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Literature Review and Assessment of Current Knowledge

Impact of Mold and Contaminated Floodwater on Selected Home Building Materials

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EXECUTIVE SUMMARY

This report summarizes a literature review and assessment of current knowledge of the effect of flooding on mold initiation and growth as well as the impact of floodwater-borne pollution on building materials. The assessment was performed in a systematic way in accordance with guidelines provided by the Resilient Home Program, lead by the Savannah River National Laboratory, of which this project was a part. The analysis was divided into two categories; these were mold and bacteria growth in building materials and floodwater-borne pollution impacts on building materials. This information was summarized in a tabular form.

The assessment of current knowledge found relatively little information directly related to these topics and even less that was based on scientific observation or experimentation. Personal anecdotal observations and discussions on the periphery of the topic were a major portion of the findings from the literature review. This lack of definitive information makes it difficult to develop appropriate remediation guidelines for flooded homes. Without remediation guidelines based on scientific knowledge, the repair of flooded home might require both extensive and perhaps unneeded efforts, or may not adequately address issues that could become long-term problems for the homeowner.

This report concludes that the "gaps" in our current knowledge are sufficiently critical to require further scientific investigation to close them. An initial step at addressing this deficiency is discussed.

In addition to the literature review and assessment of current knowledge, this work also led to the development of a brochure entitled "Mold Prevention and Treatment in a Water Damaged Home" (Appendix A), and a master's thesis and two journal articles (Appendix B).

1.0 INTRODUCTION

1.1 Background

Floods can have a destructive effect on building materials. Significant problems can occur from the mold, bacteria and/or water-borne pollution in the flood effected buildings. Flood conditions contribute to the growth of many kinds of mold, which can cause damage to building materials as well as different types of health problems for the building occupants.

Mold may cause different health problems that can be categorized as either short-term or long-term effects. Short-term effects include irritation and general symptoms such as rhinitis, sore throat, hoarseness, cough, phlegm, shortness of breath, eye irritation, eczema, tiredness, headache, nausea, difficulties in concentration, and fever. Long-term effects include infections such as common cold, otitis, maxillary sinusitis, and bronchitis, allergic diseases such as allergy, asthma, and alveolitis. Some molds cause toxic effects. The toxin affect is called mycotoxins. The toxin effects become exaggerated when a person is exposed to mold over time.

Different floodwater-borne pollutions also appear in flood-affected buildings and can potentially render the buildings harmful to the occupants. Floodwater can deposit a wide range of chemicals and heavy metals on building materials during a flood. These can range from pesticides, household chemicals, and petroleum products to lead, arsenic and other potentially toxic materials. Unfortunately, while these pollutants can be identified on building materials there are few studies that scientifically relate the impact of these pollutants at concentrations found in flooding to human health effects.

1.2 Purpose

The purpose of this report is to identify and summarize the available information about the impact of mold, bacteria and floodwater-borne pollution on common building materials. Based on the available information, gaps in our knowledge were identified that could be closed through further research and investigation. This report summarizes a literature review and assessment of current knowledge of the effect of flooding on mold initiation and growth, as well as floodwater-borne pollution on building materials. An initial step at addressing this deficiency was developed.

1.3 Scope

This report covers two areas of investigation; mold and bacteria growth in building materials, and floodwater-borne pollution in building materials. The materials selected for investigation are common residential building materials that have all been seen in floods to have issues with either mold or contaminated floodwater. They are considered “semi-porous” – able to absorb and hold water – and therefore are more likely to be adversely impacted by floodwater than non-porous materials such as metals, glass and some plastics. It was assumed that since these materials were most affected, that this is where the bulk of the literature would be focused.

1.4 Participants

The results of this report were developed by Tuskegee University in accordance with guidelines provided by the Resilient Home Program, lead by the Savannah River National Laboratory, of which this project was a part. The Tuskegee University team for this project consisted of professors Dr. Heshmat Aglan, Mr. Robert Wendt, Dr. Dave Sree, and Dr. Chadia Aji, and students Titan Paul (graduate student of Mechanical Engineering) and Amber DuBose (undergraduate student of Architecture).

1.5 By-Products of the Study

In addition to the literature review and assessment of current knowledge, this work has also led to the development of a brochure entitled "Mold Prevention and Treatment in a Water Damaged Home" (Appendix A), and a master's thesis and two journal articles (Appendix B).

2.0 MOLD GROWTH ON BUILDING MATERIALS EXPOSED TO FLOODING

2.1 Mold Growth on Flooded Building Materials

Flooded homes are usually associated with excess moisture, long periods of heat and humidity, and pools of water. All of these factors contribute to conditions that can result in mold growth in the building materials. Mold is a microscopic organism. The growth of mold in buildings requires the presence of organic building materials that can be a nutrient base for the mold, extended periods of high moisture, and ambient temperatures that will support mold growth. This is shown in Figure 1 from a home inundated for three weeks in New Orleans, LA after Hurricane Katrina.

