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Field Experiences Underscore the Importance of Moisture Control in Energy-Efficient Homes

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Abstract

Tennessee Valley Authority's (TVA) most successful energy conservation project to date is the Home Insulation Program (HIP) which was initiated in August 1977. TVA's HIP is this nation's largest home weatherization effort; it provides free home energy audits and no-interest financing for weatherization measures. Homeowners, tenants, and landlords are eligible for participation through one of TVA's 160 power distributors. As of April 16, 1982, 589,737 living units had been surveyed and 288,820 of these units had received interest-free loans for weatherization measures totaling approximately $277,000,000.

Early in 1980, TVA's central office began receiving complaints from field offices that some weatherized homes were experiencing problems associated with either excessive or insufficient moisture. An investigation was initiated to evaluate and categorize those types of problems and recommend changes to procedures or field actions as required. To date, findings indicate that there are no intrinsic characteristics of the energy-efficient house that cause a moisture problem. Field surveys of houses with complaints have underscored the need for better control of moisture as the infiltration/exfiltration rates are reduced through weatherization. The solutions to the problems encountered have generally been straightforward provided the moisture source can be readily identified. This paper will review the state-of-the-art for moisture control, provide relevant field experiences, and recommend areas for further research and field study regarding the current construction practices and building codes in use.

INTRODUCTION

Tennessee Valley Authority (TVA) is a corporate agency of the United States Government. It was established by Act of Congress in 1933 to develop the Tennessee River system and to assist in the development of other resources of the Tennessee Valley and adjoining areas.[1]

The production and sale of electric power are part of TVA's resources development program. TVA is this nation's largest electric utility with a capacity in service in excess of 32,300 megawatts. TVA supplies power at wholesale to 160 municipal and cooperative distributors and one privately owned electric system which in turn distribute power to over 2.8 million customers in parts of seven states. TVA also supplies power directly to 50 industrial customers and several federal, nuclear, aerospace, and military installations. The 1981 power sales were 115 billion kWh which generated revenues of \$3.78 billion. The power is supplied by 109 hydroelectric units, 63 coal-fired units, 48 combustion turbine units, 5 nuclear units, and 4 pumped-storage units.[2]

The power program is financially separate from other TVA programs. It is required to be self-supporting and self-liquidating.[3] The average residential cost in 1981 was 4.07¢/kWh, and the newest rate effective in October 1982 will average approximately 4.8¢/kWh.[4]

Electric power rates began a dramatic upward spiral in the Tennessee Valley and across the nation in the early 1970s. Rapidly rising fuel costs, worldwide inflation, high interest rates, and the sharp rise in construction costs contributed to the spiral. TVA's residential electric rate rose from 1.3 cents per kilowatt-hour in 1973 to about 4.8 cents per kilowatt-hour in 1982.

To help consumers cope with rising rates, TVA has undertaken one of the nation's largest energy conservation programs. Conservation programs provide savings to the power system by enabling it to defer high cost new capacity and reducing consumption of high cost fuels. These savings can then be passed on to all consumers through rates lower than would otherwise be necessary. Conservation programs also provide the most immediate savings in consumer bills.

TVA's Home Insulation Program was initiated in August 1977 to help residential consumers in the TVA service area reduce the use of electricity by installing insulation, weatherstripping, caulking, and storm windows that are cost justified based on a simple payback of seven years. The program provides free energy surveys, with recommendations for cost-effective weatherization measures and attractive financing for those that choose to take advantage of it. The loans are at zero-percent interest and are repaid on the consumer's electric bill over a period of up to seven years. Homeowners, tenants, and landlords are eligible for participation through one of TVA's 160 power distributors.[5] As of April 16, 1982 589,737 living units had been surveyed and 288,820 of the living units had received interest-free loans for weatherization measures totaling approximately \$277 million.

During the late summer of 1981, TVA's Conservation and Energy Management Branch learned that the seven TVA district offices were receiving customer complaints that weatherization measures installed under the Home Insulation Program appeared to be related to moisture problems either in or under houses. An investigation into the nature and the extent of the complaints was initiated. For the purpose of this study, an energy-efficient house is defined as one that has had weatherization options retrofitted that have a simple payback equal to or less than seven years.

