FLOOD-DAMAGE-RESISTANT HOUSING

Results from Field Testing of Envelope Materials and Systems

Work performed by Oak Ridge National Laboratory and Tuskegee University for the U.S. Department of Housing and Urban Development
September 2004

Background

This report provides the results of a project that identified and evaluated materials, systems, and methods which, when used to repair flooded building envelopes, will make a home more resistant to flood damage. Use of these materials and techniques will mean that less extensive damage occurs if the house floods again and will minimize disruption and future restoration efforts. This multiyear project, begun in 1999 and completed in 2004, was carried out by Oak Ridge National Laboratory (ORNL) and Tuskegee University, with funding from the U.S. Department of Energy (DOE), the Federal Emergency Management Agency (FEMA), and the Department of Housing and Urban Development (HUD).

The Department of Homeland Security's Federal Emergency Management Agency defines flood-damage resistance as the ability of materials, components, and systems to withstand direct and prolonged contact with floodwaters without sustaining degradation that requires more than cosmetic repair to restore them to their original condition. We expanded this definition: Individual materials that are considered flood-damage-resistant must also not cause degradation of adjacent materials or the systems of which they are a part. Cosmetic repair includes cleaning, sanitizing, and resurfacing (e.g., sanding, repair of joints, and repainting). For a material to be considered flood-damage-resistant, the cost of cosmetic repair should be less than the cost of replacing the affected item.

A complete definition of flood-damage resistance should also include a material's resistance to harboring microbes, organisms, or toxic materials that can cause adverse human health consequences. We did not test to evaluate the impact of bacteriological and toxic substances during this project. The impact of these substances on otherwise flood-damage-resistant materials could modify the results described in this report.

How We Tested

Our test facility was located on an experimental farm near an agricultural lake at Tuskegee University, in Alabama. Reproducing flood conditions in full-sized residential structures would have been extremely expensive and impractical, so we developed a series of small, prototypical test structures: 8 × 8 ft modules that were placed in outdoor basins. The floor in one basin was a slab-on-grade. The floor in the other basin had a concrete footing and a stem wall, creating a crawl space.

Module during flood testing at Tuskegee University.

Our modules were tested for resistance to the physical degradation that results from the wetting and drying associated with flooding. They were not tested for the structural impact of hydrostatic pressures.

Flooding was limited to 2 ft above floor level, which applies a pressure that is within the strength capabilities of typical wood frame construction. Following the experimental 3-day flooding event, the floodwaters were allowed to recede, the structures were left unattended, and the drying period began. Five days later (simulating the time it would take a homeowner to return after a flood) we reentered the test modules, opened them to promote drying, and began the postflood recovery efforts. The modules were cleaned and some were sanitized; they were then allowed to continue drying for a total of 28 days. After the drying period restoration efforts were made. Finally, the modules were autopsied (taken apart) to obtain samples for further testing and to investigate the condition (deterioration, mold growth, etc.) of the previously hidden portions of the structure.

We documented postflooding mold growth and analyzed selected specimens. Some test modules were also cleaned and sanitized to determine whether mold growth could be controlled in preparation for further restoration. We also attempted cosmetic repair on a number of the building materials.

Our test modules simulated the materials and structures of actual homes subjected to representative flooding and drying conditions. Exterior walls were built with commonly used residential materials and according to standard construction practices. Each module had a window and an exterior door. The crawl-space modules had two vents in the concrete block foundation. Each module had two small rooms with an interior partition and an interior-grade door between them. Walls, floors, and ceilings were constructed and finished according to conventional construction methods. A variety of finish materials were tested.

We conducted three series of tests along with a supplementary test of the slab-on-grade module only. In the first series of tests, two test modules were built with typical home construction materials and methods. The modules were flooded, and detailed information was collected to determine how typical residential construction materials and systems were affected during and after flooding. This provided a baseline with which other materials and systems could be compared.

In the modules built for the second series of tests we introduced different materials and systems that were expected to be more flood-damage-resistant. In these tests, the materials were also sanitized and cosmetically restored in order to assess their performance after exposure to a flood. Then we demolished and autopsied the modules, and samples of various materials were taken for testing.

