg, B. (1997). "House Dust Mites". *H-Facts*, University of Nebraska Cooperative Extension.

reduction associated with increased temperatures, two studies, Cain (1998)[21] and Burge (2005)[22] both demonstrated that allergens may be reduced at temperatures above 60ºC (140ºF). The Cain study showed a decrease in the DerP1 dust mite allergen and the Burge study showed a reduction in the allergen associated with *Aspergillus fumigatus*. Both studies indicated temperatures higher than normal structural pasteurization were required and as such ThermaPure® may only provide some reduction in these allergen levels. Dr. Burge stated "From these data we can preliminarily conclude that *Aspergillus fumigatus* allergen is likely damaged by heating in dust at 100ºC (212ºF)." This potential reduction from heat, combined with aerosol capture can result in reducing allergen levels within structures.

The application of high temperature to a structure as utilized in the patented ThermaPure® process has been researched and studied by numerous universities throughout the world. Dr. Walter Ebeling[23], UCLA, in numerous studies found that 120ºF in as little as 30 minutes was lethal to drywood termites. His research has since been supported and verified by Dr. Michael Rust,[24] UCR, and Dr. Vernard Lewis,[25] UCB. No other termite control process has had as much research from credible outside sources backing their claim to efficacy. The State Pest Control Board of California recognizes whole structure heat, such as the ThermaPure® process, to be the only approved whole structure alternative to chemical fumigation. An excerpt from the "Structural Pest Control Fact Sheet" issued by the State of California Department of Consumer Affairs, July 1998 stated: "There are currently two methods for total or whole-house eradication of drywood termites - fumigation and heat…For the heat method, pets, plants, and other items that might be damaged by high temperatures must be removed. The house is then covered with tarps, and hot air is blown into the tarp until the inside temperature reaches 140ºF to 150ºF and the temperature of the structural timbers reaches 120ºF. The time to complete this procedure varies greatly from one structure to another, depending on factors such as the building's construction and the weather conditions."[26]

Insects as vectors of fungal or bacterial contamination are also important to control. Abbott (2002)[27] indicated that insect-vectored spore dispersal is recognized in many groups of fungi. Insects will carry mold spores and bacteria from one location in a structure to another. For this reason, control of insect populations in the structure is important. *Stachybotrys*, for example, is a black, slimy mold that does not become airborne easily. It is, however, transported from one moist location to another by insects. This process can allow amplification of *Stachybotrys* into other wet structural areas of the building.

[21] Cain, G. et al. (1998). "The Effect of Dry Heat on Mite, Cat, and Dog Allergens." North West Lung Research Centre, Wythenshawe Hopital, Manchester, UK.
[22] Burge, H. (2005). "Thermapure Project." Unpublished research.
[23] Forbes, C.F and Ebeling, W. (1987). "Update: Use of Heat for Elimination Of Structural Pests". *The IPM Practitioner,* IX (8):1-5
[24] Rust, M.K., J.K. Grace, D.L. Wood and D.A. Reierson. (1988). "The Search for New Termite Control Strategies". *California Agriculture* 42(5): 15-18.
[25] Lewis, V.R. And M.I. Haverty. (1996). "Evaluation Of Six Techniques For Control Of The Western Drywood Termite (*Isoptera Kalotermitidae*) In Structures". *J. Econ. Entomology*. 89:922-34.
[26] State of California Department of Consumer Affairs. (1988). Structural Pest Control Fact Sheet -Termites.
[27] Abbott, S.P. (2002). "Insects and Other Arthropods as Agents of Vector-Dispersal in Fungi". Unpublished Research presented in October and November 2002 for the National Parks Service, Yosemite, CA, the American Indoor Air Quality Council, Los Angeles, CA and the Association of Applied IPM Ecologists, Elk Grove, CA. The complete article is available at www.thermapureheat.com

The ThermaPure® process is a safe and effective process to control insects and other household or structural pests. It is a cost effective approach to pest management that does not involve the use of chemicals and efficacy is equal to or better than other pest control processes. The application of high temperatures to kill insects is a proven process. Heat has an ability to reach difficult or otherwise inaccessible areas. Additionally, the process has added value in delaying future pest infestations by thoroughly drying the structure. A dry structure tends to be a healthier building for human occupation.