FINDINGS

To date, from approximately 140 houses with noted complaints, 36 houses that were thought to depict a variety of complaints have been investigated in various Tennessee Valley locations. These houses, which are listed in the appendix, do not represent a statistically significant sample when compared to the 589,737 living units surveyed, 288,820 living units with weatherization measures financed under the HIP, or the 106,014 floor-insulation jobs financed as of April 16, 1982. TVA's main concern was that these complaints might establish an early trend that warned of future problems. From the inspections performed to date, the incidence of moisture-related problems in residential structures appears to be more common and varied than anticipated, but is not restricted to weatherized or energy-efficient houses that participated in the HIP. The complaints investigated to date can be segregated into two general categories: those that appear related to problems of excessive moisture and those that appear related to excessive drying.

Before further discussing these findings, a brief introduction to wood and its properties, the wood/moisture relationships, causes of wood deterioration, and techniques for moisture control is necessary in order to understand the importance of moisture control and its complex nature.

PROPERTIES OF WOOD

Wood is our most abundant renewable resource and the building product most adaptable to a multitude of uses. Wood has high strength relative to its weight in compression, tension, bending, and resistance to impact. Wood is divided into two types--hardwood and softwood. These classifications are botanical differences and are not related to the descriptive softness or hardness of wood. The properties of wood are determined by its physical and chemical composition, and most characteristics of wood are related to the porous nature of its tubular cells.[6]

Wood cells or fibers are primarily cellulose, bonded together with a material called lignin. Wood is approximately 70% cellulose, from 12 to 28% lignin, and up to 1% ash-forming materials (exclusive of free and absorbed water). These constituents give wood its strength, its hygroscopic properties, and its susceptibility to decay.[7]

WOOD MOISTURE RELATIONSHIPS

Wood is hygroscopic. In general use it expands when it absorbs moisture and shrinks when it loses moisture. The moisture content of wood is ordinarily expressed as a percentage of the weight of the wood when oven dry. Moisture in green wood is present in two forms: in cellular cavities as free water and within cell wall fibers as absorbed water. The point at which the fibers are saturated but cell cavities are empty is called the fiber saturation point (FSP), which occurs in most U.S. wood species at between 28 to 32% moisture content (MC).[8] The significance of the FSP is twofold. First, wood shrinkage begins only below this point, and second, wood decay can occur only above this point.

Ideally, wood should be fabricated and installed at a moisture content as close as possible to the equilibrium moisture content it will attain in use to ensure that wood in service will experience only minor dimensional changes.[9] For wooden framing members of houses in the TVA service area, this is around 9 to 14%.[10]

WOOD DETERIORATION

The serviceability of wood as a building material depends upon its protection from a variety of deteriorating agents. Wood can be degraded by biological agents such as fungi and insects, environmental agents such as sunlight, storms, and moisture, and physical agents such as fire, earthquakes, and chemicals.[11] The agent of primary concern within the scope of this paper is fungal attack.

There are three major groups of fungi that attack wood. A detailed treatise on the groups and characteristics of wood-inhabiting fungi is beyond the scope of this paper but are summarized as follows:

1. Surface-staining fungi: These fungi referred to as molds or mildew produce colorless hyphae within wood and colored fruiting bodies on the surface of wood. Surface-staining fungi do not alter wood's mechanical properties, but indicate that the surface of the wood was at or above a 20% moisture content at some time.

2. Sap-staining fungi: These fungi produce colored mycelia within the wood structures which produce a discoloration that cannot be removed by brushing or sanding the surface. They do not cause wood to decay and do not reduce its strength, but, like surface-staining fungi, they increase its capacity to absorb moisture.

3. Decay fungi: These fungi cause reduction in wood strength and are commonly called "rots." They attack both sapwood and heartwood by the

production of a thread-like strands called hyphae which permeate the structures. These fungi feed on the structural wood components (cellulose and lignin), thus weakening the wood. Early stages cannot be determined by visual examination but advanced stages produce gross changes in the characteristics of wood. Decay fungi can be grouped into four classes: soft rot, white rot, brown rot, and water-conducting rot.

1. Soft-rot fungi occur in wet conditions usually associated with cooling towers or marine environments and are of little concern to the homeowner.

2. White-rot fungi destroy cellulose and lignin, primarily in hardwoods, imparting a white, bleached appearance. The wood often is stringy when broken and feels spongy to the touch. The strength of wood decreases gradually as decay proceeds. There is no abnormal shrinkage.

3. Brown-rot fungi are the principle causes of building decay in the U.S. They predominately attack softwoods making the wood brown in color, brittle, and easily crushed. Brown rot infested wood shrinks abnormally upon drying and sometime collapses.

4. Water-conducting decay fungi are also a type of brown rot. They are unique among wood destroying fungi in that they can conduct water into wood that is below 20% moisture content through large water-conducting strands called rhizomorphs. They have most of the appearance characteristics of brown rot except for the additional presence of rhizomorphs and the location of decay away from obvious moisture sources.

