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Field Observations of Moisture and Organism Damage in Insulated Houses

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ABSTRACT

Moisture management in houses is discussed as the primary means for controlling biodeterioration in wood structural members. Six houses in South Carolina with various stages of fungi attack are presented. Exterior moisture management techniques such as drains, grading, crawlspace covers and gutters are discussed. Controls for interior moisture management are discussed. These include attic and crawlspace ventilation, vapor retarders and moisture generation.

This paper is not a report of research but one of field observation made of moisture problems which develop in houses that lack adequate external and internal moisture management practices.

INTRODUCTION

This paper reports on field observations rather than on a research project. The authors were invited by home owners to help find solutions to their moisture problems. The paper is intended to help housing educators use design information in developing useful moisture management plans based on standards such as building codes, ASHRAE Handbook --1981 Fundamentals Volume, and U.S. Forest Products Bulletin #373.

House No. 1 (Anderson, SC) was three years old, brick veneer over a crawlspace. Damp conditions had generated slime molds on the floor joists. Some joists also exhibited fungal growth, with fruiting bodies in the form of toadstools and crusts. This growth occurred within the first three years of the house's life.

House No. 2 (Lexington, SC) was older and had been moved from its original location. It had been retroffited with attic and floor insulation, and a new rock chimney. Floor insulation had been installed with the vapor retarder reversed. The floor joists, walls, and subfloor near the chimney showed severe fungal decay with resulting structural damage. Other parts of the floor system experienced mold growth with fruiting bodies. Flashing around the chimney may have been inadequate. However, condensation trapped in the floor insulation was also a contributing factor to the house's condition. It was estimated that the damage had occurred within 18 months of the time the house was retrofitted.

House No. 3 (Easley, SC) had problems created by condensation and mildew in the attic. Roof sheathing was completely blackened with mildew and water stains on rafters indicated the presence of condensation. Adequate mechanical ventilation was available in the insulated attic. However, in attempt at energy conservation, polyethylene had been stapled over the roof vents. Traditional mildew preventive formulations were ineffective in removing stains on the sheathing. The mildew

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growth had apprently occurred over a 1-year period.

House No. 4 (James Island, SC), four years old, had been built over a crawlspace with insulation in the floor, walls, and attic. Insulated heating/air-conditioning ducts had been installed in the crawlspace and floor and duct insulation had become saturated from condensation of the moist crawlspace air. Insulation dropped off the ducts and fell out of several joists. Fungal growth was observed on most joists, and some joists and the plywood subfloor were completely destroyed by brown rot. These conditions had been generated in less than four years.

House No. 5 (Greenwood, SC), also built over a crawlspace, was ten years old. Severe structural damage had occurred to the entire floor system. The crawlspace moisture was elevated by improper drainage. During heavy rains, free water accumulated under the crawlspace. In 10 years, the house had four previous owners, indicating that moisture problems had existed for several of the 10 years the house had been built. The house is a total loss.

House No. 6 (Walterboro, SC) was a frame house built over a crawlspace with stud wall construction. It had stood for 23 years before being retrofitted with wall and ceiling insulation. Lack of exterior water control allowed free water to enter the crawlspace during wet periods and no attempt had been made to establish an interior vapor retarder. As a result, water-conducting and other fungi destroyed the house in 3 years.

BIODETERIORATION OF WOOD

Moisture problems can create conditions that allow mildew, molds and, occasionally, wood-destroying fungi to attack the structural members in a house. Mildew grows well at 16°C and 60% relative humidity.[1] Spores from storage molds also become active under approximately these same conditions. However, wood-destroying fungi do not become active until the moisture content of the wood exceeds 28% or the fiber saturation point.[2] Air-dried wood will range from 10 to 19% moisture content. For wood to rewet to 28 to 30%, condensation or other free water must be present. Such conditions have been observed in insulated air-conditioned houses having an insufficient ventilation rate.

Description of Some Organisms

Most deterioration is caused by fungi. These small, often microscopic, plants have no chlorophyll and reproduce by spores.