Pathogens as Vectors from Pests

Numerous pathogens are carried by pests such as rodents and birds. The affecting micro-organisms may be fungi, bacteria, viruses, or parasites. Many of these can be distributed through aerosols. Because of this, they may become a concern within a structure. Hantavirus Pulmonary Syndrome (HPS) is a potentially deadly viral disease associated with rodents. According to the CDC, HPS was first discovered in 1993 and since has been identified throughout the United States and Canada. Hantavirus is susceptible to pasteurization temperatures. According to the World Health Organization the Hantavirus can be deactivated by reaching a target temperature of 60ºC/140ºF and maintaining it for 30 minutes.[28]

Other pests may carry diseases that are pathogenic to humans or to other mammalian or avian species. Following is a table listing some of these pathogens and target requirements for inactivation:

Pathogen Species	Disease Origin	Thermal Death Point	Duration	Source Agriculture, Fisheries and Forestry, Australia[29]
Chlamydia psittaci	Chlamydial	56ºC/133ºF	5 minutes	Anderson et al., 1997
Newcastle Disease Virus	Viral	60ºC/140ºF	1 hour	Foster & Thompson, 1957
Parvoviruses	Viral	60ºC/140ºF	30 minutes	Gough et al., 1981
Poxviruses	Viral	60ºC/140ºF	8 minutes	Tripathy, 1993
Highly Pathogenic Avian Influenza (HPAI)	Viral	56ºC/133ºF	15 minutes	Blaha, 1989
Salmonella	Bacterial	60ºC/140ºF	1 hour	Feachem, 1983[30]
Coxiella burnetii	Rickettsial	63ºC/145ºF	30 minutes	Connor, 2006[31]
Infectious bronchitis	Viral	56ºC/133ºF	15 minutes	Otsaki, 1979[32]
Trypanosoma cruzi	Protozoan	45ºC/113ºF	60 minutes	Von Brand, 1946[33]
Schistosoma eggs	Parasitic	50ºC/122ºF	60 minutes	Feachem, 1983
Taenia saginata	Parasitic	71ºC/160ºF	5 minutes	Golueke, 1982[34]

[28] World Health Organization. *Manual of Hemorrhagic Fever and Hantavirus Pulmonary Syndrome*. WHO, p196.
[29] Technical Issues Paper. (2000). *The Importation of Non-Viable Eggs and Products Containing Egg*. Agriculture, Fisheries and Forestry, Australia.
[30] Feachem, R. et al, (1983) *Sanitation and Disease Health Aspects of Excreta and Wastewater Management*, Wiley, Dorchester, England, p278.
[31] Connor, D., In: "You Are What You Eat". Taken from Auburn University, Detection and Food Safety. http://www.eng.auburn.edu/~wfgale/usda_course/section0_5_page_3.htm
[32] Otsuki, K. et al, (1979). "Studies on Avian Infectious Bronchitis Virus". *Archives of Virology*. 60(1):25-32.
[33] Von Brand, T. et al, (1946). "Observations on the Respiration of *Trypanosoma cruzi* in Culture". *The Journal of General Physiology*, August 1946, p169.
[34] Golueke, C.G. (1982) When is Compost Safe? *Biocycle* March/April:28-38.

