Moisture Problems in Manufactured Housing

Manufactured homes are affordable to many. A study points the way to making them healthy by dealing with moisture problems.


FSEC

by Neil Moyer

For the millions of people living in manufactured homes, the relatively low cost of these homes should not automatically imply low energy efficiency and poor indoor air quality (IAQ). In 2000, one out of six new single-family housing starts was a manufactured home. Last year, the industry shipped more than a quarter of a million homes from 280 manufacturing facilities. More than 19 million people, about 8% of the U.S. population, live full time in 8 million manufactured homes. These manufactured homes are one of the most affordable forms of single-family detached housing available. They generally cost less than $35/ft^3 (plus the cost of land) for a centrally air-conditioned and heated home with a built-in kitchen. Available in all parts of the country, manufactured homes are most popular in the southern and western United States, where land is still plentiful, and in rural areas elsewhere. (For a description of manufactured housing, see "Manufactured Housing," p. 26.)

In 1999, the U.S. Department of Energy (DOE) selected the Florida Solar Energy Center (FSEC) as the Building America Industrialized Housing Partnership (BAIHP) team leader. This group's primary function is to serve the manufactured housing industry by fostering technology-based innovations that will increase energy efficiency through a systems engineering approach. So far the BAIHP team includes five manufacturers: Cavalier Homes, Clayton Homes, Fleetwood Homes, Palm Harbor Homes, and Southern Energy Homes. FSEC has already inspected 25 problem homes built by four of the manufacturers and has made recommendations to the manufacturers designed to alleviate the problems that it found. The testing protocols are described in a sidebar (see "Testing Equipment and Procedures," p. 28).

Moisture Problems in Manufactured Homes

A number of manufactured homes in the hot, humid climate of the southeastern United States have moisture problems. According to the Manufactured Housing Research Alliance (MHRA), solving moisture problems is the highest research priority of the manufacturers of homes that meet HUD standards. Moisture problems that can arise include extensive mold, soft wallboards, buckled floors, damaged wood molding and trim, and high relative humidity in the home. Frequently, these homes have high air conditioning costs as homeowners attempt to increase comfort by lowering the thermostat temperature. An FSEC study done last year showed that each °F drop in controlled temperature causes an approximate 10% increase in cooling costs.

In the southeastern United States, the outside air is consistently above a dew point of 75°F during the summer months. If the homeowner decides to keep the interior temperature of the home below 75°F in an effort to maintain comfort, or if an interior surface is cooled below the exterior dew point temperature, moisture-laden outside air coming into contact with colder inside surfaces produces condensation. If moisture condenses behind an impermeable surface such as vinyl flooring or vinyl wallpaper, wallboard damage, floor buckling, and mold growth can result.

In its investigation of 25 problem homes, FSEC found six main sources of moisture problems. These six sources are discussed below and a sampling of problems is shown in Table 1.

Interior temperature below outside dew point. (100% of the homes investigated) Homeowners want to be comfortable in their homes. Simply put, thermal comfort is a function of temperature, humidity, and the physical activity of the individual. Other variables include air movement, clothing level, and radiant temperature. In most homes, the only control feature is the thermostat. The common perception is that lowering the temperature will provide the cooling comfort desired. The HVAC supplier/installer wants to ensure that the homeowner has a unit that is oversized, to prevent callbacks for high interior temperatures or homeowner-perceived excessive run times of the air conditioning system. The interior temperature can be very quickly controlled, but short cycling of the equipment occurs. Oversizing can cause the following problems:

• The unit does not operate long enough to provide dehumidification.

• The interior house temperature can be lowered to a point far below the ambient air temperature dew point. This can lead to condensation on interior surfaces, with attendant material degradation and mold growth.

• The oversized unit has a large blower fan, which exacerbates duct leakage and pressure differential problems associated with the forced-air system.

Negative pressures across the envelope. (100% of the homes investigated) Negative pressure is the driver that brings warm, moist exterior air into the building through every crack, crevice, hole, or other opening that exists. The negative-pressure field may encompass the entire building, or there may be zones within the building that experience negative pressures created by inadequate return air paths, or interior door closures. For example, supply duct leakage and/or exhaust fans may create negative pressures in the entire house, while door closures may create negative pressure in a single room or zone of the house. It is important to note that we are talking about minuscule amounts of negative pressure—on the order of 1–3 Pa. Over time, however, even these tiny air pressures can lead to serious damage.