Our third slab-on-grade module was used to attempt dry flood-proofing that would allow no water to enter the structure. This was followed by a second attempt with the same module using what we learned from the previous test. We tested the third crawl-space module in the same manner as the previous modules and investigated additional flood-damage-resistant materials and systems.

During testing we measured relative humidity, temperature, and moisture in the construction materials. A weather station provided data on ambient conditions during testing. Mold was sampled from the modules and tested in a laboratory to identify its type. We determined the strength of various types of siding and wall board by mechanical testing.

Detailed protocols were developed for visual observation. While visual observation is subjective, the protocols were developed to systematize these observations and make them as detailed and consistent as possible throughout the series of tests. Extensive photographic records were made as well.

What We Found

Our experimental modules were tested using the expanded FEMA/ORNL definition for resistance to physical degradation which results from the wetting and drying cycle associated with flooding. Human health factors (beyond mold growth) were not evaluated. These limited performance criteria form the basis of our findings. Testing for the residual health effects of flooding on otherwise flood-damage-resistant materials and systems has not yet been accomplished and could change our findings.

In addition, our findings should be viewed as preliminary, since they are based on the results of the testing performed in this project and not on an accepted certifying test procedure for the flood-damage resistance of a particular material or system. A certifying test procedure must be developed and adopted before the identification of materials as “flood-damage-resistant” will satisfy building code requirements for the use of such materials.

Materials and Systems

Siding

Newly installed and painted plywood and hardboard lap siding, when exposed to floods, maintained reasonable dimensional stability and mechanical properties after being dried. These materials also had good washability but remained discolored. Restoration to preflood conditions would require stain sealing and repainting. Older, weathered siding of the same materials and/or siding repeatedly exposed to wetting and drying over several cycles is projected to have much poorer restorability. We think it unlikely that weathered plywood and hardboard sidings would be considered fully restorable.

We found that water does not evaporate quickly from behind plywood siding. Therefore, we do not consider the combination of plywood siding and wood sheathing a good flood-damage-resistant system. Lap siding with more joints than plywood allows moisture to escape more quickly and reduces the potential of long-term damage to the sheathing.

Vinyl and fiber cement sidings both withstood flood conditions better than hardboard lap siding and plywood siding. Both sidings could be restored to preflood conditions through simply washing the portion below flood level. Older vinyl siding and painted fiber cement siding with an oxidized surface may have to be cleaned both below and above the flood level in order to maintain a consistent appearance. Restoring much older fiber cement siding containing asbestos would require special procedures to avoid creating hazards.

We found that sawn wood trim and corner boards tend to swell, twist, and check where exposed to floodwater. Restoration required thorough drying, renailing, crack-filling, and repainting. Replacement with more durable trim materials such as plastic or wood/plastic composites is likely to be more cost-effective.

There was no visible evidence of mold growth from flood exposure on either the inside or the outside surface of the siding materials we tested.

Plywood T1-11 siding survived flooding with minor checking, but retained excessive moisture in the adjacent plywood sheathing.

Vinyl lap siding survived flooding with no physical damage other then needing to be washed. Its joints permitted the adjacent plywood sheathing to dry.

Fiber cement lap siding survived flooding with no physical damage other than needing to be washed. Its joints permitted the adjacent sheathing to dry.

Sheathing

We found that plywood sheathing maintained its integrity and mechanical properties. However, when covered with plywood siding it had not dried to preflood levels after the 28-day drying period. The use of plywood sheathing with a flood-damage-resistant lap siding is likely to permit adequate drying and make an acceptable damage-resistant system. We saw no visible evidence of mold growth resulting from flood exposure on either the inside or the outside surface of plywood sheathing.

