Long-term monitoring of mold contamination in flooded homes

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Abstract:
One consequence of the spring and summer of 1993 has been an enormous number of water damaged homes in the upper midwestern United States. A team of investigators with a variety of skills was assembled to monitor the effect of various cleaning, disinfecting, and drying strategies on indoor air quality of two flood damaged homes over one year's time. Additionally, six flooded homes in Marshall, Minnesota, were monitored twice, at seven and 17 months after flooding. One component of the home study was periodic measurement of indoor mold spore levels. Measurements in all homes indicated that elevated mold levels persisted long after homes were cleaned and dried. While ambient levels throughout the homes tended to return to normal after about a year, pockets of contamination remained at the end of the study. Although no comparable pre-flood data are available, these results suggest that more effective decontamination procedures may be needed to prevent subsequent mold problems in flood damaged homes.

Full Text:
Introduction

The spring and summer flooding of 1993 inundated much of the upper midwest portion of the United States. Floodwaters caused many immediate problems for homeowners, damaging structural members, depositing dirt and debris, and ruining equipment, furnishings, and other house contents. The focus of most post-flood clean up efforts was to make the flooded home habitable as quickly as possible. Mold-related indoor air quality problems have been reported in many of these homes. First responses generally consisted of pumping out the water, hosing out the mud, discarding ruined furnishings, then washing exposed surfaces with cleaning agents that contained disinfectants, such as bleach or quaternary ammonium salts. Drying was promoted by fans, dehumidifiers, air conditioners, and fresh air ventilation. Areas with difficult access, such as the interior of wall cavities, tended to remain untouched by cleaning efforts.

Elevated mold levels are often associated with building moisture problems (1,2,3). Such elevated mold levels are often associated with health problems (4,5,6). In an effort to estimate the long-term consequences of home flooding on indoor air quality, an interdisciplinary team evaluated post-flood structural moisture content and indoor mold levels. The project had two phases: 1) the long-term monitoring of two flood damaged homes in southern Minnesota over the course of a year, and 2) the two-time testing of six water damaged homes in Marshall, Minnesota.

The first phase involved two homes, both in southern Minnesota, which were selected for a long-term, ongoing study. Both of these homes (referred to as Home A and Home B) were selected as worse case scenarios, where flood-waters filled the basements and crested above the level of the first floor.

The second phase of the investigation involved testing six flood damaged homes (Homes 1-6) in the Marshall, Minnesota, area. Five of the six homes were flooded when storm runoff filled the city sewer system and backed up into basements through floor drains and toilets. These houses were tested twice, seven months and 17 months after the flood.

Materials and Methods

Homes A and B and 1 through 6

Occupant interviews

Responses were elicited to the following questions:

1) What was the duration and extent of flooding?

2) What was/were the source(s) of flood water?

3) What was the extent of damage to structure, equipment, and possessions?

4) Were there alterations in occupancy patterns related to flooding?

5) What clean-up and drying strategies were used?

6) What products were used for cleaning and disinfection?

7) Were there visible molds growing, bad odors, or other signs of biological contamination?

8) Were there long-term effects of flooding on the house?

9) What was the extent of repairs and remodeling in response to flooding?

10) Were there possible flood-related health problems?

Temperature and relative humidity

Grab samples were taken with a sling psychrometer (Bacharach, Inc., Pittsburgh, Penn.), which measures the wet and dry bulb temperatures from which relative humidity is derived.

Carbon dioxide levels

Levels of [CO.sub.2] were read with a digital [CO.sub.2] meter (Gaztech International, Goleta, Calif.)

Wood moisture content

Wood moisture content was measured with a direct reading moisture meter (Delmhorst Instrument, Towaco, N.J.). By driving the sensing pins into the wood, the internal moisture content of the wood was measured.