Fungus growth can occur in wood only if the following conditions are satisfied:

(1) an adequate food supply of organic material (which for decay fungi is the wood itself), (2) mild temperatures ranging from approximately 30°F (-1°C) to 104°F (41°C) (highest growth rates between 60°F (18°C) to 90°F) (26°C), (3) sufficient oxygen, (4) a wood moisture content in excess of the fiber saturation point (MC greater than approximately 30%), and (5) seeds or spores of decay fungi (which are sufficiently available in the air, to cause germination on any suitable host.)[12]

Of these five requirements for fungal germination and growth, three are beyond the realm of practical control. Mild temperatures are provided by the environment, oxygen is readily available from the atmosphere, and spores are found almost everywhere. The only requirements that lend themselves to control are the availability of an adequate and suitable food supply and the moisture content. Wood can be rendered unsuitable to fungal growth by the addition of preservative chemical such as creosote, pentachlorophenol, and water-borne salts (e.g. chromated-copper arsenate). Each type of preservative is best suited for specific applications and has some limitations. All have limited application in existing structures. The single condition controlling fungal growth that is the easiest and most practical to control is the moisture content of the wood.

MOISTURE CONTROL

Controlling excessive moisture is the key to preventing condensation that leads to mold and mildew problems and, ultimately, decay problems. This is accomplished by a combination of controlling moisture at its source and providing the proper ventilation.

Stopping or Redirecting Moisture at the Source

Water must be controlled to correct or prevent moisture condensation problems, whether originating from outside weather conditions (rain or snow) or from water vapor inside or below the house.

Correct Surface Drainage. All rainwater should be directed and drained away from the house, whether the house is built over a basement, a crawl space, or on a slab. The ground should slope away from the house and water should not be allowed to collect within 10 ft (3.1 m) of the house. Minimum grading specifications require a slope of 6 in. (15 cm) within 25 ft (7.6 m) on all sides of the house. The drainage ditch (if any) that collects runoff water should also slope away from the house.

Water near the footings of the foundation should be collected in tiles that have open joints and are connected to an adequate storm sewer. If the storm sewer is not available, the drain tile should be directed into an open ditch that is lower than the footing or into a dry well that is filled with sand and gravel.

Roof runoff water should be prevented from collecting on the ground next to the house or splashing onto the exterior surfaces from patios, carports, etc. A three foot (0.9 m) overhang on 1-story (single-level) houses provides adequate protection. If the house contains two or more stories or the eave projection is less than 2 ft (0.6 m), gutters and downspouts should be installed. If the storm drain is subject to flooding, divert the downspout runoff water away from the house by concrete splash blocks at least 30 in. (76 cm) long. In some cases where diversion of runoff water is impossible, waterproofing of foundations or the installation of sump pumps is an alternative.

Clothes Dryer and Washer Moisture. Using properly located ventilation to exhaust moist air from a clothes dryer can be classified as eliminating moisture at the source. Clothes drying is another important source of moisture originating in a normal household. As much as 26.4 lb (12 kg) of water can be evaporated in a day by doing a week's laundry for a family of four.[13] An automatic clothes dryer should be connected to a short vent duct 8 ft (2.5 m) long or less, preferably without any turns, leading to the outside of the house. The exhaust from a dryer should never be vented into the attic, utility room, conditioned living space, or crawlspace.

Cooking and dishwashing can add up to 35 lb (16 kg) of water to the house per week. Each shower bath can add 1/2 lb (1.25 kg) of water to the air.[14]

Water vapor added to the air by respiration from a family of four persons, after making normal allowance for children's time away at school and parents' time away at work, would be approximately 6 lb (2.7 kg) per day. House plants are only a moderate source of moisture. A group of seven house plants, for instance, would only release 1 lb (0.45 kg) of water in 24 hours. Greenhouses and swimming pools that are attached to the house can be a constant source of excess moisture and require special analysis to avoid or control moisture and condensation problems.

Crawlspace Moisture. After the laundry, the most common source of moisture leading to condensation problems within the house is water vapor evaporating from the surface of the ground in a crawlspace. Such moisture can come from ground water, misdirected surface runoff water, or air-conditioning condensate. Moisture evaporates into the air of the crawlspace even though the surface appears dry. It can enter the house structure through openings around heat ducts, wiring, and plumbing, and through the stud spaces in walls and attics. In the house it may condense on cooler wall surfaces, but it primarily causes problems on subfloor and joists. This problem will not occur if the house is built in an area with sandy or rocky subsoil which keeps the ground water at least 18 ft (5.5 m) below the crawl space. Where the ground water is within 18 ft (5.5 m) of the surface in a crawlspace of a 1000 ft^2 (30 m^2) house, as much as 19 gal (72 L) of water can be released into the air of the crawlspace during a single day.[15] In some houses this source of moisture may be easy to detect by fungus on wood floor joists and subflooring, damp earth, mold on ground, damp foundation walls, or condensation on water pipes. Decay over large areas of the subfloor and joists indicates there is condensation or water-conducting fungi.

