Mold & Moisture Intrusion Case Study Report

Prepared for:

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Acknowledgments

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Disclaimer

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Executive Summary

In this study, the NAHB Research Center investigated building issues related to elevated moisture at 18 sites representing more than 20 residences. The case study reports list symptoms, possible moisture sources, diagnoses and prescriptive remedies for the problems, and analysis of remedial measures if the builder or homeowner adopted the measures. Cases included several areas of the country representing the northern heating climate, the southern cooling climate, and the mixed climate zone situated between the two.

Based on the case study report, moisture problems were not unique to a particular climate or structure. Generally, problems with moisture came from one of three sources: 1) construction moisture present in either the building material or as a result of exposure to the weather prior to close-in, 2) elevated relative humidity levels causing condensation on building surfaces from both interior and exterior air, 3) rain and groundwater entry.

Elevated humidity, while problematic in all climates, operates in different directions based upon climate zone. In cooling climates, the humid air is exterior air that condenses upon surfaces at or below dewpoint within the wall cavity. In heating climates, the humid air is in the house and condenses on wall surfaces or within the wall cavity once dewpoint is attained.

An itemized list of common moisture problems and solutions is presented within the paper. Common moisture problems include wetting of the foundation by watering a garden adjacent to a basement foundation, wetting of exterior cladding by lawn sprinklers, downspouts terminating near the foundation, soil moisture, water vapor, humidity, air leakage into or out of homes, humid summer air entering crawlspaces and condensing on cooler surfaces, rainwater penetrating flashing at window, interior rooms excluded from air circulation and heat and air gaps between exterior cladding and sheathing are all discussed in this report.

Based on the case study report alone, no definitive conclusion can be reached about the nation's housing stock concerning moisture problems and mold. However, insight from the report reveals several actions that can reduce mold infestations in housing

- Protect building materials and assemblies from weather.
- Direct precipitation, irrigation, and ground water away from the structure.

- Monitor interior and exterior relative humidity levels and design and build accordingly :
  - Heating climates should prevent interior humidity levels from forming condensation on or in exterior walls.
  - Cooling climates should prevent exterior humidity levels from creating condensation within exterior walls.
  - Mixed climates need to prevent both of the above conditions.
- Conforming to model building code is not a definitive solution for the prevention of moisture problems. For example, ventilating crawlspaces may create a mold problem in some structures instead of preventing problems.

Introduction

The National Center for Housing and the Environment (formerly the National Foundation for Environmental Education or NFFEE) contracted with the NAHB Research Center, Inc. to develop a library of case studies to document residential system issues, moisture-based performance failures and their resolution. The National Center for Housing and the Environment (NCHE) is a non-profit organization based in Washington, DC. Established in 1999, NCHE conducts research and outreach on environmental issues that intersect with the homebuilding industry.

Purpose

The purpose of this research was to:

- evaluate homes exhibiting symptoms of excess moisture intrusion leading to mold or its potential growth,
- identify moisture sources and conditions contributing to the elevated moisture,
- propose solutions for the remediation of problems related to excess moisture.

The case studies were evaluated to determine trends in materials, design, or construction that lead to moisture symptoms. This research is expected to foster an understanding of the contributing factors to the moisture/mold problems in residential housing and to identify methods that prevent recurrence. Results are intended to provide guidance to building product manufacturers, code officials, builders, educators and others influential in the construction and maintenance of residential structures.

Approach

The Research Center conducted this research through the following tasks: solicitation for homes to investigate, selection of potential homes for relevance to the study, investigation of selected case homes, analysis of data from case homes, prescription of corrective actions and follow-up monitoring.

1) Solicitation for homes – Requests for case study homes and information were made through the NAHB network of communication media (*Nation's Building News*, *Builder* Magazine,

ToolBase hotline, and press releases for general distribution), committees and councils to identify homes with problems associated with excessive moisture and mold. Particular emphasis was given to contacting homebuilder associations within extreme cooling and heating climates.