Mold Sampling

Air sampling was performed with an Andersen N-6 single-stage viable microbial aerosol impactor (Graseby-Andersen, Atlanta, Ga.), at a rate of 28.3 liters per minute. Samples were collected on 100-mm petri dishes loaded with 35 ml of Inhibitory Mold Agar (IMA). Samples were taken under both ambient and aggressive sampling conditions (7,8). Ambient samples estimate the airborne spore load generated by active mold colonies. Aggressive sampling involves patting or scraping nearby surfaces in an attempt to disturb dormant colonies into releasing spores into the air. Plates were incubated at 25 [degrees] C (room temperature) for 72 hours before counting, and for up to seven days before typing individual colonies. Identification, to form genera, was by observation of gross colony morphology, and by microscopic examination and reference to standard fungal identification keys. Plate counts were corrected, using positive hole conversion table, before calculating colony forming units per cubic meter (CFU/[M.sup.3])

Additional monitoring in Homes A and B

Air infiltration evaluation

An outside door was fitted with a blower door (Minneapolis Blower Door Co., Minneapolis, Minn.). The blower door is a tight fitting heavy duty vinyl sheet, into which is fitted a variable speed fan. The fan is connected to gauges that measure pressure and air velocity. The fan is then turned on and air flow is increased until 50 Pascals (Pa) of negative pressure are generated. After reading the air flow gauge to determine the exhaust rate at 50 Pa, and measuring the cubic foot volume of the house, an estimate of the natural ventilation rate of the home can be estimated (9)

Heating-ventilating system inspection

Spillage of combustion products from buoyancy vented gas burning furnaces and water heaters is an immediate health-threatening indoor air problem. Back drafting potential was measured visually with a smoke bottle containing Ti[Cl.sub.4], which generates a room temperature, neutrally buoyant smoke (Nalgene, Inc., Rochester, N.Y.).

Temperature and relative humidity

Long-term fluctuations in temperature and relative humidity were measured by a data-logging instrument (ACR Systems, Surrey, B.C.).

Results

Home A

Home A is estimated by its owner to be over 100 years old. It is situated a few hundred yards from the Minnesota River. The basement and foundation have been modified several times over the life of the home. The current owner added a kitchen over a dirt crawl space, which slopes down from grade at a 45 [degrees] angle to meet the pre-existing cement basement slab, which has a walkout door to the east.

Drenching rains in late June of 1993 caused the river to begin a gradual rise of about 1 foot per hour. Realizing the likelihood of his home being flooded, the homeowner summoned friends with trucks and removed furnishings and appliances from the first floor and basement. The first floor carpet was removed, with the pad left in place. The water eventually covered the first floor to a depth of about a foot.

The homeowners then left on a month-long vacation. Upon their return they found the river returned to its banks, and the water gone from their home. The inundated parts of the house were dirty and overgrown with mold. They removed the carpet pad, which had trapped much of the flood sediment.

The homeowner, a plumbing and heating contractor, cut away all of the first floor return ducts in the basement, hosed out the first floor using the floor returns as scuppers, then used a 10% bleach solution to kill the visible mold. He repeated this treatment several times during the following month until the mold stopped reappearing on floor and baseboards. He then replaced the carpet in the dining and living rooms, and laid new sheet vinyl in the kitchen.

At the time of the first visit, in November, ductwork had not been reconnected to the furnace, which was recirculating basement air throughout the home. The exposed soil in the basement was still soggy from Hooding. Due to leaky construction, and a number of openings from the basement to the outdoors, investigators were unable to generate 50 Pascals of negative pressure with the blower door. This suggests a high natural ventilation rate for this home, probably in excess of one air change per hour. This natural ventilation rate is reflected in the low relative humidity and [CO.sub.2] levels measured during our periodic visits. Structural wood moisture content was only slightly above normal on the first visit, and measurements on subsequent visits produced readings of below 10%, which would be the expected value in a non-flooded home. (See Tables 1 and 2.)