In many houses, however, symptoms of excess moisture are not readily visible. In fact the ground may appear perfectly dry and contain large surface cracks. This lack of evidence merely indicates that the moisture is coming up by capillary action until it reaches one of the cracks. The moisture then evaporates and diffuses into all parts of the house. Vapor pressure differentials are the driving force for the movement of water vapor and may eventually lead to condensation anywhere in the house structure.

Crawl Space Ground Cover. Moisture from capillary rise can be reduced as much as 90% by installing a ground cover. It is best to use a barrier material that is not susceptible to damage by fungi, such as polyethylene film 6 mils (0.15 mm) thick. Roll roofing weighing 55 lb per 100 ft^2 (25 kg per 3.1 m^2) is also a good vapor retarder, but is subject to deterioration from fungi. In new homes, the use of full coverage and lapped seams is recommended. In retrofit applications, approximately 80% of the ground area should be covered to control but not remove all ground originating moisture from the crawlspace.[16] The area to be covered should always include the dampest or lowest areas.

An effective vapor retarder exhibits a permeance rating (rate of water vapor transmission through a material measured in perms) of 1.0 grain/h ft^2 in. of mercury vapor pressure difference (57 mg/s.m^2 Pa) or less.

In extremely damp crawlspaces, the vapor retarder should initially cover only 50 percent of the ground surface area. Then about every 4 to 6 weeks the area covered by the vapor retarder should be increased in approximately 10% increments by unfolding the overlapped material or installing additional material until 80% coverage of the ground-surface area is attained, while ensuring the dampest areas are covered. This method will allow for gradual drying of the house structure. If moisture is removed from the house structure at too rapid a rate, moisture shock may result which can cause walls and ceilings to develop hairline cracks, floors to separate, and other wood contraction problems to develop. Vapor retarders should be used in conjunction with, not as a substitute for, foundation ventilation.

Ventilation. The most important reason for ventilating attics and crawlspaces is to complement the use of a vapor retarder in controlling the migration of moisture and to protect the structure and insulation from damage. Without sufficient ventilation, water vapor cannot adequately escape from the house structure and may, therefore, condense into liquid on surfaces at dew point temperatures. The water can then invade the insulation fibers and degrade the thermal resistance (R-value) of the insulation by replacing insulating airspaces with water. Because water is a good conductor of heat, the heat flow through the insulation will be increased, decreasing the insulation's resistance to heat flow. Over an extended period, excessive moisture will not only make insulation ineffective, but as previously noted, it will promote fungal growth. Achieving sufficient ventilation will minimize these destructive processes, provided the required quantity of airflow can be determined.

Crawl space ventilation is generally provided by the installation of foundation ventilators. A ventilator is any device that allows air to move through a wall or roof but restricts the entrance of water, insects, birds, and other small animals. Basically, a ventilator is a covered hole in a wall or roof through which air can freely pass. The ventilator must perform three functions:

1. Allow for passage of air and moisture.

2. Restrict entrance of weather elements (rain) into the house structure.

3. Restrict entrance of insects, birds, and other small animals into the house structure.

Ventilators are classified in two categories--those that operate entirely by natural forces (static, gravity, or wind) and those that require electrical energy with which to operate (active).

As previously noted, achieving sufficient ventilation will minimize the occurrence of excessive moisture and condensation. But, what exactly is sufficient ventilation and how is its minimum value determined?

There are various methods for determining the required ventilation for attics and crawlspaces in residential structures. ASHRAE provides one equation for calculating the total area for crawlspace ventilation.[17]

$$a = (2L/100) + (A/300)$$

where L = perimeter of crawlspace, linear ft (m)
A = area of crawl space, ft^2 (m^2)
a = total net area of all vents, ft^2 (m^2)

ASHRAE also notes that this vent area can be reduced to 10% of that calculated if a vapor barrier is used on the ground. Also available are the guidelines in the HUD Minimum Property Standards (MPS)[18] for natural ventilation openings as a fraction of floor area:

1/150 without ground cover,
1/1500 with ground cover, both
with cross ventilation.