2) Selection – Responses from the solicitation process were reviewed and categorized. This cataloging process provided an approach to determine how to follow up with field visits and further study. Respondents consisted of homebuilders, homeowners, and product manufacturers. Phone interviews were conducted with the respondents to assess the nature of the problem, its resolution, or if it is an ongoing problem. Recurring and active unresolved problems were given first priority for study. Problems that defy conventional building "rules of thumb" and building code requirements were also given higher priority.

3) Investigation – Site visits were undertaken to document conditions, take measurements and develop approaches to resolving the problem. When possible, repairs and alterations that were made to correct problematic conditions were monitored to confirm their effectiveness. When performed, monitoring included follow-up site visits and/or measurements made through electronic data collection equipment.

4) Analysis – Information collected from the sites and from discussions with builders was reviewed by NAHB Research Center personnel and approaches were developed to assist with resolving the moisture issues. The recommendations made were non-binding suggestions for the builder's and homeowner's consideration. The analysis also included a review of conventional construction practices as well as building and energy codes requirements to identify any limitations or conflicts that may have prevented implementation of the corrective action recommendations. These code requirements were also reviewed for their possible contribution to the problem and recommended code changes were identified.

Characteristics of Case Houses

Eighteen structures were studied representing a mix of architectural styles and climate zones. Table 1 describes the building structure and climate characteristics representing the case homes. Climate zones are important because structures exhibit vastly different performance attributes based on whether they are situated in a cooling climate (hot and humid), a heating climate (cool and less humid), or a combination of the two (mixed). The number of homes studied in each climate zone is not indicative of the mold problems represented by each climate zone; it represents the pro-offered homes with issues of interest. No statistical inference is intended by the case studies in terms of inherent mold problems by climate or housing type.

Table 1 Climate and Structure Characteristics for Case Houses

Climate	Single Family	Multi-Family
Cooling	2	0
Mixed	5	2
Heating	6	3

Figure 1 displays a map of the climate zones described.

Figure 1 Map of Climate Zones[1]

[1] Lstiburek, J. and J. Carmody. 1991. Moisture Control Handbook: New, Low Rise, Residential Construction. U.S. Dept. of Energy.

A variety of different maps have been proposed in order to describe climate or hazard potential to homes as a result of climate. The map above is divided into three regions based on heating and cooling degree days. A heating degree day is calculated by averaging the high and low temperatures for a day. If the value is less than 65, the difference is the number of heating degree days. If the value is greater than 65, the difference is the number of cooling degree days. For example, a day might have a high temperature of 73 and a low temperature of 45. The average temperature is 59 degrees. This average temperature is 6 degrees less than 65 degrees thus resulting in 6 degree days. Summing up the degree days for an entire year gives the annual value for heating or cooling degree days.

The heating climate is defined as having more than 4000 heating degree days. The mixed climate represents a zone with up to 4000 heating degree days combined with a significant number of air conditioning hours. Finally, the cooling climate represents the remaining zone within the U.S. zone. It is generally defined as having a wet bulb temperature of 67º F for more than 3000 hours during the warmest six consecutive months and/or a 73º F for more than 1500 hours during the warmest six consecutive months of a year.[2] A wet bulb temperature is found by subjecting a bulb-type thermometer with a wet sock attached to the bulb to air where relative humidity is of interest. A sling pyschrometer represents this type of thermometer.

Presentation of Data

Each case was presented as a case study report describing the house or houses in terms of generic issue, climate zone, structural characteristic, symptom or building component affected, diagnosis and prescriptive remedy, and any relevant code issue. The case study reports are two- to four-page documents designed to help the building industry understand moisture and mold.

Findings

General Findings

It is difficult to make a general conclusion about moisture sources and residential mold control based on the case studies alone due to the great variability of construction practices

[2] 2001 ASHRAE Fundamentals Handbook, Chapter 24. American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.

