

DESIGN, CONSTRUCTION AND MAINTENANCE: FACTORS IN HOME MOISTURE DAMAGE IN THE SOUTHEAST

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Abstract

Inappropriate design, poor construction, and improper homeowner maintenance were leading factors in home moisture damage to houses studied in one southern state in the U.S. Additional factors were inadequate building codes, violation of building codes, and inadequate specifications and standards of materials and components. Data from two state regulatory agencies were studied to (a) learn the proportion of houses with moisture damage, and (b) identify the probable cause(s) of such damage and preventive measures. Data were comprised of consumer complaints filed during a 12 month period with the two agencies, and from site inspections to houses identified from these records. Types of moisture problems in U.S. housing vary by region, with total annual damage over \$1 billion. These costs are in addition to other repair and maintenance costs of housing, and contribute to total residential housing costs.

Introduction

A home is the single largest financial commitment most families make in a lifetime (Pifer, 1988). In addition, housing expense takes the largest share of the budget for most American consumers (Schwenk, 1988). Data from the 1988 Survey of Buying Power indicate that in 1987, 47.5 percent of South Carolina (SC) households had effective buying incomes (also referred to as disposable income) under \$20,000 and 75.9 percent had effective buying incomes under \$35,000 ("Regional and State Summaries of Effective Buying Income," 1988). The median was \$21,087 (SC Effective Buying Income, 1988).

By comparison, in 1987 the median sale price of an existing single family home in SC was \$68,433 (National Association of Realtors, personal communication, 1989). The median price of a new home was \$95,200.

For a SC household to buy the median priced existing home with a 20 percent down payment (\$13,687) would require a monthly payment of \$524 for principal and interest alone (assuming an 11 percent fixed rate 30 year mortgage). That is 30 percent of median monthly disposable income. Additional costs for property tax and insurance, utilities, maintenance and repairs would bring the total monthly housing cost to approximately \$950 per month, or 54 percent of the median monthly disposable income.

For a household with the same \$21,087 per year SC median disposable income to buy the median priced new house in 1987 (\$95,200) with a 20 percent down payment (\$19,040) would require a monthly payment of \$724 for principal and interest alone (assuming an 11 percent fixed rate 30 year mortgage). That is, 41 percent of monthly disposable income. Additional costs for property tax and insurance, utilities, maintenance and repairs would bring the total monthly housing cost to over 70 percent of monthly disposable income.

Annual routine home maintenance and repair costs are estimated to require from one to three percent of the market value of a home (U.S. Department of Housing and

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Urban Development, personal communication, 1991). Unnecessary additional repair costs from decay and insect damage related to excessive home moisture cost American homeowners more than \$1 billion each year, and statistics from the U.S. Forest Service indicate that decay fungi cause at least as much damage as termites nationwide (V. Rose, 1988). The current average cost to replace decayed structural wood such as a joist or sill is \$50 per lineal foot. Thus, if a 50 foot sill, for example, needed replacement, the cost would be \$2,500 (Beiers, 1987). These added costs can be eliminated if consumers and industry personnel are aware of the potential problems and know how to prevent or correct them.

Though no statewide data on the frequency of home moisture damage was available, over 500 requests for help were received by one SC county alone during a recent year (Gardner, 1986). Benchmark data on occurrence of damage in existing homes was needed. The data would be used to plan preventive educational programs designed to reduce this costly damage to SC homes.

Research

No investigation of home damage from excessive moisture and related insects had been conducted in SC prior to this study. Field observations of house conditions have been made (as requested by state citizens and county personnel) since the mid 1970s when Hedden, Labosky and Spray published their findings (1975). Field observations have been conducted by faculty from the Agricultural Engineering, Home Economics, Entomology, and Forestry Departments of Clemson University in an effort to answer client questions on housing problems. Slides, videotapes, and films were made of cases over the years in an attempt to document and learn more about the problems, possible causes, and preventive or corrective measures.

Several studies on housing moisture problems have been done in Scandinavian countries, Canada, and cold climate areas of the U.S. (Adamson, 1986; Lstiburek, 1987; Sherwood and Peters, 1977). However, the damp, warm climate of the Southeast and the several geographical and climatic regions of SC pose problems different from those of other climates.