Figure 1. Significant mold growth occurred in a New Orleans, LA home after Hurricane Katrina and related the flooding

2.2 Environmental Conditions for Mold Growth

Oxygen-rich environments with humidity over 70% and temperatures above 60ºFahrenheit are ideal for mold growth, which happen to also be ideal temperatures for human comfort. Different types of molds have minimum, optimum, and maximum temperature range for growth. Most of the molds grow in a temperature range of 50^{o}F to 90^{o}F (10^{o}C to 32^{o}C) and a relative humidity level above 60%, which happen to coincide with conditions that are also suitable for human comfort (Traudt “Mold”) as shown in Figure 2. The temperature and relative humidity combination also affects the mold growth time and growth rate.

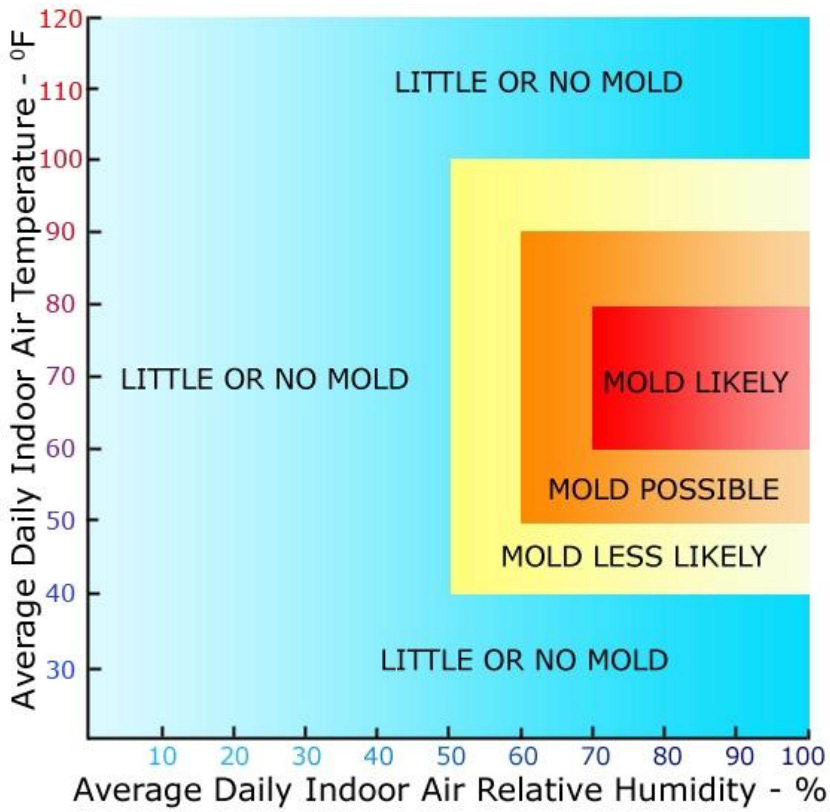

Figure 2. Mold is likely at certain temperature and humidity levels (red zone) and diminishes as the temperature and relatively humidity move away from the optimum levels (blue zone)

2.3 Food Sources Stimulating Mold Growth

Other than the sufficient temperature and relative humidity mold also needs a food source. Wood, ceiling tiles, wallpaper, paint, carpet, gypsum wallboard, some insulation, etc. are suitable food sources for mold. In wood based materials a moisture content of 20% and above is critical for mold growth (Pasanen et al., 2000).

Mycobacteria are common in moisture-damaged buildings and their occurrence increases with increasing degree of mold damage (Torvinen et al., 2006). The microorganisms are the fungi, tiny particles from mold and the insects are bacteria, termites, and animals. Fungi and bacteria are non-chlorophyllous, that means that they cannot produce their own food from basic materials like carbon dioxide and water. So they take food from the organic building materials (Ashton, 1970). Sometimes amoebae are also present in the mold damaged building materials and may be a part of complex microorganism contamination associated with health symptoms in moisture-damaged buildings (Yli-Pirila et al., 2004). These organisms were not investigated in the current study but should be examined in future work.

2.4 Mold Growth on Gypsum Products

Gypsum products have been proven to be susceptible to mold, decay, and termite damage (Fogel and Lloyd, 2002). The following are findings from the literature on the impact of mold on gypsum building materials:

- Moisture is the main factor to mold growth on gypsum wallboard. Gypsum wallboard readily absorbs moisture through direct contact with standing water and differences in water vapor pressure (Greenwell and Menetrez, 2004).

- As a result of manufacturing process gypsum wallboard contains a lot of pores and interstitial space. Within these spaces moisture will penetrate and accumulate to reach equilibrium with the surrounding environments (Greenwell and Menetrez, 2004).

- Most wallboard remediation techniques involve visual inspection and moisture content measurements to determine the extent of water damage and the presence of or potential for mold growth. Gypsum wallboards contain unbound water that increases the moisture content (Greenwell and Menetrez, 2004).

- Conventional gypsum wallboard is characterized by a sheet of gypsum covered by a thin layer of paper; the paper constitutes a virtual buffet upon which any number of fungi may feed and flourish. Indoor air quality has a significant impact on mold growth on gypsum wallboard (Maine, 2006).

- The behavior of moisture is complex in gypsum board, which makes interpretation of moisture measurements difficult; microbiological state of the material cannot be concluded reliably on the basis of momentary moisture measurement (Pasanen et al., 2000)

- Toxic mold likes to eat the paper covering of sheetrock. Both the front and backsides of sheetrock are covered with paper (Lopez and Sothern, 2005).