Duct leaks and return air pathways. (100% of the homes investigated) One of the biggest causes of moisture problems in manufactured homes in hot and humid climates is leakage from the supply ducts. In manufactured housing, the leakage is often caused by poor design and construction practices. This can leave holes at the connection points of the air handler unit (AHU) to the main trunk, the boots (or risers) to the trunk, the boots to the supply registers, the end caps, the crossover duct connections, and the other connection points in the ductwork. When the AHU moves air through the ducts located under the floor, some of it leaks into the belly and eventually to the outside through tears in the belly board (see Figure 1). This loss of air creates a negative pressure inside the house and a positive pressure in the belly, because the return, being located in the home, has no such leakage. The negative pressure draws outside or attic air into the house through the numerous cracks and crevices connecting the inside of the house to the outside or to the attic. If this outside air is cold and dry, as it is in the wintertime in the northern United States, it will increase heating energy use and occupant discomfort. This situation will not rot a home in a northern climate, but it will rot a home in the hot and humid South.

Table 1. Examples of Moisture Problems

House	3	4	11	16	19	20
Location	TX	TX	FL	LA	FL	FL
Size	4BR/ 3BA	5BR/ 2BA	2000 ft²	1008 ft²	1348 ft²	1348 ft²
Bowed/Buckled/ Soft walls	Yes	Yes	Yes	Yes	Yes	Yes
Mold location	Yes	No	M3,4	Yes	M1, 2	M1, 2
Buckled floors under vinyl	No	No	Yes	No	Yes	Yes
Problem walls vinyl covered	Yes	Yes	Yes	Yes	Yes	
Tears in belly boards	Yes	Yes	Yes	Yes	Yes	Yes
A/C tonnage			4	3	4	2.5
Duct leak, total CFM_{25}	430	188	112	135	158	128
House CFM_{50}	3247	1271	200	1261	1000	1007

M1: Marriage wall M2: Under vinyl floor M3: Closets M4: Bath

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Another aggravating factor is the lack of return air pathways when interior doors are closed. In many manufactured and site-built homes, there is a single return located in the main body of the house—for example, in the living room, dining room, or central hallway. Air returning from individual rooms can be restricted by door closure. There is often a very small pathway for return air from closable rooms; typically this pathway is the undercut at the bottom of the doors. When interior doors are closed, the bedrooms become pressurized and the main body of the house depressurizes. One house showed a positive pressure because of a disconnected main return air duct. The typical manufactured home experiences only supply leaks, since the return grille is normally located on the AHU.

Pressure Problems

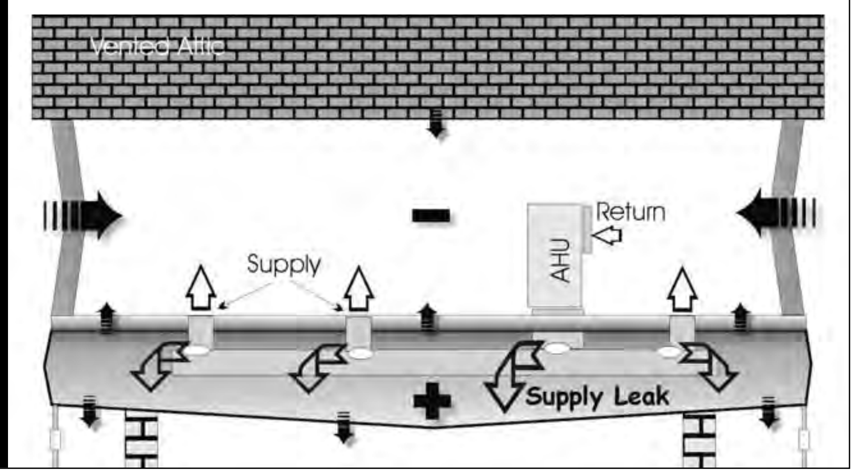

Figure 1. Supply leaks can cause positive pressures in the belly of manufactured homes. The resulting negative pressure in the living space can draw in moist air from the outside.