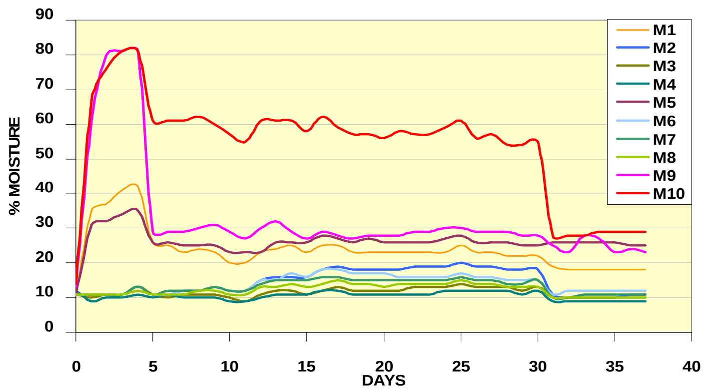
Water-resistant, fiber-reinforced gypsum sheathing [e.g., Fiberock Weather Resistant (WR) Sheathing by USG] maintained its integrity and mechanical properties. It dried to preflood levels during the 28-day drying period. Again we saw no visible evidence of mold growth on either the inside or the outside surface of this sheathing from flood exposure.

We believe that the use of fiberglass or other potentially moisture-retaining insulation in the exterior wall cavity may elevate the moisture level and extend the drying period for plywood and oriented strand board (OSB) sheathing to the point that it becomes a durability concern.

Wood Framing

Our monitoring showed that moisture levels in wood studs that were above the flood level returned to preflood levels within the 28-day drying period. The portions of the studs and floor joists that were below flood level were drying towards the preflood moisture content but had not in most cases reached the preflood level during the drying period. Autopsies showed no visible evidence of mold growth on the wood framing. We consider wood framing to be flood-damage-resistant as long as the wall or floor system of which it is a part will permit it to dry to normal levels.

We believe that the use of fiberglass or other moisture-retaining insulation in the exterior wall cavity or below subfloor may also elevate the moisture level and extend the drying period for the wood framing to the point that it becomes a durability concern.



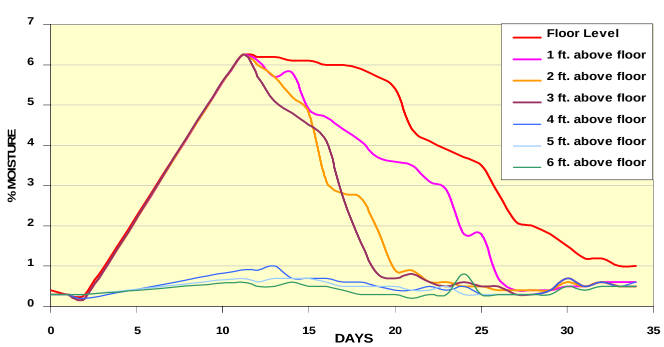
M1 - 1.5 ft above floor in stud, exterior wall
M2 - 2.5 ft above floor in stud, exterior wall
M3 - 4.5 ft above floor in stud, exterior wall
M4 - 6.5 ft above floor in stud, exterior wall
M5 - 1.5 ft above floor in stud, interior wall
M6 - 2.5 ft above floor in stud, interior wall
M7 - 4.5 ft above floor in stud, interior wall
M8 - 6.5 ft above floor in stud, interior wall
M9 - Installed in subflooring, in crawl space
M10 - Installed in joist in crawl space

This graph shows the impact of flooding on the relative moisture content of various framing members above and below flood level. The percentages should be viewed in relation to preflood percentages and not as absolute values. Moisture levels in most below-flood-level members dropped back toward preflood levels as the water receded. Moisture levels in subflooring did not drop as much until day 31, when the fiberglass floor insulation was removed. This long-term moisture retention could be a problem if the insulation is left in place.

Insulation

Our tests indicated that fiberglass batt insulation contributes to higher moisture levels in the exterior wall cavities and below the floor, which kept the adjacent walls and floor materials wetter longer and could potentially contribute to long-term damage to the subflooring, the floor and wall framing, and the gypsum wallboard. This finding supports previous recommendations by various agencies to remove and dry or replace fiberglass insulation that has been subjected to floodwater.

When spray polyurethane foam (SPUF) insulation was tested in the wall cavities, the wall board and wood studs in the exterior walls dried at the same rate as in the interior walls with empty cavities. SPUF absorbs water very slowly and was undamaged by flooding. SPUF did not retain moisture and therefore does not have the potential for adverse impact on the flood-damage resistance of the materials around it. There was no visible evidence of mold growth on the SPUF insulation.