A related survey was done of 774 houses in the Raleigh, North Carolina area in the fall and winter of 1973 and 1974 (Peterson and Levi, 1975). However, the energy conservation efforts of the late 1970s have created different conditions and contributed to different kinds and degrees of home moisture problems (TenWolde and Suleski, 1984). W. Rose's report (1987) of a study on moisture problems in the Champaign-Urbana, Illinois area, took into account current energy conservation practices, but not the warm, humid climate of SC, the variations of coastal to mountain climates, nor the building codes in effect in this state. State-specific data are critical to development of preventive and corrective educational programming.

The preliminary report of a study by a home economics Extension housing specialist at the Florida Experiment Station includes data collected during a one year time period. Surveys were sent to two groups in 12 Florida counties: a) volunteers who had first called with a mildew problem to their county Extension Home Economist and then agreed to participate in the survey and (b) a random sample drawn from each of the same 12 counties. Eighty-nine percent of the volunteer respondents had mildew in their home. Of the random sample respondents, 64 percent had mildew (Peart, 1988).

Methods

Objectives

The objectives of this exploratory survey were (a) to learn the frequency of occurrence of moisture damage in SC housing, and (b) to identify the probable cause(s) of the damage. In addition, the researchers planned to use findings to develop methods and an instrument appropriate for use in a larger, random sample study.

Sample

In SC, two regulatory agencies which receive and investigate consumer complaints regarding housing problems maintain records of those complaints. The two agencies are the Clemson University Department of Fertilizer and Pesticide Control (the regulatory body for SC licensed pest control operators) and the SC Residential Homebuilders Commission (the agency which licenses contractors who build one and two family dwellings). These public records of houses were the sample. The July 1986 through June 1987 records of the two agencies were reviewed to learn (a) the number of recorded complaints which involved moisture-related problems, and (b) the probable cause of the identified moisture problems.

The first source of data was records kept by the Department of Fertilizer and Pesticide Control (DFPC) on complaints involving inspections and/or services performed by licensed pest control operators (PCOs). Being in the "termite belt," homes in the state require the protection afforded by the use of highly toxic chemicals and the control of moisture in the substructure or crawl space. A homeowner dissatisfied with or questioning the service received from a PCO may lodge a complaint with the DFPC which then sends a field inspector to examine the property and adjudicate the complaint. The report prepared by the field inspector covers, among other things, damage caused by the presence of wood-destroying fungi, conditions conducive to decay by wood-destroying fungi, the existence of wood in contact with the soil, the presence of a vapor retarder layer over the ground in a crawl space, and any sources of moisture in the crawl space such as flooding or leaky pipework. All of these points are critical in the assessment of damage due to moisture. Excessive levels of moisture in the crawl space lead to wet timbers which encourages fungal and insect attack (Peterson and Levi, 1975).

Prior to examining these records, the investigators knew that consumer moisture problems were reported to county Extension agents most often in the spring and autumn, coinciding with the start and end of the wet seasons and the start and end of heating and air conditioning seasons. A review of the data from a number of years indicated that an approximate normal distribution of occurrences would be found over the course of the first or last six month periods in any year.

Data were also obtained from the SC Residential Homebuilders Commission (RHBC). Information is collected by the Commission in the form of formal complaints brought to their attention by homeowners experiencing problems with their dwellings. This information is recorded on complaint forms from which data can be extracted. Thirty-four cases of moisture-related complaints filed from July, 1986 through June, 1987 were studied.

The investigators then conducted site investigations of selected houses chosen from the records as exhibiting typical moisture problems. In addition, site investigations were conducted at selected moisture problem homes which homeowners had reported to county Extension agents between July 14 and August 14, 1987. A special investigator of the RHBC, certified in residential building codes in effect in SC, participated in the site inspections with the researchers.

Variables

The presence of moisture damage was the dependent variable. Probable causes identified will be used as independent variables in future studies.

Limitations

While the data can be held to be typical of the moisture problems, the data cannot quantify the moisture problems for housing in the state as a whole as the records include a relatively small and non-random sample. Further, the DFPC records were prepared by a DFPC field inspector trained in entomology, not a building specialist nor a person who was looking particularly for moisture-related problems. Analysis of the data to identify cause(s) of moisture problems and prevention procedures was based on the experience and interpretation of the researchers.