- Mold growth on gypsum plaster is commonly found along the bottom of exterior walls in older homes. This is most often a result of poorly insulated walls. Molds tend to begin growing when warm, humid air is allowed to condense on the cooler wall surface (Environix “Case Studies”).

2.5 Mold Growth on Wood

Wood is a biological material consisting primarily of cellulose, lignin and hemicelluloses. At high moisture content (20%), mold can be established on wood in 24–48 hours if temperature and humidity conditions are optimal (Clausen and Yang, 2005). All wood studs and joists are also subject to display visible mold growth (Morrell, 2002). Annual losses of over 1 billion US dollars result from fungal deterioration of untreated or inadequately treated wood (Clausen and Yang, 2007).

Under the proper conditions, wood may be colonized by a variety of fungi. Most of these fungi are common to many other materials, while a few are specialized and only grow on wood. Molds and stain fungi are the most rapid colonizers of freshly exposed wood. Molds are typically characterized as fungi that discolor the wood surface through production of pigmented spores that can be yellow, green, orange, black and an array of other colors. Stain fungi discolor the wood more deeply and are not as easily removed. Decay fungi may also grow when wood products are exposed to chronic moisture. Decay fungi attack beyond the surface of the wood into the structural polymers of the fiber, reducing its strength. The most common effect of mold attack on wood is an increase in permeability, which can lead to an increase in moisture or paint uptake (Robbins and Morrell, 2006).

Wood decay can be controlled by separating wood from moisture, using preservative-treated wood, using naturally decay-resistant wood, and applying protective wood finishes (FEMA, 2005). Lumber, which is an organic material, to be used in construction can be treated to control the growth of decay fungi (Fogel, 2002).

2.6 Mold Growth on Lime Plasters and Mortar

The porosity of the lime allows moisture to evaporate out of walls rapidly and control mold growth. Stachybotrys chartarum, Penicillium chrysogenum, Aspergillus versicolor, Trichoderma viride are types of mold that typically grow on the plaster board (Wilkins, 2000).

2.7 Mold Growth on Concrete and Concrete Blocks

Concrete block products are most frequently used for interior partition walls, exterior walls (especially load-bearing) and foundations and basements (Masonry Canada, 2004). A concrete wall system is not itself a food source for mold growth. Basements and concrete foundations can provide great conditions for mold growth. Organic materials such as floor decking, paper faced drywall and carpet are used inside concrete homes. These products can support mold growth and should be treated accordingly (Environix “Case Studies”).

Alternaria alternata, Cladosporium, spherospermum, Stachybotrys chartarum, Ulocladium tuberculatum, Aureobasidium pullulans are types of mold that grow on concrete when an external food source (dust/dirt, scum from floodwater) is present (Gutarowska, 2002). Depending on the concrete mix and detailing, the extent of mold growth varies.

2.8 Mold Growth on Ceramic Insulation

Fiberglass building insulation can be problematic for black mold growth. Penicillium and Aspergillus spores are types of mold that may typically be found in fiberglass insulation (Friedman, 2007). Nu-Wool insulation will resist the growth of mold even when exposed to conditions favorable to mold growth (Nu-Wool “Mold Resistant”). The high isolation rate for ceramic products indicates that mycobacteria are capable of adapting to alkaline conditions (Torvinen et al., 2006).

2.9 Mold Growth on Clay Brick

Clay brick does not itself support fungal mold growth (Masonry Canada, 2004). However residual scum from flood water or dirt on the face of the brick can provide food for potential mold growth on the face of the bricks. More porous "common" bricks will hold more moisture and will tend to have more mold growth than less porous "face" bricks. Ambient conditions (temperature and humidity) must also be favorable for mold to develop on clay brick.

2.10 Removing Mold from Building Materials

A wet wire brush (detergent 10% bleach solution) is recommended to remove discoloration and precipitate deposits (efflorescence) on clay bricks (Lopez and Sothern, 2005). Visible mold on gypsum wall board can be removed using household bleach (25% by volume), and tri-sodium phosphate (5% by volume) base on the study reported by (Aglan and Wendt 2005). Although no mold appeared to return on gypsum wall board throughout the test period (few months), long term elimination of active mold as well as "killed" mold spores has not been verified in this study. Porous (carpet, fabrics) and semi-porous (gypsum) materials are recommended for removal and replacement when they are exposed to flood water (ANSI/IICRC S520, 2008). Non-porous materials (plastics, metals, glass) can be effectively cleaned of mold and its residue by following recommended practices. The initial focus should be on reducing the potential for mold growth by initiating drying as soon as possible after the event, by cleaning the structure and removing non-salvageable contents quickly, and by controlling the interior environment (temperature, humidity, and air flow). Professional judgment is required to make the decision whether to replace porous and semi-porous materials that have not yet developed active mold growth. Chemicals that effectively kill mold spores do not typically remove them – that requires scrubbing, pressure washing or other means to mechanically remove them from the materials. Dead spores can be equally toxic to live ones but do not reproduce if ambient conditions return to optimal for mold growth (ANSI/IICRC S520).

Specific steps for mold removal are given below and are also presented in Appendix A.