(architectural designs, building materials, installation practices, etc.), occupant lifestyles, and climatic regions. The moisture sources that had consistently presented in all climates, however, included the following:

- Construction moisture – this is moisture resulting from the construction process either due to excess water evaporating from the building materials (curing concrete, drying lumber) or from exposed conditions during the construction process (uncovered material storage, rain-soaked wall assemblies prior to sheathed roofs).
- Elevated relative humidity – the amount of water in air compared to the maximum amount of water it can hold at a given temperature is termed relative humidity. Cold air cannot hold as much water as warm air. When air comes into contact with a surface that reduces its temperature so that the relative humidity reaches 100% (the maximum amount of water air can hold) dew point temperature has been reached. Building material surfaces at or below dew point temperature will condense water out of the air onto the surface. Keeping relative humidity low keeps the dew point temperature low and reduces the potential for condensation. The case study homes that exhibited moisture problems located in the heating climate generally had interior moisture condensing on cool surfaces either on the interior space or in the wall cavities. The cooling climate cases exhibited exterior moisture coming through the wall and condensing on surfaces such as underneath electrical wall plates or wallpaper. Mixed climate cases could have moisture sources from either interior during the winter or exterior during the summer.
- Moisture intrusion – bulk water entering the house from precipitation or groundwater sources. Faulty or non-existent flashing, poor site grading, improper or non-existent drainage planes behind exterior claddings, and non-existent or poorly maintained gutters and downspouts are all pathways for bulk moisture intrusion.

While drawing overall conclusions from just the case studies is difficult, case study information combined with a mold survey performed by the NAHB Research Center concurrent with this project offers further insight into the moisture sources and mold-prone areas for homes.

Specific Moisture Sources

Residential structures contain many sources and avenues by which moisture can enter the home. Figure 2 illustrates several of the more common conditions or areas leading to moisture problems, including mold.