This graph shows the moisture content of the gypsum wallboard above and below water level after exposure to flooding. Readings were taken upon reentering the unit on day 11. The lower cluster of readings is from above flood level and the upper cluster of readings, from below flood level. Fiberglass insulation in this wall slowed the drying on the two lower reading locations.

Interior Gypsum Wall Board

When conventional paper-faced gypsum board was used with fiberglass batt insulation on exterior walls, the gypsum board lost about 50% of its flexural strength and remained wetter than gypsum board on interior walls (without insulation). The gypsum board on interior partition walls dried out within the 28-day drying period and maintained flexural strength (see the table). We believe that if gypsum board is able to dry completely within an appropriate time, it can be restored to preflood condition with only cosmetic restoration. Although the board supported mold growth on the exposed painted surface, it could be cleaned, sanitized, and restored. We saw no visible evidence of mold growth from flood exposure on the backside or unexposed surface of the gypsum wall board we tested.

Flexural strength of paper-faced and fiber-reinforced gypsum board under differing flooding conditions

Gypsum board location/condition	Flexural strength (MPa)	
	Above water	Below water
Conventional paper-faced gypsum board[a]		
Exterior wall / fiberglass insulation	3.20	1.64
Interior wall / open cavity (no insulation)	3.68	3.56
Fiber-reinforced gypsum board (ASTM C-1278)[b]		
Exterior wall / insulated SPUF	4.19	3.68
Interior wall / open cavity (no insulation)	4.21	3.44

[a] Flexural strength as received from mfgr. = 2.80 MPa
[b] Flexural strength as received from mfgr. = 4.00 MPa

Fiber-reinforced gypsum interior wall panels (ASTM C-1278), a non-water-resistant product by USG called Fiberock, retained most of its initial flexural strength (see the table) and dried out during the drying period. Like paper-faced gypsum board, the fiber-reinforced board supported mold growth, but it too could be cleaned, sanitized, and restored. We saw no visible evidence of mold growth from flood exposure on the inside or unexposed surface of the fiber-reinforced gypsum wall board tested.

Water-resistant, fiber-reinforced gypsum exterior sheathing was applied to some interior walls. It too maintained most of its initial flexural strength and dried out during the drying period. We found it did not support mold growth on either surface and it was easily cleaned and restored.

Conventional gypsum board (*left*) after exposure to flooding typically grew mold in a 2-ft-wide band above the flood level and was stained below flood level. Fiber-reinforced gypsum (*center*) after exposure also typically grew mold above flood level and was stained below. Water-resistant fiber-reinforced gypsum (*right*) after exposure did not support mold growth and had less staining than either of the other two materials.

Wall Finishes

We found that both latex flat paint and latex semigloss enamel paint peeled, blistered, and stained after water exposure. Mold grew on both types of paint. High- and low-permeability paints were tested. Both types of paints had to be sanded and repainted to restore the walls. Water-based flat latex and oil-based enamel paints were also compared. The water-based latex flaked and blistered. Oil-based flat enamel performed better than any other paint that was tested. It flaked and blistered very little and was much easier to restore than were other paints. Of all the paints tested, oil-based flat enamel paint was the most flood-damage-resistant. However, the impact of oil-based enamel on the drying of adjacent materials and systems was not completely investigated in this testing.

Our testing showed that standard drywall compound and paper joint tape perform very poorly under flood conditions. Complete failures of the joints below flood level were the norm. We substituted quick-setting joint compound and fiberglass tape in some tests and found them to be a great improvement. When used with the water-resistant gypsum sheathing and oil-based paint, these materials required no repair after testing.

Vinyl wall covering blistered, peeled, and debonded after flooding. It damaged the surface of the gypsum board, and it may inhibit drying of the substrate or wall system. Ceramic tile performed well under flood conditions and showed no long-term deterioration. A slight bulging of the tile observed in one test is probably attributable to swelling of the conventional gypsum board substrate.