From data obtained in records of the two regulatory agencies, frequency of occurrence of moisture damage was calculated. Probable causes were determined based on the damages reported and the professional experience and interpretation of the researchers, documented research, and building codes.

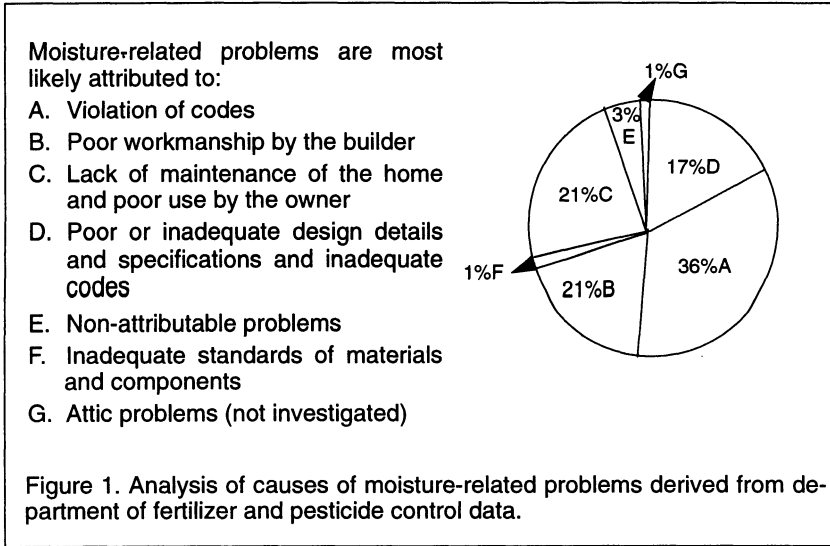
Results

Data from the DFPC reports for the period July-December, 1986 indicate that there were 215 reported cases of problems, of which 106, or 49 percent, were moisture-related. A second data set corresponding to the period January 1987 through June, 1987 shows there were 198 reported cases of problems, of which 108, or 54.5 percent, were moisture-related. Data from other years gave similar figures for the frequency of incidence of moisture-related problems. The main kinds of reported moisture-related problems were attributed to the following causes:

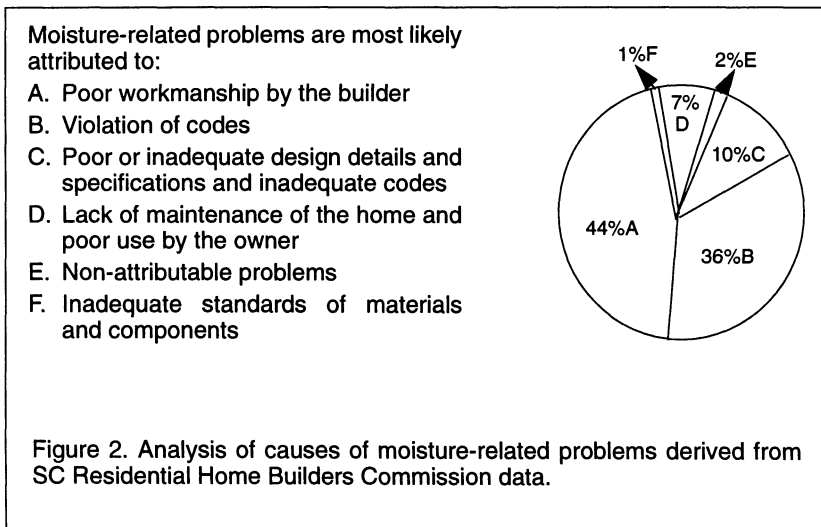
1. Substructure
 - a. Too little or no ventilation in the crawl space
 - b. Vapor barrier incorrectly installed or not installed at all in the crawl space
 - c. Inadequate crawl space height, in respect to building code specifications
 - d. Standing water or dampness in the crawl space
 - e. Debris in the crawl space (including vegetable or organic matter and even trees)
 - f. Timber in contact with the soil
 - g. Appliances vented into the crawl space
 - h. Plumbing leaks
 - i. Inadequate ground/surface water drainage away from footings and away from the building across the lot grade
 - j. Air conditioning ducts in contact with the sub-floor
2. Superstructure
 - a. Inadequate guttering or no gutters or downspouts
 - b. Inadequate roof overhang in relation to climate
 - c. Inadequate or damaged roof flashings
 - d. Improperly sealed doors and windows
 - e. Improperly installed insulation in wall paneling/siding
 - f. Attic problems (lack of ventilation/improper insulation)