When previously dry, undecayed, or nonstained wood is placed in service and wetted, a succession of fungi attack the wood. If the wetting continues, decay will eventually develop and lead to the total destruction of the wood. Slime molds are shown in Fig. 1.

If elevated moisture conditions continue, some fungi can produce stains in the wood. Growth is first evident in the sapwood, where the sugar-rich parenchyma and ray cells provide a plentiful food base. Stains may gradate from surface molds or mildew, which are restricted to the wood surface, to true staining fungi, which actually deeply penetrate the wood. They usually do not reduce the strength of the wood, but their presence is further proof of a continued moisture problem. Furthermore, they are extremely unsightly and the prodigious quantity of spores that some produce may aggravate allergies in some people. Stain fungi are not restricted to wood; they may be found on almost any organic substance from paint to shingles, Fig. 2.

The blue-staining fungi caused by *Ceratocystis*, although common in sapwood of freshly sawn lumber, are usually not a problem after wood has been placed in service. The presence of blue stain usually means that the lumber was improperly stored or dried after sawing. Blue stain can develop, however, when an internal water leak, such as from a water supply line, continually wets the wood.

Decay Organisms

Decay, the final stage of deterioration, occurs when wood is attacked by fungi of the class Basidiomycetes. Most fungi in this class are beneficial in the forest because they decay the wood and bark of fallen trees.

Many are so specialized that they can survive and grow only in the heartwood of living trees; some are restricted to only a single species of tree. Few of these fungi can cause decay of wood in service, but those that do, do it well. The genera Poria, Coriolus (Polyporus), Geophyllum (Lenzites), and Coniophora probably account for more than 70% of the fungi that decay wood in service.

Wood in the last stages of decay is usually wet and becomes attractive once again to the slime molds, which ingest bacteria and fungi in the decayed wood. These may grow through cracks in the floor and alert the homeowner that something is wrong--but by then it is usually too late.

What Are Fungi

The wood-decay fungi, as do all fungi, consist of microscopic threads called hyphae (collectively known as mycelium), which attack the wood. The hyphae secrete enzymes that hydrolyze the polymer component of wood, cellulose, or lignin to monomers (sugar) that are then metabolized by the fungi and produce energy for growth and reproduction.

Initial colonization of the wood results from germination of spores produced by the fruiting body of the fungus. The spores are blown about by the wind and are found in the air in great numbers.

Conditions Necessary for Decay

Fungi cannot decay dry wood. If wood were kept dry, it could, theoretically, last forever. The chances of decay developing increase greatly as the moisture content increases. As dry wood absorbs water, the entering water is first adsorbed and held by the microfibrils of cellulose that make up the cell wall. This water is bound, in varying degrees, by the microfibrils and is not available for use by most decay fungi. At approximately 28% moisture content, all these spaces are filled. As moisture content increases beyond this point, free water collects and fills the spaces or lumens in the center of each wood cell. It is this water that is used by decay fungi and serves as a mode of transport to carry fungal enzymes to the wood and allow diffusion of the sugars back to the hyphae.

Dry Rot

Dry rot, a commonly used term to describe a special type of decay, is a misnomer, because no decay can develop if the wood is kept dry.

The fungus causing dry rot, Poria incrassata, has root-like structures called rhizomorphs that convey water from the soil and up into the dry wood, wetting it in advance of its growth and thus assuring adequate moisture for decay to develop. This type of decay occurs in South Carolina, the location of this project. Damage can be minimized by periodic inspection of the crawlspace for dampness, surface mold, or staining of joists. Figures 3 through 5 show a house extensively decayed by Poria incrassata. The baseboard is in advanced decay and the interior of the kitchen cabinet indicates that the fungus attack has progressed up the wall studs. The exterior view shows the deteriorated wall sheathing outside, near the kitchen cabinet. This house was quickly dried by directing flow from a high-capacity fan into the crawlspace. Rapid drying caused the affected wood to shrink severely and fracture across the grain, providing visible evidence of the destruction of the wood.