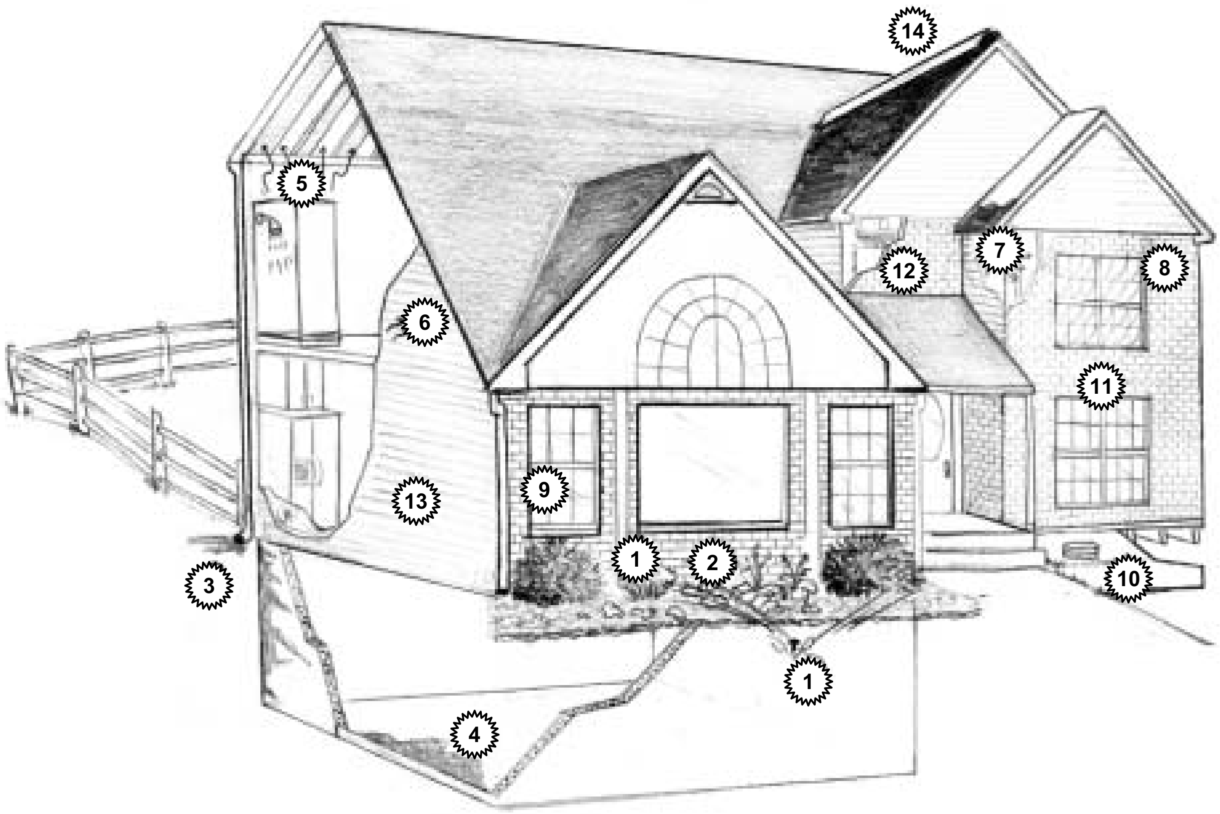


Figure 2 Moisture Sources and Problem Locations for Homes

1 Wetting of the foundation by watering a garden adjacent to a basement foundation. Excessive moisture along the foundation may find its way inside the basement area in the form of moist walls and elevated basement humidity.

2 Wetting of exterior cladding by lawn sprinkler system. Many exterior claddings, particularly vinyl, brick, and lapped sidings permit substantial quantities of water to pass through them. Maintain sprinklers to direct water away from the home.

3 Downspouts terminating near the foundation. Direct water away from the foundation at least 2 feet if discharged on the soil surface. Use splash blocks or corrugated pipe to inhibit soil erosion, which may retain water near the foundation.

4 Soil moisture wicking up through the concrete slab. Several actions can prevent this phenomenon. Properly grading soil (4% slope or more) away from the foundation and incorporating vapor barriers under the basement slab (see arrow in Figure 3) are two methods to minimize this problem.

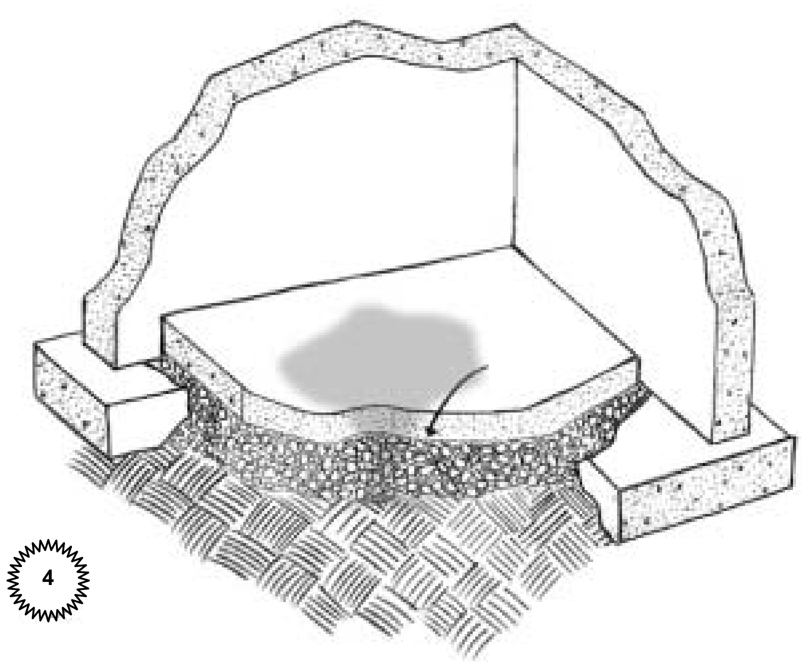


Figure 3 Moisture Wicking from Under Slab

5 Water vapor. Water vapor can come from many sources such as showering, cooking, human respiration, aquariums, etc. Strategies to reduce the effects of water vapor (lowering the relative humidity of the air) include ventilation at the source such as bath fans, opening windows during moisture generation and using dehumidifiers. The presence of condensation on surfaces is an indication that water vapor is increasing the relative humidity of the air to a level that is problematic for the house.