TABLE 1 Ventilation Data for Home A Predicted Average Outdoor Air Infiltration Rate Average [CO.sub.2] Reading More than one air change per 600 ppm hour of natural infiltration Predicted Average Outdoor Air Infiltration Rate Relative Humidity More than one air change per Upstairs: Decreasing hour of natural infiltration from 40% in November to 10% in January, then back up to 30% by April Basement: 50% avg. TABLE 2 Airborne Mold Levels in Home A, in CFU/[M.sup.3] 11/17/93 12/15/93 2/2/94 4/4/94 6/3/94 Kitchen table (*) 4,500 300 300 282 Kitchen aggressive 15,000 11,000 1,300 600 424 Basement 30,000 171,000 2,100 4,000 525 Dining room, aggressive (*) 85,000 (*) 1,500 (*) Living room, aggressive (*) 85,000 (*) 1,800 3,060 Outdoors 110 (**) (**) 160 2,295 7/29/94 10/12/94 Kitchen table 971 459 Kitchen aggressive 1,483 1,095 Basement 39,159 5,650 Dining room, aggressive (**) (**) Living room, aggressive 1,483 2,048 Outdoors 3,955 2,472

Approximately equal numbers of Penicillium and Aspergillus species constituted 95% of the molds found in all indoor samples on the first six visits. Samples on last visit were predominantly Cladosporium species. Outdoor samples were roughly 95% Cladosporium and 5% Penicillium species during the first four visits, and predominantly Cladosporium species during the last two.

(*) Sample overgrown and uncontrollable.

(**) Sample not taken.

Home B

Home B was built in 1980. It was flooded twice during the summer of 1993, first with about two feet of clear surface runoff from a rainstorm, the second time when storm runoff overfilled the local sanitary sewer. Sewer water backed into their basement through the floor drain, eventually rising above the level of the first floor. Each flood event was caused by very heavy rainfall, exceeding 10 inches in 24 hours. They used portable pumps to remove the flood water, then used an airless spray painting pump to wash off dirt and mold resulting from the second flood event. Surfaces were then washed with a disinfectant cleaner containing 1.6% quaternary ammonium salts. The inundated portions of the first floor were allowed to dry out, then cleaned. The carpeting was not immediately discarded, nor was the water-damaged wall board and wood trim.

The flooding caused a financial disaster for the residents. After the first flood, they replaced their furnace, water heater and dehumidifier, only to see the second flood ruin their new purchases. During the winter, a flood relief loan came through, and several remodeling projects began in earnest. The entire basement was framed and room partitions were added to make two bedrooms, a recreation room, and a utility room. The kitchen was remodeled with new cabinets, and a new vinyl floor was installed. A room was being added to the first floor when our team first arrived in November of 1993, and was in use before December 25, 1993. In January of 1994, the homeowner installed a wood burning furnace in the basement and a humidifier on the first floor.

The initial inspection revealed a significant back drafting and combustion product spillage problem in the basement. The furnace is installed with a high volume return grill which creates enormous negative pressure. A smoke bottle demonstrated that when the furnace was operating with the basement stairway door shut, the water heater combustion gasses spilled into the basement, even after five minutes of operation. The investigators convinced the homeowner to install an open grill on the lower portion of the basement door to relieve the negative pressure and a battery-operated carbon monoxide detector, equipped with an alarm, near the furnace. A puddle was observed on the basement floor near the furnace, 1-inch deep and 6 feet in diameter. The homeowner explained that the puddle was caused by a leaky valve from his water main. It took almost two months to coordinate with local water maintenance personnel to shut off his water supply at the curb in order to replace the defective valve. Humidity levels dropped dramatically in the basement when the wood stove began operating and further yet when the leak was repaired and the puddle dried up.

In addition to the mold/water problem on the basement floor, the homeowner runs a nursery business and was storing thousands of flower bulbs in his basement. These were stacked in flats to dry, and no doubt made a contribution to mold and moisture levels in the basement. Additional moisture sources for this home included an upstairs humidifier, and the application of joint compound to the new drywall partitions in the basement during January. Structural wood moisture content was in the normal range, below 10%.

Mold samples were taken in locations similar to Home A, concentrating on portions of the home that had been flooded. No aggressive samples could be analyzed because very rapidly growing phycomycetes obscured more slowly growing molds. Therefore, all samples taken in this house were ambient samples. (See Table 3 and Table 4.)