Figure 6 illustrates the loss of strength in the house's floor. In moving a color television set, the occupant broke through the floor.

PREVENTION AND CONTROL OF WOOD DECAY

The development and growth of wood-destroying fungi, along with surface molds and mildews, are limited by minimum levels of moisture. Air-dried wood with a moisture content of 20% or less is considered dry and will not decay. Wood with a moisture content above the fiber saturation point is subject to attack by wood-decaying fungi.

In new construction, wood structural members that may be subject to prolonged damp conditions should be pressure treated with a wood preservative. The toxic preservative material inhibits growth of fungi and wood decay for many years. Effective measures have been developed to prevent or control moisture accumulations in various locations in a residence. These measures include vapor barriers to prevent moisture migration through the walls, floors, and ceilings; ventilation to keep moisture in contained areas at reduced levels; and diversion or exclusion of both surface and subsurface water around the residence. Special circumstances may require use of mechanical equipment, such as a sump pump, to dispose of accumulated water under the house, or refrigeration equipment, to reduce inside humidity levels. This is especially crucial in modern houses, which, increasingly, are being tightly sealed to reduce energy costs.

HOW AND WHY MOISTURE PROBLEMS DEVELOP

Generated Moisture

Normal household activities (cooking, bathing, laundering--even breathing) influence the level of moisture vapor in the home. The daily amounts of moisture generated by a family of four for various activities are:

	Pints	Liter
Bathing	1	0.47
Clothes drying	26	12.3
Clothes washing	5	2.4
Perspiring and breathing	12	5.7
Dishwashing	1	0.47
Cooking (steam)	5	2.4
Possible Total	50	24.0

Migrated Moisture

Moisture vapor migrates from one area of a house to another. It will move, unless prevented by vapor barriers, through walls, floors, and ceilings. Normally, moisture moves from a warm area to a cooler one (see Fig. 7). A temperature differential on each side of a wall immediately produces a differential in vapor pressure, causing vapor migration. Vapor pressure is determined for given dry-bulb temperatures and relative humidities.

Moisture vapor in a residence should be dissipated through ventilation. Basic construction techniques and procedures can prevent or minimize most household moisture problems. Insulation, vapor barriers, weatherstripping, and storm sash used in combination with ventilation will help owners maintain a comfortable level of temperature and humidity without the annoying problems associated with excess moisture.

MANAGING INTERNAL MOISTURE

Moisture vapor can become a problem in walls, above ceilings, and in floors or crawlspaces. Insulation, vapor barriers, and ventilators can be used to manage moisture problems.

Crawlspace Moisture Management

Enclosed crawlspaces under the suspended floor of a house vary in air volume. Some property standards suggest a minimum foundation wall height of 24 in. (61 cm).

The ground enclosed by the foundation wall can become damp or wet, often raising the moisture content of the wood floor joist to a level that will support the growth of fungi. Some of these organisms do not damage the wood, but others are capable of destruction.

The primary causes of excess moisture in the crawlspace are:

1. Surface runoff water is not excluded.
2. Ventilation through vents is inadequate.
3. Excess moisture vapor is released by the ground.

Evidence of a Moisture Problem

1. The crawlspace soil is wet.
2. Surface organism growth appears on the sap wood of floor joists. This is usually a small "toadstool" organism, brown or green, and leaves a stain on the wood surface when smeared.
3. The bottom side of the floor insulation has beads of moisture on the surface or is saturated with condensed moisture in summer. This can develop in an air-conditioned house (usually in late summer). Remedial steps include adequate foundation ventilation to disperse the moisture vapor and installation of a ground cover to reduce the source of ground moisture.