- Porous materials with visible mold growth should be removed rather that treated. Porous materials include: paper-faced gypsum board, ceiling tiles, fabrics, cardboard, chipboard, OSB, and other similar materials. It is possible to kill mold and bacteria on these materials, but it is difficult to remove the residual mold and bacteria materials which can also produce adverse health effects.
- Commercial mold removers or bleach eliminate visible evidence of mold growth on non-porous surfaces. Tests have found little or no mold growth in the non-exposed (hidden) portions of walls when the flood was several days duration and the walls were able to completely dry. Treatment of the non-exposed portions of walls is not warranted in many cases.
- Bleach is convenient and frequently suggested material for mold control. It is appropriate as a sanitizer for non-porous items after they have been thoroughly cleaned. Its effectiveness at killing bacteria and mold is significantly reduced when it comes in contact with residual dirt left by the flooding. Bleach water can cause corrosion of the home's electrical components and metal parts of mechanical systems, and can also reduce

the effectiveness of termite treatments in the soil surrounding the building. These risks should be considered when using it.

- Moldy surfaces should be cleaned thoroughly first and then disinfected. Residual mold spores should then be removed by added cleaning, since killing them does not reduce their toxicity. Scrub all affected hard surfaces: first with a mild detergent solution, such as laundry detergent and warm water. Then use a commercial mold remover according to the label directions or a solution of 1/4 cup (or more for heavy mold) of bleach to one quart of water. Spraying vertical surfaces using a compression (pump-up) garden sprayer is recommended. Wait 20 minutes and repeat this process.
- After another 20 minutes apply a borate-based detergent solution (read the ingredients listed on the package label for borates) and do not rinse. This will help prevent mold from growing again.

3.0 FLOODWATER-BORNE POLLUTANTS ON BUILDING MATERIALS

3.1 Effects of Water Borne Pollutants on Flooded Building Materials

Flooded buildings can be affected by water-borne pollution and chemical contamination. In the literature, the effect of flood water contaminants on construction materials is rarely described, although a very important consideration. To study the effect of flood-borne contaminants, members of FEMA's New Orleans Mitigation Assessment Team used building material samples for lab testing (FEMA, 2006) (see Figure 3). Samples were analyzed for chemical contaminants: heavy metals, hydrocarbon contamination (diesel range organics DROs), pesticides, and polychlorinated biphenyls (PCBs). Wet and dry sludge samples, as well as wall materials above and below water level, were analyzed for these chemical contaminants. These analyses for flood-borne contaminants were applied only on wall materials below and above water level and wet and dry sludge. Those shown in red in Figure 3 exceed EPA's Risk Evaluation/Corrective Action Program (RECAP) levels and were considered because of concern over their potential impact on occupant health.

Element	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
RECAP Value (μg/kg)	3,100	12,000	16,000	3,900	23,000	310,000	400,000	2,300	160,000	39,000	39,000	550	2,300,000
Wet Sludge	650	17,000	850	42,000	25,000	81,000	130,000	260	130,000	14,000	BMDL	350	4,800,000
Dry Sludge	BMDL	9,700	1,200	2,400	33,000	64,000	170,000	63	26,000	BMDL	1,200	BMDL	750,000
Wall Materials Below Water Line	650	17,000	850	42,000	25,000	81,000	130,000	260	14,000	1,800	350	BMDL	4,800,000
Wall Materials Above Above Line	BMDL	1,900	120	160	4,400	4,800	390	89	26,000	1,800	BMDL	BMDL	11,000
Wet Sludge	BMDL	23,000	430	5,700	14,000	62,000	120,000	BMDL	130,000	BMDL	320	BMDL	2,300,000
Dry Sludge	No Sample												
Wall Materials Below Water Line	BMDL	560	BMDL	BMDL	1,400	610	2,500	ISFA	8,100	BMDL	BMDL	BMDL	23,000
Wall Materials Above Above Line	300	1,100	1,400	BMDL	1,400	540	750	BMDL	8,200	BMDL	BMDL	BMDL	4,000
Wet Sludge	No Sample												
Dry Sludge	2,300	60,000	760	10,000	36,000	220,000	240,000	140	18,000	3,100	870	340	32,000,000

Figure 3. Data collected by FEMA in New Orleans after Hurricane Katrina provides most of the available information on flood-borne contaminants within buildings

3.2 Factors Influencing the Extent of Damage from Water-Borne Pollutants

The major features of flooding that impact the extent of damage are the flood depth, duration, and contaminant type and concentration in the flood water. The type and concentration of potential flood-borne contaminants is an essential determinant in selecting a building material for its suitability.

Building materials can be influenced by the chemical structure of the water. For instance, the water could be saline or possibly contain numerous contaminants like sewage or toxic chemicals. Metals of various compositions in close proximity to one another in the presence of water are sensitive to corrosion. As the salinity of water increases, the amount of corrosion increases as well. In addition, according to (FEMA, 2006), multiple floodwater samples revealed higher bacteria levels from floodwaters that had come in contact with sewage collection system waters.

Chemicals found in floodwater, and thus in building materials, after a flood may have originated from chemicals stored in homes, businesses, industry etc. Petroleum and oil products can enter floodwaters via flood-damaged storage tanks and motor vehicles. Oil-type products can disperse swiftly, and due to their density, these pollutants can float on the water's surface. As floodwaters subside, a film of insoluble petrol products often adhere to building materials on account of their sticky substance and tendency to attract particulates. The reparation costs of oil-damaged buildings were three times the reparation costs of buildings unaffected by petrol products (Wingfield et al., 2005).