As reported in Weber (1979), feral pigeons are not harmless birds and have the potential of transmitting over 30 diseases to humans. Many of these diseases are serious to humans, some can be fatal. Feral pigeons have been identified as transmitting fungal, bacterial, viral, protozoal, chlamydial, rickettsial, and parasitic diseases as well as dermatosis. Many of these diseases can be transmitted from contact with pigeon feces or aerosols carrying the pathogens. These include fungal diseases such as Aspergillosis (*Aspergillus fumigatus*), Candidiasis (*Candida* spp.), Cryptococcosis (*Cryptococcus neoformans*), Histoplasmosis (*Histoplasma capsulatum*); bacterial diseases such as Listeriosis (*Listeria monocytogenes*), Pasteurellosis (*Pasteurella multicida*), Salmonellosis (*Salmonella* spp.), Yersinosis (*Yersinia pseudotuberculosos*), Chlamydial and Rickettsial diseases such as Chlamydiosis (*Chlamydia psittaci*);[35] parasite diseases include Trichomoniasis (*Trichomonas gallinae*) and Toxoplasmosis (*Toxoplasma gondil*); viral diseases include encephalitis, meningitis and Newcastle. Many of these pathogens are also listed in this document in other sections and most can be inactivated by ThermaPure®. Pigeon cleanup in structures has many health-associated risks and ThermaPure® is an efficient process for pasteurization of the space once bulk removal has occurred.

Mold and Fungi Studies in Wood Preservation

Studies on the temperatures required to pasteurize wood products began in the early 20th century. The question of whether treatment processes already used with wood products sustained adequate temperatures and durations to kill fungi was asked by both kiln operators and treatment facilities. It was not a question of whether heat would kill fungi in wood, but rather, what temperatures and durations were required.

Much of the early work done by Chidester (1937)[36] was to determine the depth of penetration of temperature into wood in addition to thermal death rates. This work was important for Drs. Walter Ebeling and Charles Forbes when they first developed the Thermal Pest Eradication (TPE) process in the 1970s. How long does it take a certain surface temperature to result in the specific core temperature required to kill the targeted organism? Ebeling and Forbes were using heat to penetrate into the core of framing timbers to kill drywood termites and other wood-destroying insects. One of the questions they needed answered was how long did it take the core of the timber to reach the thermal death temperature.

Chidester examined three species of wood fungi in her 1937 study. The recommendation of the 1937 Chidester paper was that all three wood fungi species were killed if the core temperature of the wood reached 66ºC (150ºF) for a duration of 60 minutes. Chidester continued her work and in 1939 her presentation to the Wood-Preservers Association included a study of temperatures necessary to kill six wood fungi. The outcome of the study was the same as her earlier work, however one of the new species was more resistant to temperature resulting in a recommendation to increase the duration at 66ºC (150ºF) from 60 to 75 minutes. The species studied were *Poria incrassata (Serpula incrassata), Fomes roseus (Fomitopsis rosea), Lentinus lepideus, Lenzites*

[35] Weber, W., (1979). "Pigeon Associated People Diseases". Wildlife Damage Management, Internet Center for Bird Control Seminars Proceedings. University of Nebraska, Lincoln.
[36] Chidester, M., (1937). "Temperatures Necessary to Kill Fungi in Wood." *Proceedings of the 33rd Annual Meeting of the Wood-Preservers Association*, New Orleans, LA.

trabea (Gloeophyllum trabeum), Trametes serialis (Antrodia serialis), and *Lenzites sepiaria (Gloeophyllum sepiarium)*.[37]

The US EPA has reviewed the literature for heat treatments to control pests on imported timber and has a section in their web site dedicated to the topic. This section, located under Ozone Depletions Rules and Regulations,[38] is a part of the EPA's literature because heat treatment is one of the methods that can be used to control pests without the use of chemicals such as Methyl Bromide. The following quote is taken directly from this section and includes a number of the primary sources for their acceptance of heat treatments:

Based on USDA risk assessments, heat treatments of logs and lumber are considered to be more effective than methyl bromide for providing quarantine security and are considered to be an effective alternative to methyl bromide for the control of quarantine pests (USDA 1996). As a result, the use of heat-based sterilization to control biological pests offers great potential for the imported timber industry. Both moist heat (steam or hot water) and dry heat have been shown to effectively control fungi, insects, and nematodes associated with logs and lumber products (USDA 1991a) (Task Force on Pasteurization of Softwood Lumber 1991, Jones 1973, Baker 1969, Snyder and St. George 1924) (Dwinell 1990, USDA 1991; Ostaff and Cech 1978, Ostaff and Sheilds 1978, Parkin 1973, Department of Scientific and Industrial Research, Great Britian 1957, Snyder and St. George 1924, Snyder 1923)… Heat treatment techniques may include the use of steam, hot water, kilns (lumber only), microwave energy, or any other method that raises the temperature at the center of the log to at a minimum of 71° C (167° F) for at least 60 minutes.