The Southern Building Code[19] specifies a similar ratio and while Building Officials and Code Administrators International (BOCA) specifies ventilation openings of 1/3 of 1% of the enclosed area.[20] The State Building Code of North Carolina[21] specifies in section 1702.8:

Without ground cover:
2 ft^2/100 ft (0.6m^2/30 m) of exterior wall + 1 ft^2/300 ft^2 (0.3 m^2/27.9 m^2) of crawl space area.

With ground cover:
1 ft^2/100 ft^2 (0.3 m^2/30 m) of exterior wall +
1 ft^2/600 ft^2 (0.3 m^2/55.7 m^2) of crawlspace area

TVA presently uses the HUD-MPS guidelines recently modified to include a minimum of four ventilators in such locations to provide the best available cross ventilation. Each of these methods is based on rule of thumb or historical numbers that have been handed down through the years and formulated on little, if any, analytical techniques that the authors can find.

DISCUSSION OF FINDINGS

The problems associated with excessive moisture will be addressed first because this can be the most structurally damaging and lead to devastating, even catastrophic, results. The incidences of excessive moisture that were observed in the 36 houses studied are of three types: (1) those that appear to be related to improper crawl space ventilation, improper control of either surface or free water, or a combination thereof; (2) those that are related to moisture condensation on the exterior of air-conditioning duct insulation; and (3) those where the moisture was of undetermined origin.

Excessive Moisture

Improper Crawlspace Ventilation and Surface-Water Control

From the observations to date, improper ventilation and improper control of water in a crawlspace can have the most destructive consequences. In the houses examined, those built over a below-grade crawlspace with the minimum net free area for ventilation appear to be the most susceptible to excessive moisture accumulation that can lead to decay. This low profile style of house, which appears to be built on a concrete slab but, in fact, is built over an excavated crawl space, is the most difficult to adequately ventilate and, consequently, to keep dry. Positioning for foundation vents is limited because of the location of large porches and garages or carports, and the building practice of installing vents within the end of the joist cavity.

Although these houses meet the HUD-MPS (Tab. 4-3.1) and the Southern Building Code ((Section 1302.5(e)) for ventilation, the authors have serious doubt that their net-free ventilation areas produce ventilation rates that are adequate in the many instances where houses are built over areas of high moisture content. Seventeen of the studied houses that meet the "letter of the code" do not appear to meet the "intent." Moisture condensation was only observed within stagnant crawlspace areas without true cross ventilation. The word "cross" must be emphasized because having ventilation on two adjacent foundation walls does not appear to provide even marginal ventilation for the other side of the structure.

Contributing to this apparent problem of lack of ventilation is the lack of proper control and removal of surface and rain water around the perimeter of the structure. The lack of proper grading, drainage, and the location or lack of downspouts contributes to a potentially damaging situation.

In houses with a below-grade crawlspace, surface and other free water has been found to accumulate on top of the crawlspace ground cover from either seepage or migration through the foundation or through improperly located or protected vents. Once in the crawlspace, this excess moisture is contained because the ground cover prohibits its percolation into the soil, and inadequate ventilation prohibits its evaporation and transport to the outside. This creates a microclimate where the water that does evaporate condenses on the cool floor joists and insulation above and rains back to the ground cover. Increased ventilation and better control of surface water appear to be logical approaches to remedy this problem.

Moisture Condensation on Duct Insulation

The second group of excessive moisture occurrences is the condensation of moisture on the exterior of air-conditioning or heat pump duct insulation. This was observed to occur in ten houses during periods of extremely high humidity and high dew-point temperature. The cool aluminum foil backing or plastic film commonly utilized on duct insulation makes an ideal location for condensation when the necessary ambient conditions exist. Condensation was observed on numerous occasions but is considered to be a transitory phenomenon that does not appear to require specific corrective action provided the condensate does not saturate the insulation. The only alternatives appear to be mechanical ventilation or additional insulation so that the surface of the backing will never reach the dew point temperature. These actions do not appear to be warranted at this time.

Undetermined Sources of Moisture

Two houses were examined that had moisture-related phenomena that were difficult to understand. These involved condensation on the upper walls of an interior hall with no apparent source of moisture or reason for condensation. These were grouped together as moisture problems of undetermined origin. Generally, there must be an undetermined source of moisture for incidents like these to occur, and several remedies are being tried with additional action to follow. Problems like these require individual attention and no general corrective action can be recommended.