Exterior Doors

Exterior wood-paneled doors and exterior prehung metal-clad doors in wooden frames were stained slightly, but could be washed and restored. The wood panel door was installed new and had received multiple coats of urethane varnish just prior to testing. Whether or not the performance we saw can be assumed for an older door is unknown. Fiberglass and foam-filled metal doors were restored to preflood conditions with minimal effort. We reused the fiberglass and metal doors from the second tests in the third set of tests, and they were once again easily restored. After flooding, extra effort was needed to open several of the doors due to swelling of their wooden door frames. This difficulty diminished as drying continued.

The joints between the outside of the door frame and the rough opening were tested left open or filled with low-expansion foam. We do not recommend the common practice of filling this joint with compressed fiberglass insulation because it may retain excessive moisture in this location.

Interior Doors

We tested the following door types: solid-wood six-panel, louvered-wood bifold, hollow-core-wood flush panel, and formed-wood-composite six-panel. All interior doors tested were severely stained, and some were warped, split, and/or peeling. Considering the relatively low cost of replacement, it is not considered economically feasible to restore such doors.

Formed wood-composite panel door delaminated after flood exposure. The low initial cost of such doors makes a restoration effort difficult to justify.

Windows

We were able to restore all vinyl and aluminum window frames to preflood conditions with a minimal cleaning effort. Flooding did not affect the glazing or the operation of the movable parts. No fogging of the interior of the glazing occurred. The joints between the outside of the window frames and the rough openings were tested left open or filled with low-expansion foam. We do not recommend the common practice of filling this joint with compressed fiberglass insulation because the insulation may retain excessive moisture in this location.

Floor Structure

The sealed concrete floor slab in all slab-on-grade modules remained undamaged during and after flooding. Carpeting, vinyl, and wood flooring held or trapped water above the slab and slowed the overall drying process. We removed these materials as part of the flood recovery process. Ceramic and quarry tiles absorbed little water and did not significantly slow the drying process.

The ¾-in. T&G plywood subflooring retained very high moisture content throughout the drying period when unfaced fiberglass batt insulation was installed underneath the subflooring. With no floor insulation, the subflooring returned to preflood moisture levels during the drying period. Wood subflooring and framing insulated with fiberglass batts could be subject to long-term moisture problems. We also found that carpeting, vinyl, and wood flooring held or trapped water above the subflooring and slowed the overall drying process. Again we removed these materials. Ceramic and quarry tiles absorbed little water, did not significantly slow the drying process, and were left in place. Drying of the subfloor was predominantly through its bottom side into the crawl space.

Floor Finishes

Ceramic tile and quarry tile on both concrete and plywood subflooring performed well under flooding conditions and required only cleaning to be restored. However, a wood flooring system using these materials must have the potential to dry thoroughly, usually into the basement or the crawl space. Floor insulations can impede the drying (see the section on insulation, page 4).

All carpeting (including water-resistant carpeting) and padding that we tested became dirty and smelly after flooding. It also retained large amounts of moisture, which can slow the overall drying rate throughout the house. Even if the carpet is able to withstand the flood, it should be removed for cleaning and drying and to promote drying within the home.

A simulated wood flooring (composite wood fiber and plastic) warped and had open joints larger than 1/16 in. when left in place on the floor after the flood. When the simulated wood floor panels were removed, washed, and stacked to dry after flooding, this flooring had much less warping and shrinkage, but the process of removal damaged some of the pieces.

We tested both glued-in-place and floating vinyl flooring on padding. Both had “bubbles” of water trapped beneath. The padding under the floating vinyl flooring was saturated. We removed both systems to promote drying of the subflooring. If the flooring can be removed without damaging it, the floating flooring itself might be reused. Whether or not this effort would be cost-effective depends on the age, condition, and value of the specific flooring.

Foundation Vents

We tested both conventional foundation vents and operable flood vents, and both performed as intended. Conventional vents may become blocked by debris during flooding, and such blockage could induce unintended hydrostatic loads on the structure and damage it.