Foundation Vents. A standard metal foundation vent is 8 by 16 in. (20 x 41 cm) and is usually in the top course of the foundation and usually is under a window. It has a metal grid of about 1 in. (2.5 cm) squares and may have a wire screen to exclude mice, etc., and an operating metal shutter. One standard suggestion for vent sizing is 1 ft^2 (930 cm^2) of unobstructed ventilating area for each 150 ft^2 (14 m^2) of crawlspace area. Thus, each standard vent has about 60 to 75 $in.^2$ (387 to 484 cm^2) of unobstructed area and is adequate to ventilate about 75 ft^2 (7 m^2) of crawlspace area. The ventilator location should permit cross ventilation.

The function of the foundation ventilator is to dissipate the moisture vapor in the crawlspace; therefore, the ventilator should remain open year round, except during the coldest days. Exposed water pipes should be insulated and protected with heat tapes in climates colder than that of South Carolina.

Plastic Ground Cover. Under laboratory conditions, with a 3-ft (1 m) water table, 12 gal. (45L) of water in vapor form can be released per 1000 ft (93 m^2) each 24 hours.

Polyethylene plastic ground covers are used over about two-thirds to three-fourths of the crawlspace area to reduce the amount of moisture vapor in the crawlspace air. Some ground area needs to be exposed, particularly if the house has hardwood floors. Some moisture is needed to prevent excessive drying of oak flooring and trim around doors and windows. If the floor or the head joint in trim begins to open, more ground can be exposed by rolling back some plastic.

For new construction, in which all floors are covered with carpet and vinyl products, the entire crawlspace can be covered with plastic. Some suggest covering the plastic with a few inches of sand to protect the plastic from light deterioration and reduce the condensation under the plastic. Plastic on the surface will frequently have condensation droplets during cool weather. The soil under the plastic may be saturated with condensed moisture.

Plastic ground cover reduces the foundation ventilator need to 1 ft^2 (930 cm^2) of unobstructed ventilator area for each 1500 ft^2 of plastic-covered crawlspace area, or one standard ventilator for each 750 ft^2 (70 m^2).

Vapor Retarders and Vapor Pressure

Vapor retarder is a term describing a material that resists the passage of moisture vapor through it. Retarders are needed on insulation to prevent moisture vapor from penetrating the insulation, with some of the vapor condensing out within the insulation. Such a development would cause the insulation to become wet and, therefore, cease to be an insulator.

Vapor pressure is a measurable pressure at a given temperature and relative humidity. Thus, a difference in temperature on each side of a wall, floor, or ceiling automatically sets up a difference in vapor pressure. This difference in pressure causes warm, moisture-laden air to migrate toward the cooler side of the dividing wall, floor, or ceiling.

Figure 8 illustrates the action of a vapor retarder during cold weather in both insulated and uninsulated heated houses. The illustration applies to ceiling and floors.

Aluminum foil and bituminous-treated kraft paper are extensively used as vapor retarders on one side of blanket-type insulation. Aluminum foil is totally resistant to vapor passage; the treated kraft paper is highly, but not totally, resistant. Polyethylene plastic, a highly resistant vapor retarder material, is sometimes installed on the living side of insulated walls, floors, and ceilings.

Window Condensation

Condensation on windows in cold weather can be reduced or eliminated by installing storm windows over existing window units. The air space separating the storm window unit from the regular window becomes an insulator. This space allows the temperature of the storm window unit to approach the temperature of the cold outside air while the temperature of the inside or regular window can approach the temperature in the house, or at least stay above a temperature that will cause condensation to take place on the inner unit.

In new construction or window-unit replacement, double or insulating glass within the sash coupled with weatherstripping is also an effective method of reducing or eliminating condensation.

Occasionally, after a storm window has been installed, the regular or existing window continues to have condensation, indicating that the storm unit does not fit tightly enough and is permitting an excessive amount of cold air to reach the regular unit. Caulking around the storm window usually corrects this problem. If, after a storm unit has been installed, condensation begins to form on it, the regular window probably does not have a tight fit and should be taped around the sash to reduce air leakage.