6 High humidity, outside air entering and condensing on wall cavity surfaces through diffusion. This can be a problem during the cooling season. Limiting the use of vapor barriers on the interior of the wall such as vinyl wallpaper will allow moisture that does enter walls to dry to the inside of the home. Allowing an air gap between exterior claddings and sheathing will help prevent moisture from diffusing into the wall cavity.

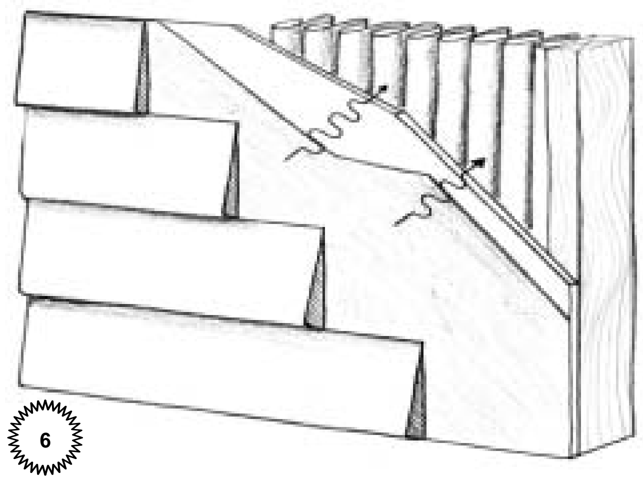


Figure 4 Moisture Migration from Outside to Inside

7 Moisture movement from the humid interior out through exterior walls and condensing in the wall cavity. This phenomenon occurs commonly during winter in heating climates. Keeping interior air relative humidity levels low, appropriate use of vapor retarders, and incorporating higher R-value measures such as more wall insulation and energy-efficient windows help control this problem.

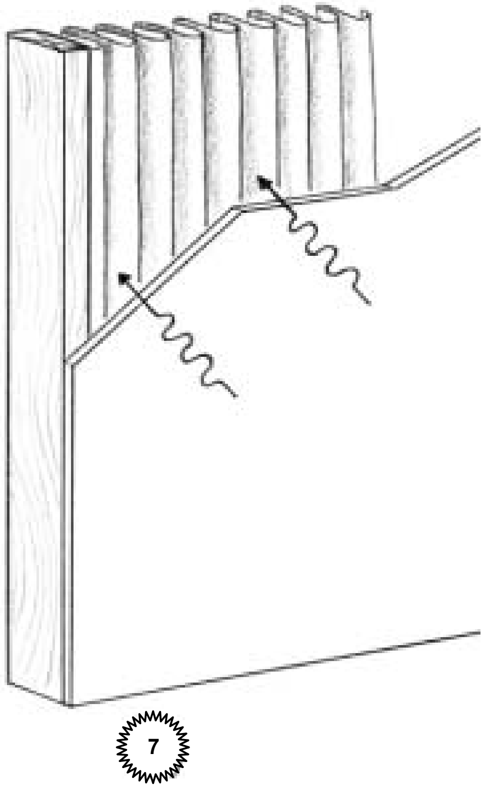


Figure 5 Moisture Migration from Inside to Outside

8 Moisture movement from humid interior up through ceiling attic hatches or recessed light cans. This is similar to condition 7, however the direction is up through the ceiling and often involves air leakage as well. Again, maintaining low relative humidity greatly alleviates this problem. Using gaskets or seals around penetrations through the ceiling also minimizes this problem.