Moisture diffusion through floor assembly. (100% of the homes investigated) One of the moisture diffusion pathways in the homes we inspected was in the belly of the home, between the earth and the floor coverings. When belly boards have numerous penetrations, both air and water vapor pass freely into the floor cavity. In many cases, we found standing water, or evidence thereof, in the crawlspaces below the belly boards. A skirting that is designed to hide the crawlspaces surrounds these high-moisture sources, giving warm, moist air ample opportunity to rise up through the tears and other openings of the belly boards into the subfloorings. This may be the result of air-transported moisture or moisture vapor diffusion or both. The subfloorings, composed of either plywood or wood composite materials, allow moisture vapor to pass through to the floor coverings. Carpeted surfaces offer little resistance, and moisture passes into the home. Vinyl flooring, on the other hand, is impermeable and prevents moisture from passing into the home. But if the vinyl flooring is at or below the dew point temperature of the crawlspace air, condensation occurs on the underside of the flooring, creating a favorable environment for mold growth.

A pattern of floor moisture and staining problems appears when the duct system is located overhead, in an attic space. We found stained and warped vinyl-covered floors in areas under the ceiling registers. The areas that were being washed by cold air from the supply registers showed the worst staining. It is reasonable to assume that areas being washed by the supply air will tend to be cooler than other areas. This cooling of the floor surfaces creates temperatures below the dew point temperature of the crawlspace and condensation occurs.

Vapor retarder in the wrong location. (100% of the homes

Manufactured Housing

Manufactured and modular home units are built in a factory, transported to the site, and installed there. In contrast, panelized and precut homes, which are essentially flat units (factory-built panels or factory-cut building materials), are transported to the site and assembled there. Manufactured homes are federally regulated by HUD's "Manufactured Home Construction and Safety" standards (HUD code) under Title 24 CFR 3280. The HUD code specifies the design and construction requirements for the complete production of the entire home in the factory, with some modifications permitted for on-site completion.

Construction

The process of constructing a manufactured home is very different from the process of constructing a conventional site-built home—the home is built from the inside out as it travels down an assembly line. A steel chassis is constructed and the floor assembly (containing plumbing, wiring, and ductwork) is attached. Floor coverings, interior walls, plumbing fixtures, and a furnace are installed. The exterior walls, with the interior finish and insulation, are hoisted into place and attached to the floor. The finished ceiling assembly is then lifted from the construction jig and lowered onto the home. As exterior sheathings and coverings are attached, a flurry of interior activities continues within to provide the finishing touches. The newly constructed assembly is then moved to the operational test site, where the various plumbing and electrical systems are checked.

Manufactured homes have a permanent steel chassis with axles attached below the floor. After production, the home may travel a few hundred miles, hauled by a truck, before being set up in its final location. The homes are set upon blocks or piers and the steel frame chassis is firmly anchored to the ground. The typical barrier between the earth and the floor coverings on a manufactured home is a belly board made of reinforced plastic that protects investigated) The homes inspected followed the HUD code ruling on moisture vapor control as defined by Section 504. This states that ceilings should have a vapor retarder with a permeance of not greater than 1 perm. (For manufactured homes designed for Zone 1, which includes Texas, Louisiana, Mississippi, Alabama, Georgia, South Carolina, and Florida, the vapor retarder may be omitted.) Exterior walls should have a vapor retarder not greater than 1 perm (dry cup method) installed on the living space side of the wall; unventilated wall cavities should have an external covering and/or sheathing that forms the pressure envelope. The covering and/or sheathing should have a combined permeance of not less than 5 perms. The typical wall assembly has a vinyl wallpaper on the living side as defined by the HUD code (warm side in northern climates, cold side in southern climates).