3.3 Water-Borne Pollutants on Gypsum Products

Gypsum products have been proven to be susceptible to water borne pollutants. Literature findings show:

- Prolonged water exposure will cause the paper to delaminate from the gypsum core of plasterboard. However, water resistant grades of plasterboard are commercially available (USG "Moisture and Mold Solution").

- Gypsum wallboard will fall apart if it is bumped before it dries out (Kane County, 2005).

- Gypsum samples have been tested in the literature for: 1) heavy metals (e.g., antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); 2) hydrocarbon contamination (e.g., Diesel Range Organics (DROs)); 3) pesticide contamination (e.g., chlordane, alpha-chlordane, gamma-chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, and heptachlor); and 4) PCB (polychlorinated biphenyls) contamination. No PCBs were detected in the samples (FEMA, 2005). Interior gypsum board walls dried out and maintained flexural strength. If gypsum board is able to dry completely within an appropriate time it can be restored to preflood condition with cosmetic restoration (Aglan and Wendt, 2005).

- Limited data is available on exposure of gypsum board to oil and sewage during flooding (Aglan and Wendt, 2005).

3.4 Water Borne Pollutants on Lime Plasters and Mortar

Lime plasters and mortar products have shown susceptible to water borne pollutants. Literature findings show:

- Lime plasters allow more water vapor transmission through the walls, which aids the drying process. Lime mortar will allow cyclical movement of a building without any major cracking (Scott, 2005).

- Lime plasters and mortar samples have been tested in the literature for: 1) heavy metals (e.g., antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); 2) hydrocarbon contamination (e.g., Diesel Range Organics (DROs)); 3) pesticide contamination (e.g., chlordane, alpha-chlordane, gamma-chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, and heptachlor); and 4) PCB (polychlorinated biphenyls) contamination. No PCBs were detected in the samples (FEMA, 2005).

3.5 Water-Borne Pollutants on Concrete and Concrete Blocks

Concrete and concrete blocks are subject to water borne pollutants. Literature findings show:

- Resistance of concrete to moisture ingress is related to its porosity and the degree of continuity between the pores (Illston, 2001).

- Lightweight concrete blocks are susceptible to cracking after a flood due to expansion on wetting and drying shrinkage (Crichton, 2003).

- Drying time is essential for all types of concrete blocks including autoclaved aerated concrete block; calcium silicate brick; lightweight aggregate concrete block; dense aggregate concrete block; and common concrete brick (Bowker et al., 2007).

- Neutron radiography can be used to determine the height of water and fuel oil absorbed for certain types of concrete (Hanzic and Ilie, 2003).

3.6 Water-Borne Pollutants on Insulation

Insulation is also subject to water borne pollutants. Literature findings show:

- Low water absorptions are likely for Extruded Polystyrene (XPS), Expanded Polystyrene (EPS), and for polyurethane (Blaga, 1974a & 1974b). This characteristic resists contaminations of the insulation.

- It can be difficult to dry and recover mineral wool and fiberglass batt insulation (Crichton, 2003).

- Insulations have been tested in the literature for: 1) heavy metals (e.g., antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); 2) hydrocarbon contamination (e.g., Diesel Range Organics (DROs)); 3) pesticide contamination (e.g., chlordane, alpha-chlordane, gamma-chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, and heptachlor); and 4) PCB (polychlorinated biphenyls) contamination. No PCBs were detected in the samples (FEMA, 2005).

- Fiberglass batt insulation appears to retain moisture after floods when located in the exterior wall cavities and below the subfloor (Aglan and Wendt, 2005).

4.0 CONCLUSIONS AND FOLLOW-ON ACTIVITIES

Among all of the natural disasters flooding has the most hazardous post-disaster conditions. Floods cause a vast impact on the environment and society. The effects on common building materials come during and after the flood. During the flood there are different water-borne contaminants that spread with the flood water. This water-borne contamination may affect building materials like gypsum wallboard, wood, insulation, clay brick etc. Due to the floodwater the moisture content of the building materials increases. Moisture is the main cause of material degradation in a building envelope. The effects that moisture has on construction materials can be classified as resulting in physical, chemical, and biological damages. Mold and other microbiological organisms tend to thrive in the excessive moisture that occurs after a flood. There are many health problems that can be caused by mold.

Despite the significance of these impacts, the assessment of our current knowledge found relatively little information directly related to these topics and even less that was based on scientific observation or experimentation. Personal anecdotal observations and discussions on the periphery of the topic were a major portion of the findings from the literature review as can be seen in Sections 2 and 3. This lack of definitive information makes it difficult to develop appropriate remediation guidelines for flooded homes. Without remediation guidelines based on scientific knowledge the repair of a flooded home might either require extensive and perhaps unneeded efforts, or may not adequately address issues that could become long-term problems for the homeowner.