Problems cited in 1 and 2 are most likely attributable to one or more of the following categories, as illustrated in Figure 1:

- Violation of codes
- Poor workmanship by the builder
- Lack of maintenance of the home and poor use by the owner
- Poor or inadequate design details and specifications and inadequate codes
- Non-attributable problems
- Inadequate standards of materials and components
- Attic problems (not investigated)



A similar list of problems has been derived from data of the SC Residential Home-builders Commission. Those problems can be attributed to a similar number of categories (see Figure 2).



The quantity of data available on problems in superstructure (n=13) was not large enough to allow any conclusions to be made. The discussion therefore concentrates on problems arising from the substructure. The survey of records from the regulatory agencies provided data which was used to develop and field test a survey instrument for use in later research.

Discussion

Main Problem Areas Identified

Having identified the most commonly reported moisture problems as cited in lists 1 and 2, the researchers then grouped them into categories based on probable causes as shown in Figure 1. The problems and causes which required most urgent action were improper standards of ventilation to the crawl space, lack of a dampproof layer in the substructure walls, lack of a vapor retarder layer over the ground in the crawl space, improper grading of the ground inside and outside the foundation wall, and lack of treatment to the walls of the substructure.

Improper ventilation, the first of these, was largely attributable to a code violation. Clause R-309-1 of the CABO (Council of American Building Officials, 1986) building code details how to calculate the required number of vents based on the ground floor area. Table 1 shows the number of ventilators required for rectangular shaped houses of given floor area, allowing for one ventilator at each corner of the building, assuming each ventilator has 72 square inches of net free area.

Table 1. Number and spacing of foundation ventilators in crawl space construction.

Area of lowest floor in sq. ft.	Example Approximate perimeter in ft.	Number of vents required by R-309-1	Spacing of vents (allowing one at each corner)
1000	130	14	12 feet apart
1400	155	18	11 feet apart
1800	180	24	9 feet apart
2000	195	28	8 feet apart
3000	250	40	7 feet apart

When compiling Table 1, it was assumed that the house plan was a simple rectangle, ventilators would be spaced evenly around the walls, and a ventilator on each corner would be provided to avoid occurrence of "dead" air pockets in the crawl space. "Dead" air pockets were found to be all too common in houses which were physically inspected, and in every case resulted in high levels of moisture content with resulting fungal infestation. Moisture content varied substantially from one area to another in the same crawl space due to these dead spots. The CABO building code does allow that one wall or a substantial portion of a wall, can be left without ventilators. The prudence of this practice has to be in doubt following the initial observations carried out as part of this study.

The next problem to be addressed was the omission of any dampproof layer in the substructure walls. By taking measurements of the moisture content in the masonry and in wooden members resting on it, the researchers did ascertain that moisture was being transferred from the ground to the walls, and finally to the wood. This happens in the United Kingdom (U.K.) as well as in the U.S. (The Building Standards [Scotland] Regulations, 1981). The question of a termite shield was raised at this point. In the past, it has been customary to build a sheet metal strip onto the top of the masonry foundation to prevent termites from gaining access to the timber above. This strip could perform the dual function of moisture barrier and termite barrier. None of the 20 houses inspected had such a barrier. Thus, where the ground was damp, the moisture was being transferred to the timber. The reason for the lack of termite shields was simply that their efficacy in dealing with termites was in serious doubt; therefore, they had been discontinued. The researchers recommend termite shields should be re-introduced to provide a dampproof layer in the walls.

Soil Levels and Drainage

Another common problem was the lack of proper grading of the soil in the crawl space together with the lack of any control over the ingress of ground water, rainwater run-off, and moisture evaporating from the soil surface. It was the opinion of many builders that some moisture from the soil was necessary to avoid undue drying shrinkage in decorative hardwood flooring. While this might be true of older buildings where the introduction of a dampproof membrane would upset the balance of moisture content, it should not be the excuse to continue what is inherently improper building practice. Modern timber technology allows the builder to lay hardwood floors with a moisture content which will alleviate drying shrinkage when the house is occupied (Timber Research and Development Association, 1988).