It is common practice for manufacturers to use vinyl-covered wallboard as the interior finished surface. This is one of the most economical finishes that can be applied and meets the vapor retarder requirement. The Manufactured Housing Institute tested the wallboard with

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This kitchen has a vinyl floor covering and an overhead supply register. Mold can occur under the vinyl that is washed by cold air from the register.

the vinyl finish according to the ASTM E-96 standard. The results showed that a $^3/_8$-inch gypsum wallboard laminated with 4-mil vinyl has a perm rating of 0.42. In this case it's the vinyl wallpaper that determines the perm rating.

All the homes inspected that experienced wallboard failure used vinyl-coated wallboard. Typical symptoms included staining of the vinyl wall coverings and bowing of the wallboards. Additionally, negative air pressures within the buildings were created by duct leakages, door closures, or a combination of both.

Homes with vinyl floor coverings, where the vapor retarder is located on the interior surface, have similar problems. However, we saw moisture problems only in the houses with overhead duct systems. We believe (testing to verify this is ongoing) that the cool air from the supply registers is being blown down to the floor and is cooling the surfaces below the outside air dew point. The solution so far has been to replace the current unidirectional registers with multidirectional ones. In addition, the belly board is sealed to reduce crawlspace vapor intrusion. (Sometimes the skirts are vented, according to homeowner acceptance and current local venting practices.)

Inadequate moisture removal. (Approximately 80% of the homes investigated) Proper sizing, operation, and maintenance of the air conditioning system is necessary to maintain interior

the underside of the home during transportation. A vented skirting conceals the underside of the home.

The Duct Systems

Manufactured homes are typically heated or cooled by a forced-air system employing ductwork, which delivers hot or cold air from the AHU. The ductwork may be located in the attic or in the belly cavity (beneath the flooring) of the home, and the AHU is located in the conditioned space. The ducts are typically made out of aluminum or fiberglass trunk lines that supply air to the floor registers through inline boots or through flex ducts, terminating at perimeter registers on the floor. The most common method of sealing the various joints and connections at the factory is with foil tape.

Multisection homes also require a section of the ductwork to be connected during the onsite setup operation. A flexible duct is used to connect the supply sections together in the attic or in the crawlspace. These connections are usually made with duct tape and/or a tie strap.

The Ventilation Systems

All HUD code homes are required to have a ventilation system installed. This ventilation system should be capable of providing 0.35 ACH. Natural infiltration and exfiltration are assumed to provide 0.25 ACH, and the remaining ventilation capacity of 0.1 ACH can be provided by a mechanical system, a passive system, or a combination passive and mechanical system.

Currently, two main types of ventilation system are employed by the manufactured housing industry to meet the 0.1 ACH requirement. Typically, these ventilation systems use small fans rated at 50 CFM. Both ventilation types are used in hot and humid climates—an exhaust-only system that is located in a hallway or utility room, and an outside air supply system that is ducted from the roof to the return air side of the air handler fan. The exhaust ventilation system is manually controlled. The outside air supply system is linked to the operation of the air handler and controlled with an automatic damper in systems with barometric or motorized dampers.

temperatures and provide humidity control. Houses 19 and 20 are the same size and model, were manufactured in the same plant, and are located a short distance apart, yet one has a 4-ton air conditioning system and the other has only a 2.5-ton system. Both experienced problems, however. The house with the larger unit had a more severe moisture problem. Based on the comments of the homeowners, some of the units can lower interior temperatures as much as 30°F below the ambient exterior temperature. Any unit that can do this is probably oversized. An oversized unit will tend to short-cycle, lowering the interior temperature, but in hot, humid climates it cannot adequately remove moisture from the air. In an effort to be comfortable, the occupants will lower the thermostat.

Excessive duct system leakage also prevented adequate moisture removal. Three houses that we investigated had a portion of the duct system completely disconnected. One (house 9) had a return duct that failed and was pulling most of its air from the crawlspace, which pressurized the house. One (house 3) had a disconnected crossover supply duct. Most of the conditioned air was lost to the attic space. And one (house 16) had the supply duct connecting the package air conditioning system to the house fall off at least three times within the first few months after being installed. Unfortunately, when a home leaves a factory there is little inspection of the home. Local code officials will usually look at electrical, plumbing, and septic hook-ups only.

Maintenance and operation of the equipment also affected moisture levels within the home.