This report concludes that the “gaps” in our current knowledge are sufficiently critical to require further scientific investigation to close them. An initial step at addressing this deficiency was proposed as a follow-on project, entitled: *“Effective Mold and Contaminant Remediation for Flood and Water Damaged Homes”.* This project was approved and begun in late 2009. It is a collaborative effort between Mississippi State University, Tuskegee University, and Savannah River National Laboratory. The project will investigate the impact of both mold and floodwater-borne contaminants on some of the materials listed in Sections 2 and 3. It will also investigate the effectiveness of various remediation strategies on these materials. While not addressing all potential materials, hazards and circumstances it will provide a first step with scientific investigation that can lead to further studies to begin to close the numerous gaps in our current knowledge.

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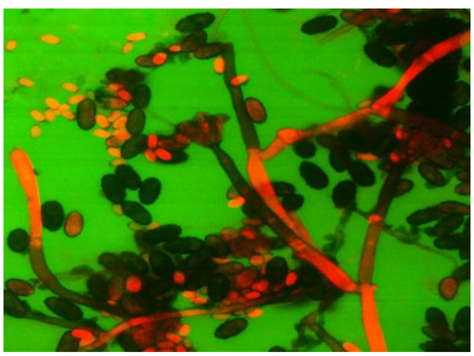
APPENDIX A

Mold Prevention and Treatment in a Water-Damaged Home

This guide describes what the homeowner can do to help prevent mold or treat it effectively should it occur in their water-damaged home after floods, storm damage to the structure, a broken water line, or a backed-up sewer.

What are molds and why are they a problem?

Molds are microscopic organisms that produce enzymes to digest organic matter and spores to reproduce.



Household mold viewed through a microscope

Molds thrive in warm and humid conditions, but you can find them year-round in virtually every type of environment. Molds need moisture to begin growing and digesting whatever they are growing on.

In addition to a "musty" smell, molds can adversely impact occupant health. When molds are disturbed, their spores may be released into the air. Some individuals, especially those who have existing health concerns, may be sensitive to mold exposure. If you have allergies or asthma, you may experience skin rash and itching, running nose, eye irritation, cough, congestion, and aggravation of asthma.

More serious effects may result from mold exposure, including fever, flu-like symptoms, fatigue, respiratory dysfunction (including coughing-up blood), frequent and excessive nose bleeds, dizziness, headaches, diarrhea, vomiting, and liver damage.

How to prevent mold in a water-damaged home

The "Mold Zone"

For molds to grow they need adequate moisture, appropriate temperatures, and "food." Removing any or all of these factors in a timely manner can prevent the occurrence of mold in water-damaged homes.

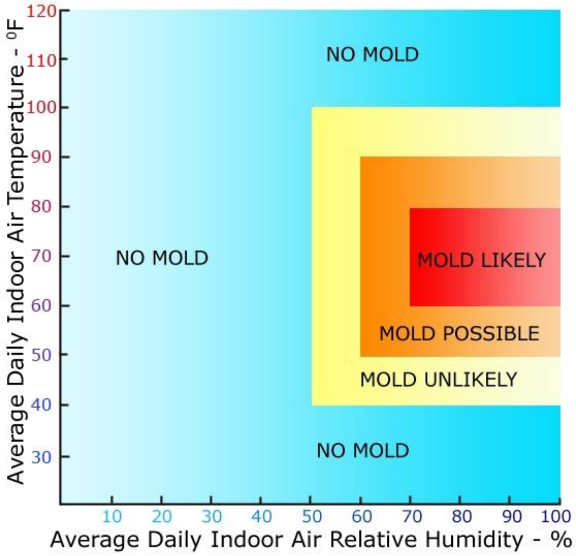
When excess moisture (average daily relative humidity above 70%) occurs in your home for an extended period due to a damaged roof, broken water pipe, or flooding, interior conditions are often ideal for molds.

Molds prefer average daily temperatures of 50-90^{o}F and grow most vigorously in the 60-80^{o}F range. Unfortunately, this is also the same temperature range that humans prefer.

Molds can grow on wood, ceiling tiles, wallpaper, paints, carpet, sheet rock, insulation, as well as the scum left by flooding which provide "food" on other materials.

Getting out of the "Mold Zone"

The best way to prevent mold development is to get your home out of the "mold zone" as quickly as possible. This involved three steps:



The "Mold Zone" – getting your house into the light blue and keeping it there is key to preventing mold

- Start the home drying process as soon as possible
- Reduce/remove mold's food sources
- Control the home's interior relative humidity and temperature

To avoid mold you should begin the clean up process as soon after the water damage event as possible.

Steps to follow to clean up water-damaged home

If you are uncertain as to how to proceed, consider using professionals (See – Choosing Professional Help). If you decide to do it yourself follow the guidance below.

First steps

- Act quickly when water damage occurs. You can minimize the potential for mold by responding to the situation quickly and thoroughly. Water damaged materials left unattended frequently results in mold growth.
- If water is from a burst pipe or damaged appliances, shut off the home's water supply valve.
- Immediately remove standing water and all wet materials.
- If your home was damaged by a flood or storm, take appropriate actions to prevent further water damage once it is safe to do so. This may include boarding up damaged windows, or covering a damaged roof with plastic sheeting.