In each of the 20 houses physically inspected, the ground of the crawl space showed the following evidences of running water: scour marks in the soil, "tide" marks on walls and columns, and puddles of water and mud. In one or two cases, water was standing to a depth of several inches over the whole area of the crawl space. In some of the houses the exterior ground adjacent to the house was entirely above the ground level in the crawl space. In other houses, two or three sides of the building suffered from the same conditions. In all but one, the ground around the house was sloping toward the house on at least one side. This meant that surface water run-off could build up under the house if it penetrated the walls of the substructure. In most instances, the concrete carport or driveway was on the end of the house where the ground level was highest, thus concentrating run-off water against the building. In the majority of instances, the substructure walls were of half brick thick construction (4.5 inches) without any surface treatment and so presented no barrier to water seepage. Where brick was not used, concrete block was substituted and of a type which was generally more porous than clay brick. No examination was made of the sub-soil conditions on any of the sites, but where houses were built on flat areas and the crawl space was below the exterior ground level, standing water was a result of run-off. In one building examined, standing water resulted from ground water. Apart from the hazard to building materials from potential fungal attack, standing water is a potential health hazard for the occupants (Sterling, Arundel and Sterling, 1985).

The soil had not been leveled out under some houses. Attempts were being made in most problem cases to regrade the soil under the floors. This was to allow any water entering to drain to a point where the water could be drained from the crawl space. In one or two instances, builders were returning to dig a trench around the inside of the substructure, lay a perforated drain pipe and backfill with gravel. Polyethylene sheeting was being laid over the crawl space in an attempt to control the rate of evaporation from the crawl space ground. Though these are admirable efforts to resolve these problems, they are no substitute for proper measures being taken when a building is first erected. For example, the introduction of perforated drain pipe inside an existing building foundation is very expensive and might be avoided if a proper drain were put outside when the house is first built, and for less cost.

Proper control over the ingress of ground water and the evaporation rate requires that an impervious layer be laid over the entire crawl space (The Building Standards [Scotland] Regulations, 1981). This layer should be laid horizontally and should be no lower than the outside ground level, although the layers may be stepped down to follow the natural slope. The use of polyethylene alone is not the ideal solution. Too often it is disturbed when (a) maintenance personnel enter the crawl space or (b) it is moved aside by a flow of water. There are a number of solutions, one being a layer of concrete no less than 3 inches thick laid over a layer of compacted gravel 4 inches thick, with a top finish layer of sand or ash. The layer of gravel can be thickened to take up any slope in the crawl space ground but should not be less than 4 inches thick.

Though it has been found to be reasonably satisfactory as a vapor retarder in the southern part of the U.K., concrete is not entirely waterproof or vaporproof. Scottish

Building Regulations require a layer of polyethylene under the concrete to achieve full waterproofing and vaporproofing. Other materials can be used, one being a layer of hot applied bitumen or coal tar pitch over a compacted gravel bed with sand or ash finish layer. The layer of bitumen should be a minimum of 0.357 inch thick and the gravel a minimum of 4 inches thick. This is generally a less expensive solution than a concrete slab.

Crawl space ground treatment is required where the crawl space level is below the outside ground level. Stopping the ingress of surface water through the walls is critical. Techniques available and already widely used where the habitable part of the house is below ground level could be easily and inexpensively applied to all similar substructure walls up to ground level. Table 2 includes cost estimates of a coating of cement mortar over the brickwork, finished with two coats of a bituminous paint.