Excessive Drying

Excessive drying is related to the problem of excessive moisture. As was pointed out earlier, wood only shrinks as its moisture content falls below the fiber saturation point. The dimensional changes that occur in wood can be considered a linear function of moisture content between 30% with no shrinkage and 0% with maximum shrinkage.[22] (6) The installation of a ground cover is recommended in crawlspaces to reduce the moisture accumulation in the substructural wood which in turn reduces the likelihood of decay.

A ground cover will also help maintain a more uniform moisture content and thus minimize dimensional changes.[23] (9) Some complaints investigated were related to dimensional changes that occurred when a ground cover was installed in an existing crawlspace. Wood that had established a high equilibrium moisture content in service was rapidly dried and non-uniform dimensional changes occurred. These are typified by floors that develop buckling, doors that drag, floors that crack, and furniture that might become loose. Many occupants associate these incidents with an excessive moisture problem when, in fact, the opposite is true.

Generally, the incidents that occur from excessive drying are either cosmetic or aesthetic compared with the destructive consequences that can occur from excessive moisture which can lead to decay. This is not an attempt to lessen the importance of excessive drying to the occupants but an effort to keep the alternatives in perspective.

Mechanical humidification is one technique that could be utilized in some instances of excessively dry houses to help control the inside moisture level. By properly introducing the correct quantity of moisture, a stabilization in the dimensional characteristics of wood could be achieved. However, mechanical humidification appears to be justified only in extreme cases involving large dimensional changes or for the health of an occupant. It is not believed to be justified or acceptable in most cases.

General Observations

During the past decade, the single-family dwelling has been subjected to greater changes than occurred during the previous half century. The energy crisis focused the spotlight on energy efficiency both in the residential and industrial sectors. The single-family residence has evolved from an elementary structure into a complex one with many simultaneously interacting variables. Unfortunately, construction practices and technology transfer have not kept pace with this progress. When combined with the general lack of homeowner and builder education in dealing with moisture, this lack of information has caused moisture-related problems to appear in alarming numbers.

In summary, the control of moisture within a house is a more delicate balance than anticipated between excessive and insufficient moisture. The best illustration the authors have developed to depict the overall interaction of moisture control is presented in Fig. 1. The proper use of the elements of moisture control is essential for maintaining a proper balance in the control of house moisture. Wood's dynamic nature and affinity for water and the ever changing environment within which wood is used make this proper balance difficult. The consequence of too little or too much moisture can tip the balance, but the effects of excessive moisture can be much more damaging.

CONCLUSIONS AND RECOMMENDATIONS

The national effort to conserve energy has lead to increased weatherization of residential structures. This has caused a reduction in the air change rates of these tighter houses and has increased the importance of moisture control.

Crawlspace ventilation appears to be a key element in the control of residential moisture problems. Predicting the required ventilation has become an increasingly complex matter. Old tried and true rules of thumb do not seem adequate in many energy-efficient structures because of reduced infiltration and better thermal envelopes. Techniques for calculating crawlspace ventilation requirements should be reevaluated on the basis of more scientific and analytical methods, and further research should be continued on alternative approaches to conventional floor insulation.

A great deal of misinformation exists within the residential community of builders, contractors, architects, building inspectors, pest control operators, and homeowners regarding the importance of and techniques for residential moisture control. Moisture problems are entirely preventable. The techniques available are relatively simple and inexpensive if initially incorporated in the design and construction of a building. Moisture control technology must be transferred from the wood products area to the builders and users of residential construction.

No intrinsic characteristic has been identified that causes a moisture problem within either an energy efficient or typical house. If construction practices include proper allowance for the control of moisture potential problems can be eliminated.