Attic Moisture Management

Attic ventilation is a basic method of moisture management. The usual source of attic moisture is migration of moisture vapor from the living area below, so many homeowners have loose-fill insulation blown into the attic with no vapor barrier. Some houses not having adequate attic ventilation have moisture condensation on the roof sheathing, rafters, and gable walls. Some may have frost on the bottom surface of the plywood sheathing during the coldest weather. And in some cases, the bottom of the roof sheathing turns dark because of organism growth such as mildew.

Proper attic ventilation is discussed in Ref. 4. The most efficient ventilation technique would be for 50% of the ventilation to be in the soffit board and 50% ventilation capacity in a ridge vent. The natural convection currents permit heated air to rise, drawing cooler air into the attic through the soffit vents and exhausting the air immediately through the ridge vent.

Figures 9 and 10 show the locations and types of commercially available ventilators for attics. Figure 9 shows the location of one type of soffit vent, and Figure 10 shows the locations of gable vents, two vents high on the roof, and a ridge vent. Soffit vents are needed to make the others perform efficiently.

Additional Moisture-Management Topics

Mildew can be annoying in houses that have cold spots or cold walls that cause condensation; in turn, mildew develops on these damp areas. Cold spots may cause mildew development along the edge of the ceiling on an outside wall. Usually, rearrangement of the ceiling insulation over these areas corrects a deficiency in coverage of the attic area. Occasionally, an uninsulated air-conditioning duct in a stud wall will allow mildew to grow on the wall over the duct.

Exhaust fans in the bath, laundry, and kitchen should be vented to discharge air to the outside. The amount of moisture vapor generated by a family of four varies between 21 to 51 pints (6 to 24 L) daily.

Fans should be selected for the particular job. Fan capacity is measured according to the number of cubic feet (cubic meters) of air it will move per minute. The size required for a particular job may be determined using standard ASHRAE techniques. An approximate technique for finding fan size in cfm is:

$$\frac{\text{Cubic Meters}}{\text{Minute}} \quad \text{CFM} = \frac{\begin{matrix}\text{(crawl space volume)}\\ \text{(room volume)}\\ \text{(attic volume)}\end{matrix} \times \begin{matrix}\text{number of air changes}\\ \text{desired per hour}\end{matrix}}{60}$$

Crawlspaces and basements need a minimum of 10 air changes per hour, kitchens require a minimum of 10 to 15 and bathrooms require eight.

A hood on a wall over a range should be rated at 40 cfm (36 m^3) per lineal foot (meter) of range top, and one placed on an island would require 50 cfm (4.7 m^3/min) per lineal foot.

Attic fans may also be installed to force ventilation. In fact, this is their most common use. They are sized according to the foregoing formula, with six to eight changes per hour required for ventilation. Larger fans aid the cooling of mechanical equipment. Installing a larger fan (instead of air-conditioning equipment) that will change air 30 to 60 times an hour, usually creates comfortable conditions.

MANAGING EXTERNAL WATER

Surface and other water external to the house must not be allowed to accumulate around or under a house. Lot drainage, roof downspout systems, and foundation waterproofing techniques will prevent free water from entering the house, where it can cause moisture vapor problems. Uncontrolled external water will produce excessive amounts of moisture in crawlspaces, creating ideal conditions for the growth of mildew and fungi. Common external moisture problems can be controlled.

Lot Drainage System

Every dwelling should have a grading and landscaping plan that provides control of all surface waters on the lot. One minimum property standard suggests a 2% grade sloped away from the house in all directions for a minimum distance of 10 ft (3 m).

It is not unusual for houses about 25 years old and older to need complete renovation of the landscaping and grading of the lot. Additions to the landscape plan, maturity of shrubbery, and soil erosion tend to change drainage patterns and, often, surface water meanders against the foundation wall.

Figure 11 illustrates the most common drainage problem of a sloping lot. The uphill side of the house must have a drainage waterway (valley) to conduct water around the house. This drainage valley should be at least 10 ft (3 m) from the house and sloped to conduct accumulated water away from the dwelling efficiently.