The solid operable flood vents (by Smart Vent) were closed prior to flooding and opened by themselves during the filling and draining of the floodwater, as designed. Their larger opening during a flood is intended to minimize the potential for blockage from debris. We blocked these flood vents open throughout the drying period to permit air to circulate through the crawl space.

Flood vents opened and closed with the ebb and flow of the flood as designed. This action prevents hydrostatic pressure from occurring should conventional vents become plugged with debris.

Crawl Spaces

Humidity in the test module crawl space reached 100% after flooding and remained high during the 28-day drying period. This humidity level is not acceptable in the long term because it would promote mold growth and wood decay. We believe that the high humidity level in the crawl space was the result of the test module’s being placed in a basin that was subjected to a significant amount of rain throughout the drying period. Flood-damaged homes undergoing restoration in wet climates may require regrading of the site to promote drying in the crawl space.

To cut off potential pathways that would allow excess moisture and mold to enter the interior of the home, the crawl space area must be effectively sealed at all penetrations in the flooring. Ductwork within the crawl space, especially return air ducts, should also be sealed after they have been cleaned, sanitized, disinfected, and repaired as necessary. This will prevent the excess moisture and mold from being drawn from the crawl space into the house.

Procedures

Punching Holes in Walls for Drainage

We punched holes above the floor molding of the interior walls (a commonly recommended practice) and found that these holes do not drain any water nor do they cause the wall to dry any faster, especially if floodwater has receded for several hours. We found in most instances that if holes are not punched in the walls, the gypsum board can be easily repaired and restored. As a result, the practice of punching holes in gypsum board walls to promote drainage is not recommended as an effective flood recovery procedure. Under some circumstances, restoration professionals may use holes along with special drying equipment to speed the drying process in difficult-to-dry situations.

Punching hole at the bottom of walls to promote drainage requires significant repair effort and does not contribute to drying of the wall.

Cleaning

As a cleaning procedure we first used a clear water rinse from a garden hose, which removed some dirt and staining, but not mold. A second washing of selected materials (vinyl and fiber cement siding, fiberglass doors and window frames) with soap and water restored them to their preflood condition. On other building materials, mold growth continued until sanitizing was completed (see the following section); after sanitizing, no mold was visible for the remainder of the testing period.

Severe mold growth occurred in the first tests, in which no attempt was made to clean or sanitize surfaces. Mold growth also occurred on exposed interior surfaces in most subsequent tests, and efforts were made to sanitize surfaces and remove mold.

We do not recommend scrubbing surfaces to remove dirt and stains at this stage.

Cleaning of the walls removed some staining and dirt but did not reduce mold growth. The photos show a wall before washing (*left*) and after washing (*right*). The mold continued to grow after washing.

Sanitizing

Sanitizing and cleaning with a solution of bleach, trisodium phosphate, and water, followed by additional drying time, enabled the restoration of most materials that were not physically damaged to their preflood condition. Although no evidence of mold reappeared throughout the test period, the long-term elimination of mold has not been verified.

In autopsies of these units, we found very little or no evidence of mold growth in the non-exposed (hidden) portions of the structure that were not sanitized. Sanitizing does eliminate evidence of mold growth on exposed surfaces and is therefore recommended procedure for restoring flood-damaged homes. Sanitizing the non-exposed portions of the structure for mold control does not appear warranted based on autopsy results.

We found that spraying vertical surfaces in our test structures using a compression (pump-up) garden sprayer with a solution of water (70% by volume), household bleach (25%), and trisodium phosphate (5%) until the surfaces were thoroughly wetted was effective in eliminating evidence of mold. Floors were wet-mopped with the same solution. Other sanitizers and cleaner-disinfectants may be equally effective. We do not recommend treating metallic items such as hinges, fasteners, and electric outlets with this solution because of the potential for corrosion.