Start the drying process

- To promote drying, open all exterior doors and windows whenever you are present and leave as many open when you are not present, as security will permit. Upper floor windows can usually be left open all the time and will also assist in drying the whole house. Try to take advantage of cross-ventilation by opening windows on multiple levels and opposite sides of the building.
- Open all interior doors, especially closets and interior rooms, to allow air movement to reach all areas of the building.
- Take interior doors off their hinges if necessary to promote air-flow. Don't open doors so that they are against a wall, as this will slow drying behind the door.
- Open kitchen cabinet and bathroom vanity doors; remove drawers and stack them to dry.
- Open the attic access, if available, to increase ventilation.
- When electricity is available, use fans to move moist air outside and air into the house. However, avoid use of fans if the house is contaminated with sewage as the air movement may spread bacterial contamination.
- Use residential dehumidifiers, if needed, to assist in the drying of the interior portions of the house or when the windows are closed up.

Choosing Professional Help

To find a professional, look in your Yellow Pages under "Fire and Water Damage Restoration". Not all firms are equal so look for evidence of their training, certification, and years of experience working on problems like yours. Check out their references. After major natural disasters inexperienced and potentially unqualified firms appear – be wary. Doing it "right" is important to your long-term satisfaction.

Remove wet items

- Remove saturated porous materials such as rugs, drapes, mattresses or upholstery. Move them out of the building as soon as possible. Cover contaminated items with plastic drop cloths prior to moving to prevent spread of contaminants.

- Remove wet carpet and padding. Tack strips should also be removed to minimize potential injury during subsequent activities.

Cleaning

- Remove mud and gross contamination from floors by shoveling into suitable containers. Reduce soil and contaminant levels on surfaces by flushing off with clear water. The fastest and most efficient method to clean and decontaminate materials and surfaces is by using a residential-type pressure washer to apply a cleaner-disinfectant solution to the affected areas. Brushes improve decontamination of floors and some walls by scrubbing solution into affected surfaces. Avoid scrubbing drywall and plaster walls at this time because they have become softened by the flooding and moisture and may have their surface damaged by scrubbing. Following the first cleaning, floors and walls should be rinsed with water and then cleaned a second time. Squeegees and wet vacuums can be used to remove spent solution.

What to do should mold occur

Even with fast and effective action mold may develop in portions of, or the entire water-damaged home. Should this occur the following steps will eliminate mold problems.

Be realistic about your limitations

- Even initial assessment and salvage can be hot, heavy work. If at all possible, work with another person while in the house. Unforeseen hazards can exist, so having help nearby is prudent.
- Consider having a professional cleanup the area. If you decide to clean up on your own, follow the guidance below.

First steps

- Protect yourself by using goggles, gloves, and breathing protection while working in the area. You should use an OSHA (Occupational Safety & Health Administration) approved particle mask.
- Seal off the damaged area from the rest of your home. Prior to beginning tear out of water damaged materials, install plastic barriers between affected and unaffected areas of the home (typically between the first and second floors). This will reduce the potential for secondary damage occurring in the unaffected areas. Cover heat registers or ventilation ducts/grills.
- Remove all your furnishings to a neutral area to be cleaned later.
- Bag in plastic all moldy materials you will be discarding.

Cleaning

- Following any necessary tear out, clean up any remaining debris and muck. Squeegees, shovels, and brooms are effective for such cleaning. Personal protective equipment should be utilized. Detailed cleaning and sanitizing of the remaining materials should be conducted. Use a shop vacuum with filters in place and with a solution of clean water and disinfectant in the tank (2-inch depth) to minimize the spread of dust.

Mold removal

- Treatment with commercial mold removers does eliminate visible evidence of mold growth on exposed surfaces and is recommended for restoring water-damaged homes. Tests have found very little or no evidence of mold growth in the non-exposed (hidden) portions of the walls for floods of several days duration. Treating the non-exposed portions of the walls for mold control does not appear warranted in most cases. Spraying vertical surfaces using a compression (pump-up) garden sprayer with a commercial mildew remover is recommended.

Mold growth can be very heavy as in New Orleans after Hurricane Katrina

More typical mold growth is seen in the Tuskegee University test house.

- Understand the limitations of bleach. While this material is convenient and appropriate as a sanitizer for hard, non-porous items after they have been cleaned, it has distinct drawbacks when cleaning flood-impacted buildings. Application of bleach water can cause corrosion of electrical components and other metal parts of mechanical systems, and can compromise the effectiveness of termite treatments in the soil surrounding the building. Its effectiveness at killing bacteria and mold is significantly reduced when it comes in contact with residual dirt.
- Moldy surfaces should be cleaned first and then disinfected. Residual mold spores should then be removed by added cleaning, since killing them does not reduce their toxicity. Scrub all affected hard surfaces: first with a mild detergent solution, such as laundry detergent and warm water. Then use a commercial mold remover or a solution of 1/4-cup bleach to one quart of water. Wait 20 minutes and repeat.
- After another 20 minutes apply a borate-based detergent solution and do not rinse. This will help prevent mold from growing again. To find a borate-based detergent, read the ingredients listed on the package label for borates.

Drying

- Once the cleaning process is completed, the building and any remaining contents need to dry. Over time, all wetted building materials will dry.
- Exterior rooms with excellent ventilation can take 2 to 4 weeks to dry, depending on the temperature and humidity outside. Interior rooms, or those with minimal ventilation, can take 4 to 6 weeks or more to dry and are candidates for the use of mechanical drying equipment. The use of fans, dehumidifiers, air conditioners, and/or auxiliary electric heaters will speed drying.
- Failure to allow for adequate drying prior to reconstruction can trap moisture in the building, which can cause rot and mold problems in the future. Be sure to check the moisture content of materials before enclosing them in reconstruction.