Gutter Water Management

Two basic methods are used to manage gutter water. They are splash blocks and drains. A masonry splash block is a precast concrete product designed to receive gutter water from the downspout. Its function is to prevent erosion and rapidly conduct and release the water at least 2 ft (0.6 m) from the foundation wall. Positive drainage away from the house prevents water from accumulating near the foundation wall. Some splash blocks are made of plastic and lack the sturdiness and durability of masonry or concrete.

Downspout water may be released into a clay tile or flexible pipe and conducted underground to a suitable release outlet. PVC plastic pipe may be used to conduct the water for some distance underground to a release point. Both rigid and flexible pipe are satisfactory underground and require a minimum of maintenance. Most gutters on a house need frequent inspection and any leaf accumulations should be removed. Gutter guards are partially effective in preventing clogging by leaves. Larger downspouts with a minimum of sharp turns have fewer stoppage problems.

Foundation Waterproofing

Site selection, landscaping the lot, and waterproofing the foundation can prevent water problems around and under a residence. Figure 12 illustrates a standard construction procedure for effectively waterproofing a masonry wall. Two thin coats of portland cement plaster are applied directly to the masonry surface, sealing the voids in the mortar joints and establishing a dense, impermeable layer. The foundation wall below grade is mopped with one or two coats of a bituminous foundation-coating material. Most manufactured foundation-coating material contains an ingredient to aid in establishing a bond between the masonry wall and the coating material. In any event, the manufacturer's instructions should be followed. Some materials require a primer before being applied to the wall. The label will specify what is needed.

A footing drain is installed at a level with the bottom of the footing, as indicated. The footing drain is also encased in gravel and the drain pipe is extended to an outfall away from the house.

Floor Slab Waterproofing

Concrete floor slabs on the ground must have a vapor barrier to prevent the movement of ground moisture through the concrete slab. Penetration of moisture can affect floor adhesives and mustiness in carpets. A standard construction procedure is to install both gravel and a polyethylene plastic-sheet vapor-barrier under the concrete. The function of the gravel is to break capillary water movement toward the concrete. The polyethylene impedes vapor movement above the gravel.

SUMMARY

The high cost and the variable availability of energy have created super-insulated houses with reduced ventilation in the attic, crawlspace, stud walls, and interior living space. Excess moisture, which is not as readily dispersed as in older, less well-insulated houses, can encourage condensation, mildew, and fungi.

Control of external water around and under a house is essential. Functioning lot drainage plans, gutter systems, waterproofed foundation walls and floor slabs, and sump pumps will eliminate water problems. Basements and crawlspaces can be dry.

On a year-round basis, positive ventilation is needed in attics, crawl-spaces, and living areas to disperse any accumulation of generated, migrated, or condensed water vapor.

Moisture and temperature conditions favorable to wood-destroying fungi will occur from time to time in most houses. Adequate ventilation is needed throughout the year to disperse any excess accumulation.

Household moisture problems are a product of smaller, tighter houses.

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2. Structures and Environment Handbook, Midwest Plan Service MWPS-1, 10th Edition (Ames, IA: Federal Extension Service, 1980), p. 25.

3. F. H. Hedden, Managing Internal Moisture in Residences, Clemson University Extension Guide Sheet (Clemson, SC: Cooperative Extension Service, 1981).