Drying

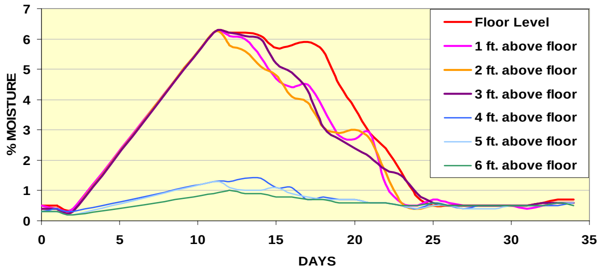
The postflood drying of a home is perhaps the single most important step in the restoration process. The homeowner should begin this process as soon as a return to the property has been deemed safe by the cognizant authority. The American Red Cross's *Repairing Your Flooded Home* provides excellent guidance on the safe and prudent return to a flooded property.

Our testing illustrates the impact of opening the home and removing saturated items to facilitate drying. As the top graph on the right shows, drying of materials such as gypsum board does not begin until the doors and windows of the structure have been opened after the flood. The lower graph of relative humidity (RH) shows that, within the structure, RH remains high (even above the outdoor RH) until the structure has been opened.

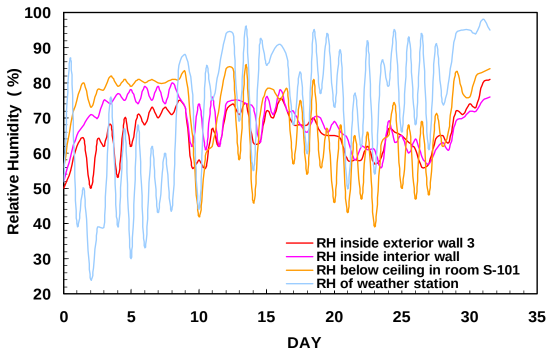
Drying rates for flooded homes may be slower (in some cases much slower) than we experienced with our test structures. The ratio of our window and door area to building area was high, as was the ratio of wall surface to building area. Both of these encourage drying.

While our test structures dried in a reasonable time frame, an actual flooded home may require assistance from heaters, fans, and dehumidifiers, and other measures. Certified professional restoration contractors are expert in these matters and should be contacted to answer any questions regarding drying the home.

Sanitizing eliminated evidence of mold from the walls. Mold did not recur during our testing.



With doors and windows opened on day 11, the walls of the test module returned to preflood moisture levels by day 25. Larger, more complicated structures may require longer drying periods or mechanical assistance to return to preflood moisture levels.



Indoor relative humidity (RH) exceeded the outdoor RH during the flood and before the opening of the test module on day 11. After opening, the indoor RH trended downward but also reflected the changes outside.

Restoring

Our restoration efforts ranged from washing of materials (e.g., vinyl siding, ceramic tile floors, and sealed concrete slab), to washing and sanitizing (e.g., some interior wall panels and trim), to washing, sanitizing, resurfacing, and repainting (as shown in the adjoining photo). Most flooring materials and interior doors tested required replacement, either because they could not physically be restored or because restoration was not cost-effective.

The left side of this wall is awaiting restoration, while the right side has been restored through washing, sanitizing, some resurfacing, and repainting.

Dry Flood Proofing

We attempted dry flood proofing twice without success. In our first test we caulked the interior joint between the floor and sill plate. We added door and window dams made of 2-in.-thick polystyrene insulation boards held in place with silicone caulk (see photos). These dams appeared to be effective in preventing the entry of water through door and window openings. However, water entered the units through other paths, such as the joint between the interior partition and the exterior walls at floor level. The interior joint between the sill plate and the concrete slab had been caulked, but water entered there as well.

Video cameras inside the test modules revealed that water entered in similar amounts from all walls during flooding. There was no visible evidence that water had gotten through the door and window dams. The effectiveness of these dams cannot be confirmed, however, because there was water on the inside from other sources that could have disguised a leak at the dams. During the flooding process, the outside water level was about 4 to 8 in. higher than the inside water level.

One place where the module was particularly vulnerable to the entry and exit of water was the joint between the interior partition and the exterior walls at floor level. When the module was drained, water exited at the corners of the module, between the door and the threshold, and at one bottom corner of the door dam which had been pushed outward by the differential pressure of retained water.

A flood dam of 2-in. polystyrene foam insulation being installed in window frame and held in place with silicon caulk.

Water draining from behind flood dam (lower right corner).