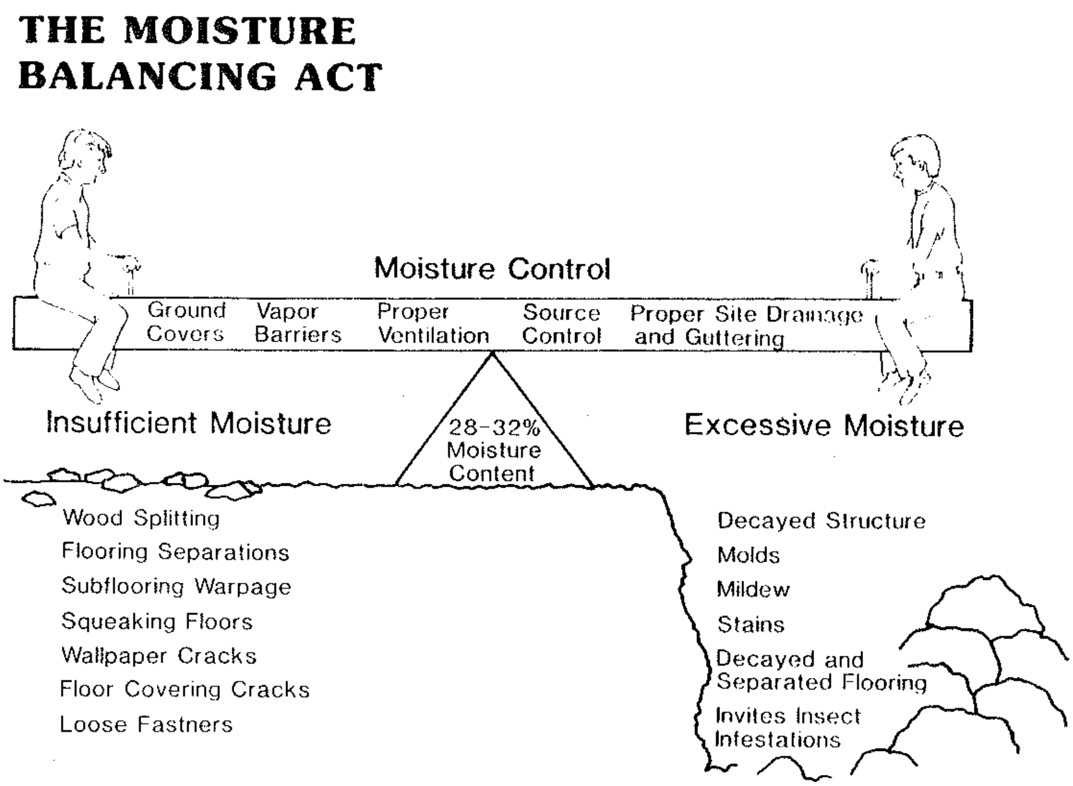

Figure 1

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Appendix

Case Study Location	Date	Construction Type: Crawl space	Basement	Slab	Combination	Percent of crawl space below grade	M.C.: Moisture content of substructure (range of 10 tests)	Crawl Space Ventilation: Number of crawl space ventilators	Located in skirt wall	Located in band joists	Provides cross ventilation	Visible Moisture: Visible signs of condensation or surface water	Estimate of coverage	Location	Visible Decay Fungi: Visible signs of fungal decay	Estimate of coverage	Location	Remarks for Contributing Factor
Spring City #1	9/81	X				10%	11-15%	5	X		No	No	n/a	n/a	No	n/a	n/a	Shrinkage cracks-floor-wall
Brainerd #1	7/82		X			n/a	8-11%	0			n/a	No	n/a	n/a	No	n/a	n/a	Shrinkage cracks-floor
Knoxville #1	9/81	X				25%	12-18%	7	X		Yes	Yes	25%	HVAC ducts	No	n/a	n/a	Flooring cracks-dragging doors
Manchester #1	12/81	X				10%	9-13%	7	X		Yes	No	n/a	n/a	Yes	20%	Joists	Floor buckling
Hidden Harbor #1	10/82		X			n/a	11-14%	0			n/a	No	n/a	n/a	No	n/a	n/a	Floor warpage
Collegedale #2	6/82	X				10%	10-14%	5	X		No	No	-	-	No	n/a	n/a	Floor settling
Hixson #1	6/82	X				50%	20-24%	4	X		No	Yes	25%	Floor insulation and joists	No	n/a	n/a	Condensation
Huntsville #1	7/82	X				100%	12-28%	5	X		No	Yes	25%	Floor insulation and joists	Yes	10%	Subfloor joist	Condensation and drainage
Brainerd #2	9/82	X		X	X	25%	12-19%	4	X		No	Yes	10%	Floor insulation and HVAC ducts	Yes	75%	Subfloor joist	Condensation and drainage
Bowling Green #1	8/81	X				100%	17-23%	6		X	No	Yes	25%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation and drainage
Bowling Green #2	8/81	X				75%	15-23%	4		X	No	Yes	25%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation and drainage
Bowling Green #3	8/81	X				50%	13-19%	4	X		No	Yes	25%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation and drainage
Oaklands #1	8/81	X				75%	13-21%	5	X		No	Yes	50%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation and drainage
Knoxville #2	11/81	X				10%	11-15%	8	X		Yes	Yes	n/a	HVAC ducts	No	n/a	n/a	Condensation
Knoxville #3	11/81	X				75%	15-18%	6		X	No	Yes	10%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation and drainage
Knoxville #4	11/81		X			n/a	8-15%	0			n/a	Yes	5%	Interior walls	No	n/a	n/a	Dryer
Goodletsville #1	11/81	X				50%	15- 30%	4	X		No	Yes	75%	Flooring and joists	Yes	50%	Joist, sill, header	Condensation, drainage & dryer
Tullahoma #1	10/81	X				25%	13- 30%	5	X		No	Yes	25%	Vapor barrier and floor insulation	Yes	75%	Joist, sill, header, flooring	Also termites, poor drainage
Tullahoma #2	10/81	X				0%	11-15%	3	X		Yes	Yes	10%	Subfloor	Yes	25%	Floor delamination	Also plumbing leak
Tullahoma #3	10/81		X			0%	8-12%	0			n/a	Yes	75%	Exterior walls	No	n/a	n/a	Severe mildew
Lawrenceburg #1	10/81	X				10%	7-12%	5	X		Yes	Yes	10%	HVAC ducts	No	n/a	n/a	Condensation
Eastridge #1	8/82	X				10%	11-17%	5	X		Yes	Yes	10%	Walls	No	n/a	n/a	Molds & Mildew
Nashville #1	5/82	X				50%	13-18%	6	X		Yes	Yes	10%	Floor insulation	No	n/a	n/a	Condensation
Nashville #2	5/82	X				100%	15-20%	6		X	No	Yes	50%	Floor insulation and HVAC ducts	No	n/a	n/a	Condensation
Nashville #3	7/82	X	X		X	25%	9-15%	0			No	Yes	25%	Walls, floors, furniture	No	n/a	n/a	Molds and mildew
Smithville #1	5/82		X			25%	8-12%	0			n/a	No	n/a	n/a	No	n/a	n/a	Floor settling
McMinnville #1	5/82	X				25%	11-16%	4	X		n/a	No	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew drainage
Clarksville #1	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew no vents
Clarksville #2	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew
Clarksville #3	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew
Clarksville #4	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew
Clarksville #5	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew
Clarksville #6	5/82			X		0%	n/a	0			n/a	Yes	10%	Walls and ceiling	No	n/a	n/a	Molds and mildew
Elder Mtn. #1	9/82	X				25%	13-23%	8	X		No	No	n/a	n/a	No	n/a	n/a	Drainage
Collegedale #1	6/82	X				10%	10-12%	8		X	No	Yes	25%	Floor insulation	No	n/a	-	Condensation
Kingston #1	9/82	X				100%	15-22%	6		X	No	Yes	50%	Floor insulation and joists	No	n/a	n/a	Condensation