TABLE 3 Ventilation Data for Home B Predicted Average Outdoor Air Infiltration Rate Average [CO.sub.2] Reading 0.5 air changes per 1,400 ppm hour of natural infiltration Predicted Average Outdoor Air Infiltration Rate Relative Humidity 0.5 air changes per Upstairs: 40% hour of natural infiltration Basement 50% initially; 15% by the end of winter TABLE 4 Airborne Mold Levels in Home B, in CFU/[M.sup.3] 12/1/93 1/19/94 2/9/94 4/6/94 6/3/94 Kitchen 11,000 5,000 3,700 4,900 2,789 Living room 18,000 5,000 2,800 8,500 4,343 Basement 85,000 6,700 11,000 27,000 11,052 New addition (**) 5,300 3,700 5,200 (*) Outdoors 88 (**) (**) 150 388 7/19/94 10/12/94 Kitchen 847 1,448 Living room 518 1,130 Basement 8,333 1,483 New addition 494 494 Outdoors 895 6,038

Approximately equal numbers of Penicillium and Aspergillus species constituted 95% of the molds found in all indoor samples on the first six visits. Samples on last visit were predominantly Cladosporium species. Outdoor samples were roughly 95% Cladosporium and 5% Penicillium species during first four visits, and predominantly Cladosporium species during the last two.

(*) Sample overgrown and uncontrollable.

(**) Sample not taken.

Results from Homes 1 through 6

In the second phase of the project, six houses in Marshall, Minnesota, were examined. During the spring and summer of 1993, several areas of Marshall were flooded. The flooding occurred after heavy rains on May 18, June 21, and July 4, 1993. The heavy rainfall filled the city's sewer system, causing extensive sewer backup in lower lying neighborhoods. This resulted in basement flooding, which occurred more than once in many residences.

The houses were evaluated for evidence of flood damage and for mold. Five of the six houses were flooded with sewer water, which entered the homes through the floor drains, while one house was flooded with surface run-off water from a drainage ditch. All of the houses had been flooded more than once. One of the homeowners reported being flooded three times. The extent of flooding varied considerably. One house had flooding that did not get much further than ankle deep, while others had several feet of water in their basement. All of the homes flooded with sewer water had electric sump pumps in the basement floor. Unfortunately, the pumps were non-submersible, and hence incapable of handling the rising water from the floor drains.

The level of basement usage varied considerably. The houses which had children at home used the basement for family rooms, play rooms, and bedrooms. Four of the houses had laundry facilities in the basements. Five of the houses had some sort of shop or hobby activity located in the basement.

After the water had been pumped out of the basements, the homeowners used a variety of cleaning strategies for their basements. Three of the houses were cleaned exclusively by professional cleaners. Two of the houses used professional cleaners, but did a lot of additional cleaning themselves. The cleaning products varied. Cleaning was needed several times after the flood. Many furnishings were discarded, including furniture, cabinets, drywall, and carpeting.

The moisture content of wood in the basements of all of the homes was relatively low,well below 30% moisture content when wood decay would be expected. One the issues related to drying strategies was whether the wood had been dried out sufficiently to prevent decay fungi from becoming established. It is generally recognized that decay fungi need moisture contents of 30% or above before they can become established in the wood. The moisture contents which were sampled were all well below this level; the highest were 12.5% and 14%.

While not decaying, damp wood is a source of moisture and a medium for mold to live on. Home 4, which had a wood foundation, had the greatest mold problems. The basement vapor barrier had been detached from floor level and folded up to expose the bottom four feet of the wall cavity. Some of the insulation had been cut out at the base. This exposed wood represented a considerable source of moisture for the rest of the house.

Home 4 had the highest humidity levels. There was only one occupant, and there were no indications that this person could have generated high levels of humidity. The probable sources of moisture could have been the saturated soil around the foundation, the moisture in the wood basement itself, and the lack of fresh air ventilation suggested by the [CO.sub.2] level. On our second visit, well over a year after the flood, the wood foundation was still dirty and damp. The basement yielded high mold levels under both ambient and aggressive sampling conditions. (See Tables 5, 6, and 7.)