In addition to a door dam, the joints between the slab and the wall were sealed with silicon caulk and covered with butyl rubber tape in the second attempt. All visible points of potential water penetration were sealed.

Second attempt at dry flood-proofing; note deflection of flood dam at door.

Additional steps were taken in the second attempt at dry flood proofing. The lower siding was removed, and the external joint between the sill and the slab, as well as other potential leak pathways on the exterior, were sealed. Despite thorough efforts to seal potential water penetration points and to dam windows and doors, floodwater found a path into the unit. Inspection showed that the external seal was inadequate in several locations. These locations corresponded to the points where water was first noticed on the video cameras. Once within the walls, the water leaked through the small cracks between doubled studs and between the studs and sill plate, as can be seen in the photo at right.

Even with our extraordinary efforts to dry flood proof, the slab-on-grade test modules still flooded. We believe our efforts to seal the outside of the modules were more thorough than the efforts homeowners and possibly contractors would make. If, after very careful efforts, we did not achieve dry flood proofing, we believe that other efforts would also not succeed.

We believe that dry flood proofing is not an economical or practical way to reduce flood damage in wood frame construction. We further believe that homeowners should not be given guidance that recommends this approach. Dry flood proofing is simply too difficult to achieve to be practical for residential applications.

Water came through the small cracks between stud and sill plate.

Recommendations

To Homeowners:

- Follow the guidance in the American Red Cross's *Repairing Your Flooded Home* regarding when and how to reenter your home after a flood and assess the damage. Don't, however, punch holes in walls to promote drainage.
- Promote drying throughout the house by opening windows, doors, crawl-space vents and access doors, attic access panels, etc., to permit airflow throughout the house. Also open interior doors, second-floor windows, and bath and kitchen cabinet doors and drawers.
- Remove water-soaked materials such as drapes, furniture, rugs, and if possible, carpeting. Salvageable materials should be spread to dry in a carport or garage. Non-salvageable material should be moved away from the house to a debris pile.
- Follow the guidance in the American Red Cross's *Repairing Your Flooded Home* regarding how to proceed with reconstruction—e.g., in hiring a contractor or doing it yourself.
- If hiring a contractor, follow the guidance in FEMA's *Avoiding Fraud in Home, Business Flood Repairs.*

To Reconstruction Professionals:

- Follow recommended procedures from professional organizations such as ASCR or IICRC with regard to the treatment or removal and replacement of existing housing envelope materials. In most cases, do not punch holes in walls to promote draining or drying, as this is usually not effective.
- When existing envelope materials are removed, replace them with flood-damage-resistant materials such as those identified in this pamphlet. We recommend that insulation and wall materials be installed to the full height of the walls subjected to flooding. Uncertainty regarding future flood levels and the wicking of floodwater through materials make the combining of conventional materials and flood-damage-resistant ones imprudent.
- When selecting envelope materials and finishes, and caulking/sealing methods, it is wise to assume that floodwater will permeate the system and that there will be hidden pockets of moisture that will require a means of escape. This escape could be through permeable materials such as gypsum board or through cracks such as through the joints in vinyl siding. Don't block this means of drying with low-permanence paints and wall coverings on walls or with caulking joints.
- Because our studies have not evaluated the impact of chemical or biological contaminants (e.g., fuel oil or sewage), definitive recommendations for envelope materials and systems appropriate for contaminated environments are not yet available.

Additional Information

- The full technical report on this project, *Field Testing of Energy-Efficient Flood-Damage-Resistant Envelopes*, is available at http://www.ornl.gov/sci/res/res_buildings/NaturalDisaster.
- To obtain a copy of the American Red Cross's *Repairing Your Flooded Home* go to http://www.fema.gov/hazards/floods/lib234.shtm.
- For information on the Association of Specialists in Cleaning and Restoration, Inc. and a membership listing go to http://www.ascr.org/index.shtml.
- Information on the Institute of Inspection, Cleaning and Restoration Certification and a membership listing is available at http://www.iicrc.org/.
- For information on *Avoiding Fraud in Home, Business Flood Repairs* go to http://www.fema.gov/news/newsrelease.fema?id=8054