The thermostat of house 4 was not operating correctly and the air handler fan was always on. Operation of the blower with supply leakage and door closure continuously placed the home in a negative pressure of -1 Pa. The interior wallboard of all the exterior walls was replaced within the first year of occupancy due to moisture damage. The repair crew could not find the cause of the problem, so the damaged wall was replaced, only to fail again.

Testing Equipment and Procedures

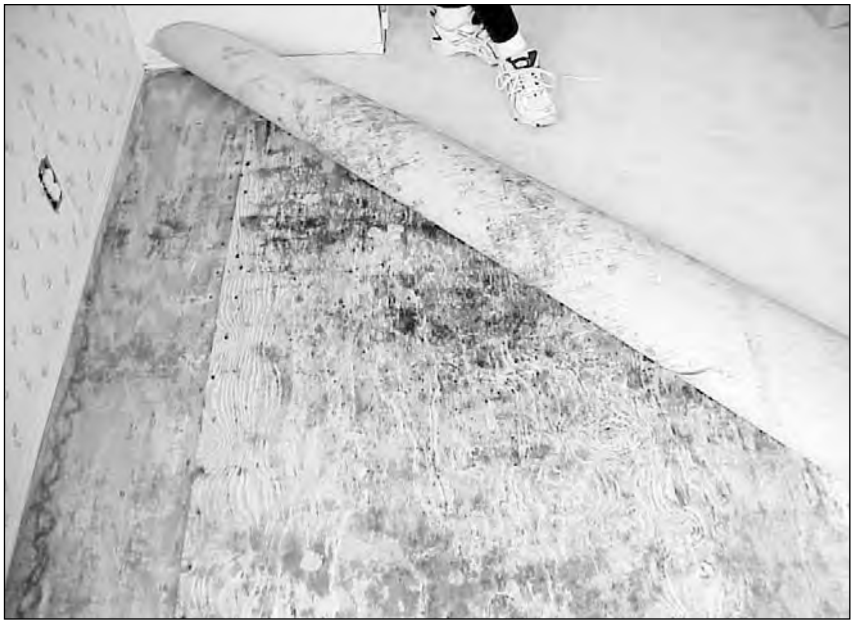
FSEC's testing protocol employs a battery of tests to establish the integrity of the building envelope and the duct system. These tests help determine the potential for air-transported moisture problems that can cause severe damage to building components, increase energy consumption, and decrease occupant comfort. Ideally, the protocol should begin with three tests using a calibrated blower door and a calibrated duct tester. Most of the time this is done, unless the problem appears not to be related to air transport. (Even then, we try to do the testing.)

The first two tests employ the calibrated blower door and establish a leakage rate for the house at a specific pressure differential. One test measures the total leakage from the duct system to the interior and exterior of the building (CFM_{25}) by pressurizing the duct system. The second test measures leakage to the exterior of the building only (CFM_{25}), by pressurizing the building and the duct system to the same pressure and removing any driving force for leakage between the building and the duct system. The remaining leakage is to the outside of the building envelope. The results are air flow at 25 Pa (CFM_{25}) and air leakage at 25 Pa normalized by the house's conditioned floor area (CFM/ft^2 at 25 Pa). A duct system is considered to be essentially leak free in the BIAHP project when the normalized duct leakage to the outside is less than 0.03 CFM/ft^2 and the normalized total duct leakage is less than 0.06 CFM/ft^2. This is approximately equal to 10% duct leakage. Most manufacturers or contractors, with a few hours of training, can meet this standard.

The third test consists of a series of pressure differential measurements across the building envelope and across various zones within the building as defined by interior doors. A digital manometer with a resolution of 0.1 Pa is used in all of the pressure differential measurements. Pressure differences may be created by the normal operation of the building's heating and cooling equipment, ventilation system, or exhaust fan (including clothes dryers and kitchen range hoods). Measurements are made to determine the magnitude and direction of flow across the envelope when the various fans operate. We also measure the interior door closure effect when the air handler fan is on. Ideally, the pressure differentials created across the building envelope and bedroom doors should be fairly close to neutral. Pressure across the envelope should be zero or positive (short-term negative pressures are acceptable providing that the long-term average is not negative) and pressure across bedroom doors should be no greater that 3 Pa.