The temperature and duration required by USDA APHIS is stated at 71°C (167°F) for at least 60 minutes. This temperature is recommended because the imported timbers may be infested by a wide variety of pests. Additionally, their research has indicated that "Temperatures up to 82.2°C (180°F) for periods up to one hour do not appreciably affect the properties of wood (USDA 1994a)". Therefore, these temperatures can be successful at eliminating unwanted pests without damage to the timber or wood products.

Pasteurization of Soils for Plant Pathogens

Soil pasteurization is another application of high temperatures to manage unwanted micro-organisms. The practice of soil pasteurization increased during the 1960s after research determined it was effective in reducing plant pathogens, including bacteria, actinomycetes and fungi. Research by Bollen (1968)[39] determined that of these soil micro-organisms, fungi were the most sensitive to soil pasteurization. Bollen performed seven trials and determined the results by species to be fairly consistent. There were too few isolates to determine exact thermal death points, but maximum survival temperatures were determined.

Following are some of Bollen's results. The two charts below present thermal efficacy temperatures in different ways. In the first table, the listed temperature is the point at which the

[37] Chidester, M., (1939). "Further Studies on Temperatures Necessary to Kill Fungi in Wood." *Proceedings of the 35th Annual Meeting of the Wood-Preservers Association*, New Orleans, LA.
[38] U.S. Environmental Protection Agency, "Heat Treatments to Control Pests on Imported Timber". http://www.epa.gov/Ozone/mbr/casestudies/volume2/heatlog2.html
[39] Bollen, G. (1968). "The selective effect of heat treatment on the microflora of a greenhouse soil." *Neth. Journal of Plant Pathology*. 75 (1969) 157-63.

thermal death point has been achieved and would therefore be equal to or slightly below this value. In the second table, the thermal death rate has not been achieved, but it is estimated that it would be within the next five degree increment. These species were described by Bollen as "heat tolerant." All species were exposed to the designated temperature for 30 minutes.

Species Did Not Survive These Temperatures (Thermal death point reached)			
Species	**Temp**	**Species**	**Temp**
Oőmycetes	50ºC/122ºF	*Trichoderma lignorum*	55ºC/131ºF
Preussia fleischhakii	60ºC/140ºF	*Cladosporium herbarum*	60ºC/140ºF
Sordaria spp.	60ºC/140ºF	*Stachybotrys atra (S. chartarum)*	60ºC/140ºF
Sporormia aemulans	65ºC/149ºF	*Fusarium oxysporum*	60ºC/140ºF
Sordaria carbonaria	65ºC/149ºF	*Rhinocladiella mansonii*	60ºC/140ºF
Zygorhynchus moelleri	55ºC/131ºF	*Myrothecium verrucaria*	60ºC/140ºF
Chaetomium spp.	55ºC/131ºF	*Fusarium redolens*	60ºC/140ºF

Maximum Temperature "Heat Tolerant" Species Survived (Thermal death point not reached)			
Species	**Temp**	**Species**	**Temp**
Stemphyium botryosum	60ºC/140ºF	*Penicillium funiculosum*	70ºC/158ºF
Phialaphora mustea	60ºC/140ºF	*Phoma herbarum*	75ºC/167ºF
Penicillium corylophilum	60ºC/140ºF	*Penicillium lapidosum*	70ºC/158ºF
Aspergillus fumigatus	65ºC/149ºF	*Trichocladium piriformis*	80ºC/176ºF