4. ASHRAE Handbook --1981 Fundamentals Volume, Table IV, p. 21.16.

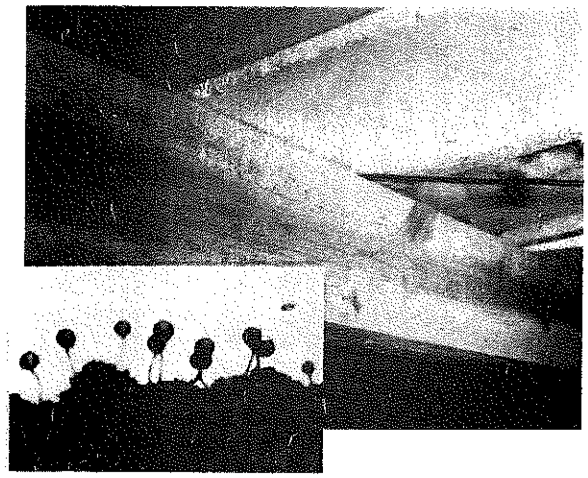

Figure 1. Slime mold fruiting on wood

Figure 2. Surface mold growing on ceiling

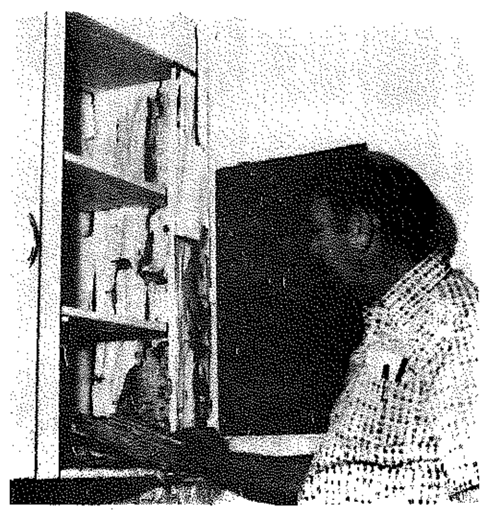

Figure 3. House extensively decayed by *Poria incrassata*

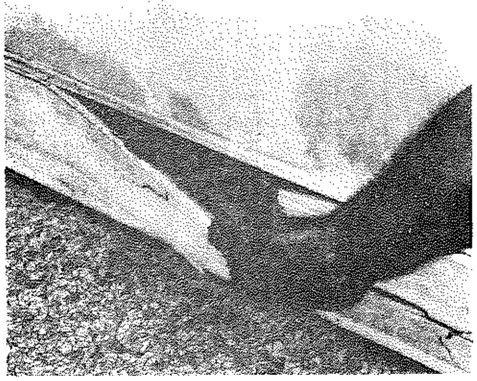

Figure 4. House extensively decayed by Poria incrassata

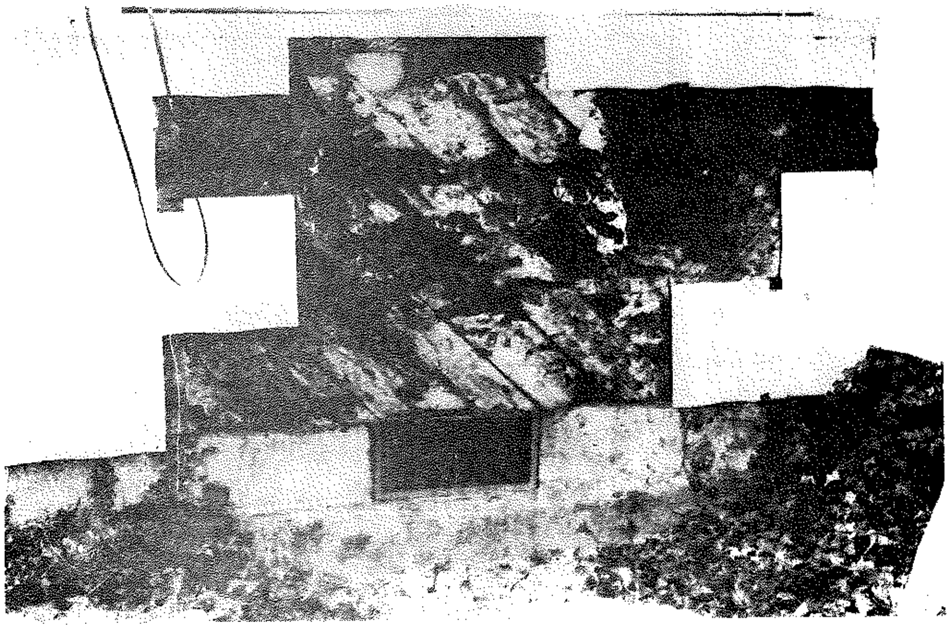

Figure 5. House extensively decayed by Poria incrassata

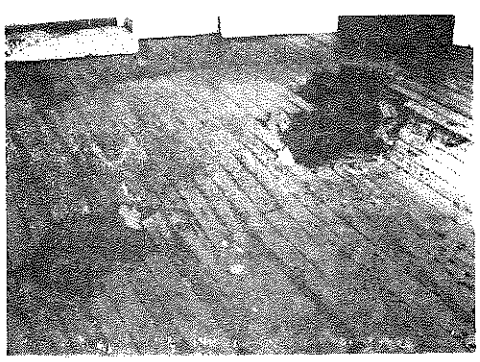

Figure 6. Floor of house extensively decayed

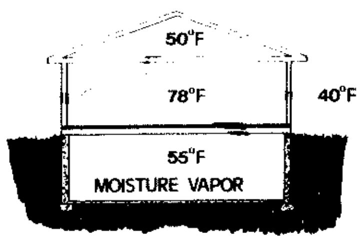

Figure 7. Temperature differentials cause moisture vapor to migrate between areas unless impeded by vapor barriers

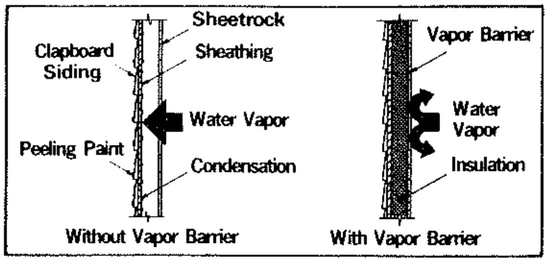