Blockage in the condensate drain line appears to have been the final element needed to cause catastrophic floor and wall damage to house 11. The homeowners reported that the house had operated adequately for the first year. They reportedly kept the thermostat between 78°F and 80°F and were fairly comfortable. Then, all at once, the home felt uncomfortable and the thermostat setting was lowered to compensate. During our investigation, we found a pie tin and plastic wrapper in the drain pan of the evaporator coil of the package unit. The plastic wrapper was effectively blocking the condensate drain-line, causing flooding of the cabinet and recycling of the water back to the house. Failure of materials and mold growth soon followed.

Exhaust fans. (8% of the homes investigated) Negative pressures can also



Vinyl flooring in manufactured homes can cause moisture damage, since the low moisture permeability of vinyl can lead to condensation.

be created by the use of exhaust fans. In our inspections, we found only one home (house 4) where the factory-installed, occupant-controlled ventilation fan ran continuously—and that home suffered moisture problems. In most manufactured homes the exhaust fan is not operated because of the noise that it creates.

Another case we investigated (house 16) involved the installation of a dual-fan window unit. The owners had converted a bedroom into a pet care room and operated the window fans to control odor. Unfortunately, this not only removed the pet odor, but also depressurized the entire house by 1 Pa. High dew point crawlspace air was pulled into the floor assembly through numerous penetrations in the belly board and entered the home via the plumbing, electrical, and other penetrations in the floor. The result was mold growth in the bathroom cabinets and the deterioration of the subfloor under the kitchen vinyl.

Solving Moisture Problems

We recommended that manufacturers eliminate moisture problems by:

• directing the homeowners to maintain an air conditioner thermostat above the ambient dew point (at least 75°F);

• eliminating long term negative pressures created by AHU fans or ventilation equipment;

• tightly sealing all ductwork and providing adequate return air pathways, such as transfer grilles or ducts that are not hard connected to the duct system;

• enhancing moisture removal from the conditioned space by correct sizing and maintenance of equipment;

• eliminating ground source water by diverting roof drainage and lawn drainage away from the crawlspace instead of letting it flow underneath the home, and providing an adequate moisture barrier for the floor assembly; and, if possible,

• removing vapor retarders located on the wrong surfaces (and not replacing them—in the South).

Preliminary results are very encouraging. Bert Kessler, vice president for engineering at Palm Harbor Homes, reported that, from the Palm Harbor factories that ship homes to the Southeast, none of the homes produced in 2000 and beyond have had a single moisture problem related to the issues discussed above. One manufacturer on the BAHIP team has been working for the last five years to incorporate best-practice designs and techniques into their product. The result is that last year they reported no moisture vapor related failures for the first time in several years. Research is continuing to determine if these steps will be sufficient to prevent problems even in the presence of vapor retarders (still mandated by the HUD code) in the wrong locations for hot, humid climates.

There is still much to do in the area of moisture research as it relates to the interactions of a building and its mechanical systems. Negative pressures created by mechanical systems within buildings are sometimes difficult to correct. Installing tight, well-constructed duct systems with adequate return air pathways is a giant step in the right direction. There are still issues with ventilation, especially exhaust-only ventilation in hot, humid climates. Currently the HUD code does not address ventilation type; it states only that ventilation must exist. Clothes dryers are mechanical exhaust devices found in many manufactured homes. What is the effect of long-term operation in a home where the clothes dryer may operate three to six hours per day? The industry, especially the HUD code manufacturing industry, is slow to change—change costs money. It is looking for ways to lower the manufacturing costs of these changes and still provide affordable housing.

HUD code manufacturers, suppliers, retailers, setup crews, and various code officials all struggle with moisture-related problems, especially those problems caused by moisture in the vapor form. Correct, simple, and to-the-point training materials and courses are needed to assist in the design, construction, operation, and diagnostics as it relates to moisture and moisture movement mechanisms.

The Building America Industrialized Housing Partnership will continue working with manufacturers, suppliers, and building officials in an effort to provide research, training, and support.

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