9 Air leakage into or out of a home. Water movement due to airflow is greater than diffusion (water moving from areas of high concentration to low concentration). Limiting unintended air infiltration (air moving into the house) or exfiltration (air moving out of the house) helps minimize moisture problems accompanying this air movement. Sealing all envelope penetrations such as windows, doors, plumbing and electrical penetrations will help reduce this moisture source.

10 Humid summer air coming through crawlspace vents and condensing on cooler building surfaces. Reducing the humidity in crawlspaces such as using

impermeable ground coverings such as sheet polyethylene may help in reducing moisture problems. In some cases, sealing the crawlspace vents may be required. Other measures such as dehumidifiers, increased insulation on foundation walls and subfloor surfaces also reduce condensation potential.

11 Rainwater penetrating flashing at window head and penetrating wall cavity. Improperly installed, or missing, flashing can be a major contributor to water penetration into the wall cavity. Caulks and sealants, if properly installed, generally are not long lived and must be continually maintained to prevent leakage. Properly installed flashing prevents most leakage problems associated with doors and windows.

12 Interior rooms excluded from air circulation and heat. Rooms such as closets are often excluded from the ventilation and heating experienced by the rest of the home. Since warm air holds more water, ventilation can be useful to increase either heat air to increase its ability to hold water or remove air that is excessively humid. The lack of this ventilation and heat can lead to moisture problems leading to mold.

13 Air gap between exterior cladding and sheathing. The presence of an air gap can greatly reduce rain and water vapor from entering a wall cavity. Brick or masonry veneers are particularly troublesome for moisture movement from outside to inside the wall cavity. Maintaining an air gap and minimizing the occlusion of the gap by mortar or other substances helps prevent this problem.

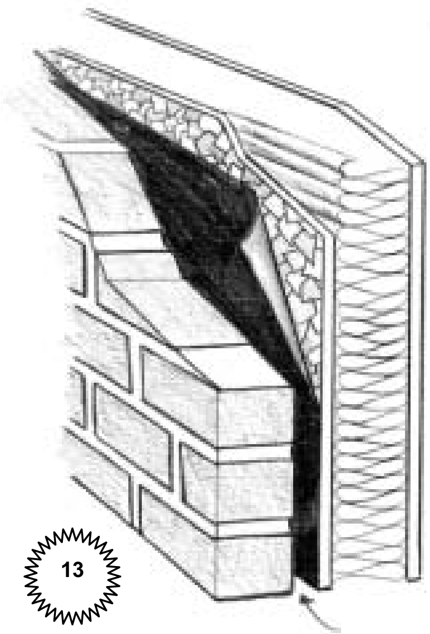


Figure 6 Gap Between Exterior Cladding and Sheathing

14 Attic ventilation. Local code dictates what must be done in regards to attic ventilation. However, improperly installed attic vents have been associated with problems resulting from wind and snow or rain. Non-vented roof designs are available and may be an attractive option for hot and humid climates but performance data on these assemblies over time is not yet sufficient to make conclusions about their effectiveness.

Conclusions and Recommendations

Based on the case studies alone, no definitive conclusion can be reached about the nation's housing stock concerning moisture problems and mold. However, insight from the studies reveal several actions that can reduce mold infestations in housing

- Protect building materials and assemblies from weather.
- Direct precipitation, irrigation, and ground water away from the structure.
- Monitor interior and exterior relative humidity levels and design and build accordingly :
  - Heating climates should prevent interior humidity levels from forming condensation on or in exterior walls.
  - Cooling climates should prevent exterior humidity levels from creating condensation within exterior walls.
  - Mixed climates need to prevent both of the above conditions.
- Conforming to model building code is not a definitive solution for the prevention of moisture problems. For example, ventilating crawlspaces may create a mold problem in some structures instead of preventing problems.

Other Topics to Explore

An area of research need concerns remedial mold treatments and mold-resistant products. Associated with the products, a more uniform test protocol is needed so that different products can be more accurately compared prior to purchase and use. Test protocols that involve assemblies or larger-sized samples with dynamic conditions may more accurately evaluate product effectiveness against mold.