Discussion

M. Zieman, Radco, Carson, CA: Did you have experience with moisture problems in mobile homes?

C.W. Jennings: No, mobile homes are not included in the Home Insulation Program at this time and, consequently, we have not been involved with them.

S. Tuma, Dept. of Energy and Natural Resources, Springfield, IL: What are your feelings about closing vents to crawlspaces during winter?

C.W. Jennings: I believe the best practice is to leave the crawlspace vents open year-round. This might present a potential problem for frozen plumbing during a prolonged period of frigid temperatures. During these periods, I feel is is acceptable practice to close the vents to minimize the potential for damaging the plumbing. My only reservation about recommending that the vents be closed at any time is that most occupants forget to reopen them.

G.M. Hughes, Bonneville Power Admin., Seattle, WA: Will the conditions, including the materials in place, i.e., vapor retardants, ventilation, be described in detail in your paper?

C.W. Jennings: Yes, the appendix includes a table that should provide the details you requested.

S.L. Matthews, Rockwool Industries, Inc., Denver, CO: Do you find the HUD/FHA MPS crawlspace ventilation requirements adequate?

Jennings: Personally, I believe the time has come to reevaluate the HUD/FHA MPS crawlspace ventilation requirements. These guidelines were selected when residential construction was typified by higher infiltration rates and poorer thermal envelopes. Today's newer homes are tighter and better insulated and many older homes have been retrofitted to make them tighter and more thermally efficient. Some of the houses that have been inspected in the field met the minimum guidelines set in the MPS but some type of moisture related problem still occurred. So, in some cases, I do not feel the ventilation is adequate.

D. Burch, National Bureau of Standards, Washington, DC: From your observations of moisture problems in crawlspaces, were you able to determine the time of year when moisture problems seemed to be worse?

C.W. Jennings: It is difficult to pinpoint a single time or season where the worst problems appear. We have seen different types of problems year-round. Many of the crawlspace condensation problems were invertigated in the spring and summer when dew point temperatures were high, while many of the interior mold and mildew problems were recorded in both the warmer summer months and the cold winter months.