TABLE 5 Interview Information from Marshall, Minnesota, Homes Flooding Year (amount, date, Drying Home # Built & cause) Strategy 1 1964 4 in. - 5/18/93 Fans & A.C. 6 in. - 6/21/93 sewer backup 2 1955 2 in. - 5/18/93 Fans, A.C., 2 in. - 6/21/93 dehumidifier sewer backup 3 1965 15 in. Fans sewer backup 4 1991 27 in. - 5/18/93 Fans & 32 in - 6/21/93 dehumidifier 5 in. - 7/4/93 sewer backup 5 1979 7 in. Fans surface water 6 1952 24 in. - 5/18/93 Fans & 36 in. 6/21/93 dehumidifier sewer backup Cleaning Home # Strategy 1 Lysol to scrub floors & walls; basement carpet discarded 2 Professional cleaners & bleach solution used by homeowners 3 Professional cleaners 4 Professional cleaners, homeowner tore out water-stained insulation 5 Professional cleaners, contractor replaced portions of 1st story flooring 6 Professional cleaners, bleach, and cleansers used by homeowner TABLE 6 [CO.sub.2] Levels (ppm) in Marshall, Minnesota, Homes Home #1 929 ppm Home #2 800 ppm Home #3 1,050 ppm Home #4 1,100 ppm Home #5 600 ppm Home #6 650 ppm TABLE 7 Mold

Levels (CFU/[M.sup.3]) in Marshall, Minnesota, Homes Home 1 Home 2 Home 3 Home 4 Home 5 Home 6 Basement Visit #1 (*) 5,200 640 830 9,800 1,200 265 Visit #2 (**) 950 250 830 2,260 459 195 Basement, aggressive Visit #1 86,000 500 1,200 110,000 20,000 5,085 Visit #2 19,500 3,500 1,300 185,580 1,340 4,025 First floor Visit #1 650 810 265 240 3,200 270 Visit #2 210 1,050 475 460 265 230 First floor, aggressive Visit #1 3,300 2,300 (**) 57,000 10,135 (**) Visit #2 (*) (*)* (**) 12,075 2,684 (**) Outdoors Visit #1 450 110 (**) (** 565 150 Visit #2 (**) 3,145 (**) 3,10 (**) 636

(*) Visit #1 occurred on March 5-6, 1994.

(**) Visit #2 occurred on November 14-15, 1994.

Predominant indoor molds were Penicillium and Aspergillus species (80%), with lesser numbers of Cladosporium and yeast species (20%). Outdoor populations varied by location, but Cladosporium, Aspergillus, Penicillium, and yeast species were most commonly recovered.

(*) Samples overgrown or uncontrollable.

(**) Samples not taken.

Discussion

Every flooded home tested as part of this study had elevated mold levels. Some were certainly worse than others, but all appear to harbor at least some contaminated areas. Localized mold problems were usually areas within wall cavities, or other sequestered spaces untouched by cleaning efforts. Ambient mold spore levels during the initial visits to Homes A and B were nearly at agricultural levels. At this degree of contamination, the Andersen impactor is perhaps not the best tool for precise quantification (10). With no data for these houses prior to the flood events, no definite conclusions can be drawn. But in comparing these results from those obtained in other homes and from a study of the literature on mold in homes, it can be stated that the mold levels in these houses are well above the 200-300 CFU/[M.sup.3] level that might be considered as acceptable (7).

Homes A and B had remarkably elevated ambient mold spore levels during the early phase of the study, in some cases measuring over [10.sup.5] CFU/[M.sup.3]. Over time, these ambient levels began to fall, and by the end of the study, indoor/outdoor ratios were less than one, with indoor species reflecting the outdoor populations. Aggressive sampling still generated elevated levels, indicating that reservoirs of contamination remained long after flooding.