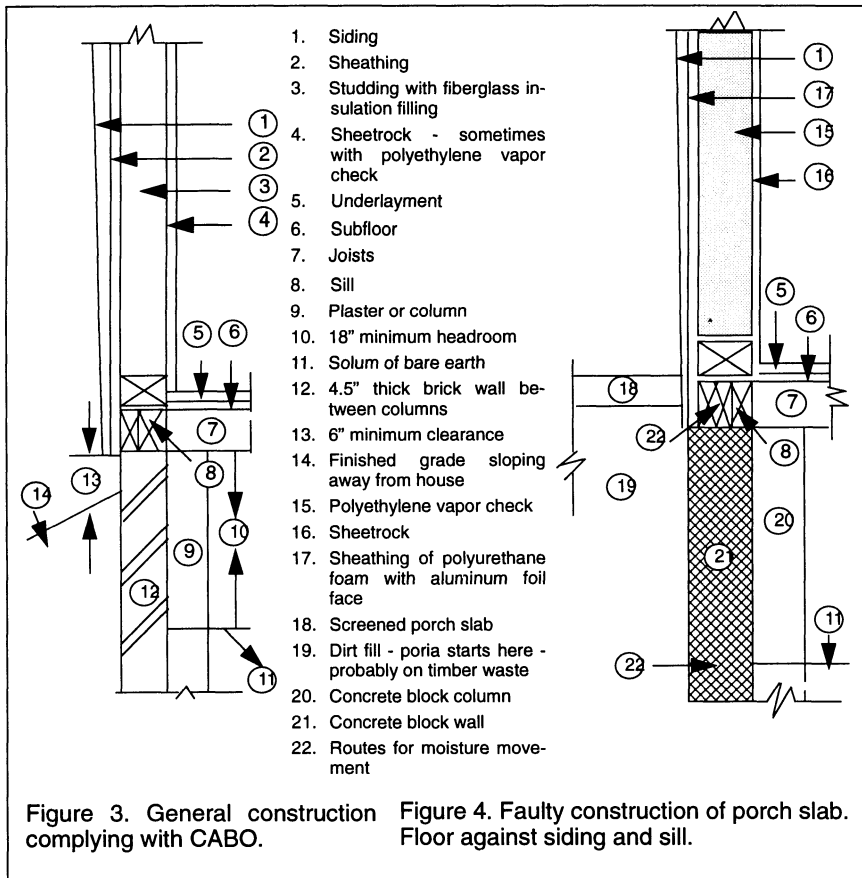
Table 2. Cost estimates of construction details to prevent moisture damage (1987 prices).

Area of House in Sq. Feet (1 story)	Cement Mortar Parge and Bitumen	Dampproof Layer in Wall	Proper Number of Vents	Concrete on Gravel Grade in Crawl Space	Total for All Items	Cost of Medium Quality House	Total as% of Cost of House
1000	\$156	\$26	\$84	\$900	\$1166	\$65,000	1.80
1400	\$186	\$31	\$108	\$1260	\$1585	\$91,000	1.75
1800	\$226	\$36	\$144	\$1620	\$2016	\$117,000	1.72
2000	\$234	\$39	\$168	\$1800	\$2241	\$135,000	1.66

Another problem addressed was the presence of carport slabs, garages, driveways, screened porches, and similar structures, all with concrete floors and dirt fill against the side of a house with a crawl space. Here again there were code violations. The CABO (Council of American Building Officials, 1986) building code states that untreated wood siding should not be within 6 inches of the ground level. Figure 3 illustrates construction practice to comply with CABO.

In most instances, the finished surface of all types of slabs was the same as, or only a few inches below, the floor level of the house. This means that dirt fill carried up past the level of the structural sill and the siding. Moisture moved up from the ground and transferred to the timber, which rotted. Not only did the sill rot, but so did the siding and the wall studs. One house examined had been attacked by *Poria incrassata*, a virulent fungal growth. The fungus started in the sill in a dirt filled screened porch, rotted out the floor joists for about 6 feet of their length, rotted out the floor adjacent to the porch and was attacking the wall studs to a height of 7 to 8 feet above floor level. Figure 4 illustrates the form of construction used in that instance.