Control of future mold problems

- There is no practical way to eliminate all molds and mold spores in the indoor environment. The easiest way to control indoor mold growth is to control moisture and keep the house out of the "mold zone".
- Reduce indoor humidity by venting to the outside bathroom exhaust fans, range hoods, clothes dryers, and any other moisture-generating sources.
- Use air conditioners or residential dehumidifiers to reduce indoor humidity during periods of high outdoor humidity.
- In areas where there is a perpetual dampness like basements avoid installing carpeting, ceiling tiles and other materials that can retain the excess moisture.
- Keep your home in good repair to avoid incidences that could bring unwanted moisture into your home.

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Sources for this guide: *Centers for Disease Control & Prevention; Federal Emergency Management Agency; Institute for Business and Home Safety; National Center for Environmental Health; Savannah River National Laboratory; Tuskegee University; U.S. Department of Housing and Urban Development; Washington State Department of Health*

APPENDIX B

Abstracts of Related Work at Tuskegee

MOISTURE MIGRATION IN BUILDING ENVELOPES AND ITS IMPACT ON INDOOR AIR QUALITY (IAQ) *(M.S. Thesis)*

T. C. Paul – Mechanical Engineering Department, Tuskegee University

Abstract

Moisture in building envelopes can contribute to unhealthy indoor air quality, mold/fungal growth, wall deterioration, and eventual structural damage. It is therefore important to understand moisture migration in buildings influenced by environmental conditions. In the present work, the Tuskegee Healthy House (THH) was used as an experimental test bed to study and evaluate the indoor air quality including moisture migration behavior. Different studies are carried out in the research work.

Heat and moisture migration modeling was done by using the WUFI software, which is designed to calculate heat and moisture transport in one-dimensional multi-layered building components for a given input of wall and weather conditions. Here the study involves both the experimental and simulation work. In experimental work the indoor temperature and relative humidity were measured by using the dual temperature/relative humidity sensors and weather data from nearby weather station. The results show a good agreement between the experimental data and the simulated data in terms of the indoor and outdoor temperature and relative humidity. WUFI simulation also revealed that the foam board sheathing used in the THH wall construction has a much lower moisture content in comparison with the oriented strand board normally used in conventional wall construction. It is believed that the use of foam board sheathing can lead to potential reduction of mold growth on the interior surfaces.

Effect of induced ventilation fresh air on Indoor Air Quality (IAQ) was also studied. Experiments were conducted keeping the outdoor weather conditions almost identical during the "fan OFF" and "fan ON" periods. The experiment was carried out during the summer month of August 2008. Results show that the effect of mechanically induced ventilation ("fan ON" period) is to raise the indoor RH, interior wall moisture content, and indoor dust particle concentration values significantly above those measured during the "fan OFF" period. In addition, the carbon dioxide (CO_2), and carbon monoxide (CO) levels decrease with the induced ventilation fan air.

A simple methodology was introduced to determine an empirical relation between area difference of the temperature profiles and the power consumption. The methodology was described based on the indoor and outdoor temperature profiles. The power consumption was measured during the winter 2009 period involving heating load. The empirical equation was verified for the earlier period 2002 winter season data. It shows the thermal performance of the building has not degraded in the last 7 years.

Temperature and power consumption measurements as a means for evaluating building thermal performance

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Energy and Buildings Journal – Available online 11 December 2009.

Abstract

A simple methodology is introduced to obtain an empirical relation between power consumption and indoor–outdoor temperature variations for a small residential building. The effects of house occupants, air/moisture leakage, material deterioration, etc. were not considered in the analysis. The Tuskegee Healthy House was used as a test building for the experiment. Empirical equations for power consumption as a function of temperature area differences were obtained from the measured data of winter 2009 with and without mechanically-induced ventilation fresh air, i.e. using fan "ON" and fan "OFF" condition, respectively. The equations were applied to the measured temperature data of winter 2002 to compare and evaluate the thermal performance of the test house. The equations agree favorably with the winter 2002 data revealing that there is no significant difference in power consumption values of winter 2002 and winter 2009 and, hence, no appreciable change in the thermal performance of the house. The methodology presented in the work can be utilized to compare and evaluate the thermal performance of a given building envelope from season to season and between the same seasons in different years.

Effect of mechanically induced ventilation on the indoor air quality of building envelopes

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Energy and Buildings Journal – Available online 23 September 2009.

Abstract

Experiments were conducted to study the effect of mechanically induced fresh-air ventilation on the indoor air quality (IAQ) of the Tuskegee Healthy House (THH), selecting the outdoor weather conditions almost identical during the "fan OFF" and "fan ON" periods. Measurements of outdoor and indoor temperature and relative humidity (RH), in addition to the indoor dust particle concentration levels and interior wall moisture content, were systematically carried out during the summer month of August 2008. Results show that the effect of mechanically induced ventilation ("fan ON" period) is to raise the indoor RH, interior wall moisture content, and indoor dust particle concentration values significantly above those measured during the "fan OFF" period. The indoor temperature increases only slightly during the "fan ON" period.