Figure 8. Vapor barriers prevent water vapor from condensing in the insulation or wall cavity. Wet insulation loses most of its insulating properties

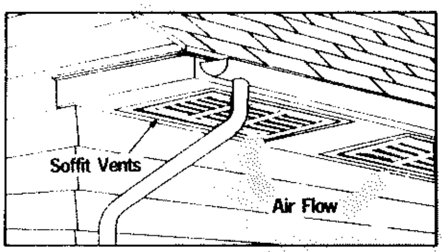

Figure 9. Soffit vents are needed to provide an air inlet and complete flow path when used with gable or roof vents

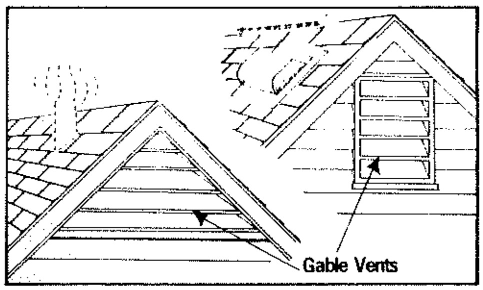

Figure 10. Gable and roof vents are needed to ventilate attics. They are used with soffit vents to provide a flow path

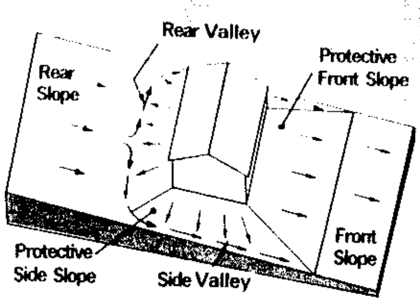

Figure 11. Illustrated surface water management plan of maintaining a 2% slope away from the dwelling for a minimum distance of 10 ft (3 m) in all directions

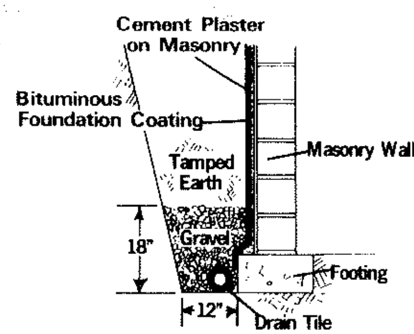

Figure 12. Waterproofing foundation wall