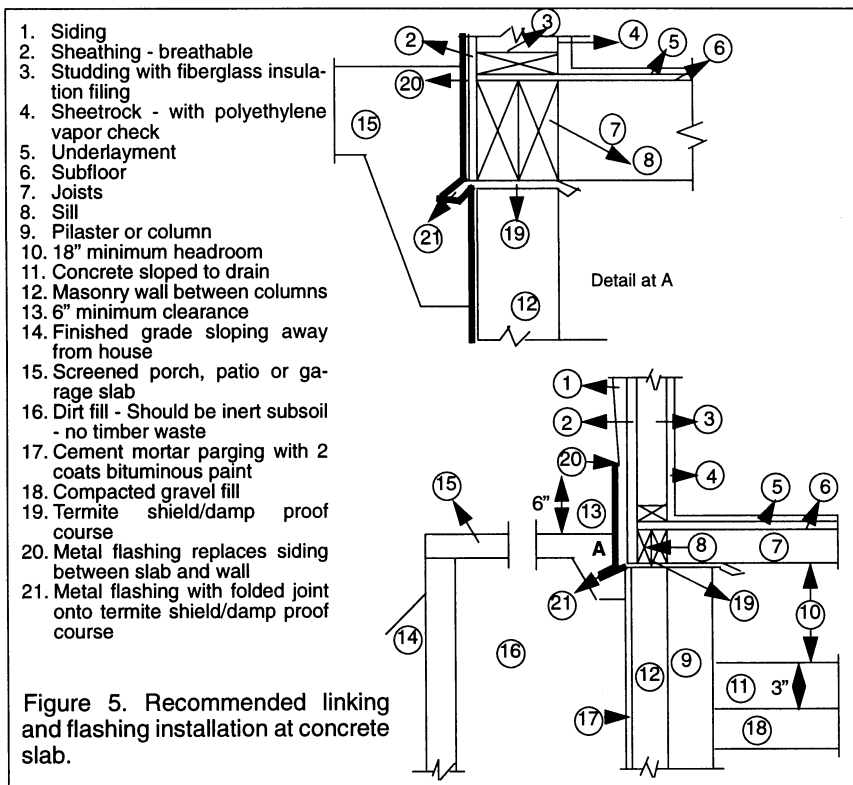
The problem of dirt filled porch construction in one house examined could have been prevented at little or no extra cost if the builder had (a) utilized the detailing noted in Table 2, and (b) linked the wall surface coating to the dampproof course (The Building Standards [Scotland] Regulations, 1981). Figure 5 illustrates this recommended simple construction technique. The house examined had only a loose polyethylene vapor retarder, inadequate ventilation, a crawl space level below the exterior ground level, and no coating of the external walls.



Home Use and Maintenance

Poor use of houses by owners, as well as lack of maintenance, were found to cause moisture-related problems in 21 percent of the DFPC cases and 10 percent of the RHBC cases. Poor use could include such management practices as (a) allowing yard sprinkling or irrigation to come in contact with building materials or to raise the moisture content of soil near the house; (b) closing and blocking foundation and attic vents and thereby blocking ventilation; (c) storing organic materials in a crawl space; (d) disturbing vapor retarder films in crawl space while doing inspections or repairs or allowing children or animals access to the crawl space; (e) storing firewood or leftover building materials in contact with house; (f) venting a clothes dryer into a crawl space to retain dryer heat; or (g) incorrectly installing additional insulation in attic or crawl space.

Lack of maintenance could include failure to (a) repair plumbing leaks; (b) keep appliance and HVAC ducts properly secured and sealed; (c) maintain proper drainage in spite of settling and changes in soil and ground cover levels; (d) maintain gutters, downspouts and roof flashings and coverings in good repair; and (e) check and replace caulking around doors and windows as needed. Lack of maintenance also could include failure to keep vents unblocked by dust, spider webs, paint, or insulation.



Conclusions and Implications

In this study of damage to homes from excessive moisture, damage was attributable to inappropriate and inadequate design details and specifications; poor construction including violation of building codes and poor workmanship; lack of maintenance on the home and poor use or management by the owner; and inadequate building codes and standards of materials and components. Design, construction, and maintenance methods are available for the prevention of home moisture damage.

Results of this research will guide ongoing planning and delivery of research-based educational programs for consumers and industry groups across SC. These programs should increase awareness of potential moisture damage to homes, and suggest preventive and corrective measures. The beneficiaries of these research results include not only homeowners, but also various industry groups who at the present time are increasingly subjects of litigation (Patterson and Bagby, 1987) to determine fault and responsibility for costs of repairs necessitated by moisture damage. An estimate of the magnitude of the socioeconomic benefits in South Carolina takes into account current repair costs for specific repairs times the frequency of occurrence of that type of damage. The implications for economic savings by state residents are clear. Further, decreased damage to homes preserves the real estate tax base. Finally, additional economic savings may be achieved in other states with warm, humid climates.

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Authors' Note

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