The HVAC systems of both homes seem to have acted as efficient distribution conduits for airborne mold spores. Home A experienced a decrease in molds upstairs when the return ductwork was reinstalled. which effectively removed basement air from the recirculating forced air heat system. Home B draws significant amounts of basement air into its HVAC system because of the large return in the basement furnace. This conclusion is supported by the samples taken from the new addition, which was built after the flood. Levels here are comparable to the rest of the house, and the mold colonies were of the same species distributed throughout the rest of the house.

Home A was much drier over the winter than Home B. Although basement relative humidity was the same. it should be noted that Home A's basement was not heated, while Home B's basement was kept quite warm. In addition, the basement of Home A had numerous openings to the outdoors, and, therefore, received substantial fresh air ventilation. A relative humidity of 40% at 55 [degrees] F indicates much less moisture in the air than a relative humidity of 40% at 75 [degrees] F. Home B experienced measurable drying when the leaking valve in the basement was repaired.

Remodeling and repair efforts coincided with a marked decrease in the aggressive samples taken in the kitchen of Home A. The homeowner removed and replaced the baseboards in the kitchen during March 1994. He reported that there was dense mold growth behind the baseboards, and he bleached the entire area before installing the newbaseboards.

One Home A resident, who insisted that she had no mold-related health problems, also mentioned that she received a weekly "allergy shot." In spite of the elevated mold counts in Home B, the residents reported no health problems that could be logically attributed to molds. They did not report allergic problems, colds, or other upper respiratory complaints, such as persistent coughing, sore throats, sinus pain, or congestion. Interestingly during the April 1994 visit to Home B, the homeowner was processing flower bulbs on a table in the basement. He was violently coughing, and claimed there must be something in the bulbs that bothered him. The authors noted a spike in our mold levels on samples taken on that day, so it is possible that the homeowner was experiencing mold-related discomfort.

The Marshall, Minnesota, homes raise interesting questions as well. Most of the homes were cleaned, disinfected, and dried promptly after flooding, but there seemed a general reluctance to tear into finished walls. Carpets were usually discarded, but wall surfaces were simply cleaned, disinfected, and left to dry. Aggressive samples taken in such areas always turned up elevated mold counts, no matter how clean they appeared to the eye.

Home 4 appeared to have the most serious mold problem. This house had a treated wood foundation. Such foundations are usually carefully installed with good drainage around the foundation perimeter. But the flooding in Marshall generally came into the homes through the floor drains, flooding the homes from the inside. The sump pumps in all these homes were of the non-submersible variety, and they quickly shorted out. This allowed the basements to fill with standing water. The wood foundation was thoroughly soaked. The wood at the floor plates in this home was damp to the touch, eight months after the flood. The homeowner had cut away and discarded floodstained insulation, and had lifted the plastic vapor barrier up a few feet. But when this plastic sheeting was pulled away, it was discovered that the wood and insulation behind it were soaked all around the basement, all the way up the walls to the ceiling.

As the deepest flood level in this basement was only about 3 feet, it must be assumed that this moisture resulted from condensation of warm moist air migrating up behind the insulation and contacting the cold wood foundation. While treated wood can stand this sort of soaking without compromising its structural integrity, aggressive samples taken near the treated wood demonstrate that when the wood is dirty and damp, its surface can support mold growth. In the period between the first and second visit, the homeowner removed the old insulation and attempted to clean the basement with diluted bleach. At the time of the second visit in November of 1994, the wooden foundation walls remained damp and moldy.

Summary

These results suggest that simply cleaning, disinfecting, and drying flooded surfaces may not prevent mold contamination from persisting long after floodwaters have subsided. Unless some strategy for decontaminating hidden surfaces can be devised, homeowners may be forced to face much more extensive demolition and replacement of those portions of their homes that have been flooded.

Long-term monitoring of the indoor air quality and moisture conditions in these homes has led to the conclusion that prompt drying and cleaning of these badly flooded homes has not prevented serious mold contamination. While ambient levels returned to acceptable levels over the course of a year, areas of sequestered contamination persist, reflecting the durability and lowered moisture requirements of well-established mold colonies.

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