Structural pasteurization temperatures will generally not exceed 71ºC/160ºF. Although higher temperature can be achieved under certain conditions, such temperatures may begin to cause damage to building contents. Some structural materials may be impacted at these temperatures as well. If species are known to be present that are more heat tolerant, the application of ThermaPure® will typically be to attain the highest temperature possible without damage to the structure and contents, and the duration of treatment increased. For example, if *Trichocladium piriformis* were a target with a thermal death in excess of 80ºC/176ºF, the temperature goal would be 71ºC/160ºF but the duration would increase to three or four hours. In these cases, specific efficacy studies would be required to demonstrate the reduced viability of the target organism. This approach would be taken with any of the thermotolerant species.

Compendium of Soil Fungi

The Compendium of Soil Fungi (Reprint 1993)[40] is one of the most important references for soil-borne fungi. The data is a primary reference for mycologists. Following are a few of the references made to thermal death points of some pathogenic fungi. This data was developed through a variety of measurement techniques. Some of the pasteurization temperatures were reached in an apple juice mixture, one was in soil, and one did not have a specific reference as to how the temperature was achieved. Some of these are duplicated in other studies:

[40] Domsch, K.H., Gams, W., Anderson, T. (1993 Reprint). Compendium of Soil Fungi. Vol 1 & 2. Academic Press, London, UK.

Thermal Death Point Listed			
Species	**Temp**	**Time**	**Citation**
Alternaria alternata	63ºC/145ºF	25 minutes, apple juice	Page 37
Aspergillus niger	63ºC/145ºF	25 minutes, apple juice	Page 102
Aspergillus ustus	62ºC/144ºF	25 minutes, none	Page 119
Stachybotrys chartarum	60ºC/140ºF	30 minutes, in soil	Page 745

Recent Structural Pasteurization Publications and Resources

There has been considerable excitement over the ThermaPure® process in various publications over the past couple of years. Numerous articles have appeared in professional trade journals addressing the concepts of structural pasteurization and the successes of ThermaPure®. According to John Apgar, ThermaPure®'s public relations manager, in the last twelve months there have been ninety-one articles either published or scheduled for publication in a variety of electronic and hard copy publications.[41] These publications range from industry magazines such as Insurance Journal, Pacific Builder and Engineer, Risk Management, Claims, and Construction News to consumer publications such as Better Homes and Gardens and Consumers Digest. Articles have been published in environmental, construction, lodging, property management, pest control, risk management, insurance, HVAC, and building management journals. ThermaPure® can be successfully deployed in any type of structure. These publications are representative of the businesses, the markets, and the pests that can be managed by the proper application of structural pasteurization.

Efficacy Arguments through Research Literature

The literature demonstrates that there are an abundance of research studies in which mesophilic micro-organisms were subjected to various levels of heat or combinations of heat and other processes resulting in thermal death. The process of pasteurization has been used for management of pathogens in food products, soils, timber, and waste management. All of these applications demonstrate that pasteurization temperatures from 60-70ºC (140-158ºF) and durations of seconds to hours will successfully reduce most mesophilic pathogens to levels safe for humans. Even thermo tolerant species, such as *Aspergillus fumigatus*, are susceptible to a combination of temperature and duration that will be successful in reducing their viability to acceptable levels. Applied to a structure, pasteurization will also reduce both mesophilic and thermo tolerant organisms to safe levels. It is not a question of whether high temperatures applied to a structure will kill the pathogens, but whether or not the application of high temperatures was correctly performed. Efficacy, therefore, is not a question of thermal death points, but rather a question of appropriate application.

The application of ThermaPure® provides the additional tool of aerosol generation and capture resulting in a more thorough disinfection or sanitization of the space. Structural pasteurization is the result of the combination of reaching the target thermal death point and duration and the air scrubbing to reduce particulate and bioaerosol. The next section of this paper will show how ThermaPure® licensees have successfully used this process.

[41] Apgar, J. (2006) Personal communication dated December 22, 2006.

III. Implementation of Structural Pasteurization by ThermaPure® Licensees

Overall Experience of Licensees