Secondly, model building codes should be explored in numerous climate zones to identify and remedy code provisions that create rather than prevent moisture problems.

TOOLBASE TECHNOTES

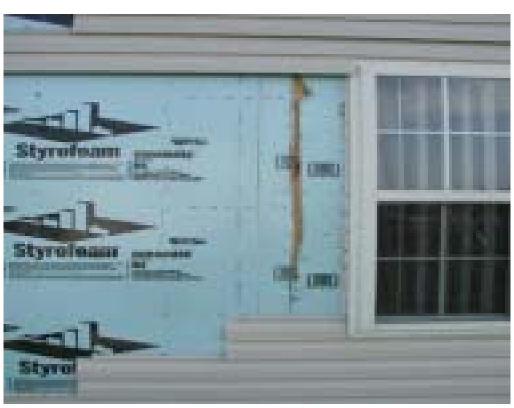
Issue: Condensation on windows, Mold on baseboard moulding.

Location: Heating

Keywords: High indoor humidity, baseboard molding

Structure:

- Occupied in July 2001
- Site visit April 2002
- One and a half story house
- Single-family detached
- Slab foundation
- 2” x 4” wood-framed walls
- R-13, un-faced, fiberglass batt insulation
- OSB at corners
- ½-inch extruded polystyrene and/or asphalt impregnated fiberboard for exterior sheathing
- Vinyl siding
- Interior polyethylene vapor retarder
- R-38 blown fiberglass insulation in attic
- R-30 fiberglass batt in the cathedral ceiling
- Double-paned, double-hung, vinyl windows
- No housewrap or building paper was used



Vinyl siding without housewrap

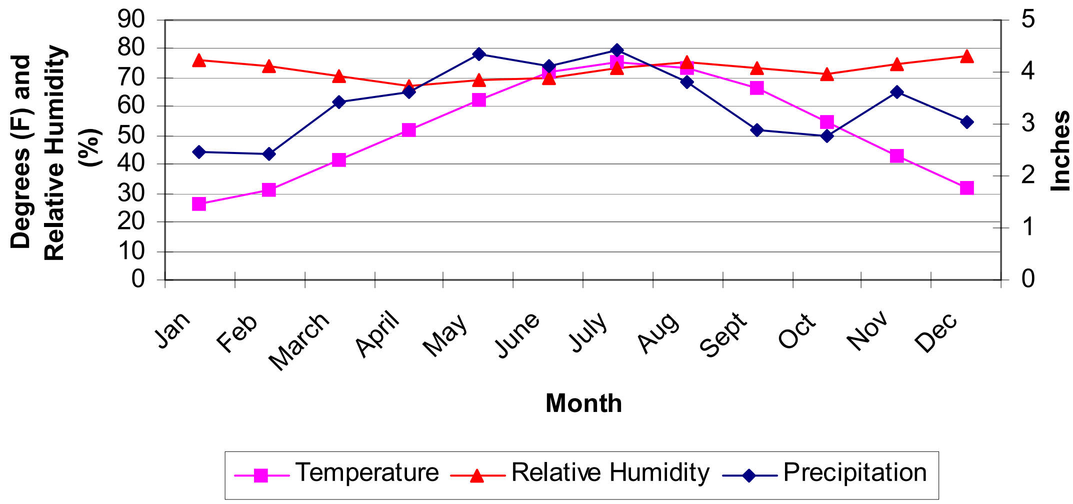

Mold on floor and baseboard

Site Conditions:

The home is a 2,040 ft^2, one and a half story house, on a slab foundation. Wall construction consists of 2" x 4" framing with R-13, un-faced, fiberglass batt insulation. OSB is used at the corners and ½-inch extruded polystyrene and/or asphalt impregnated fiberboard is used for exterior sheathing beneath the vinyl siding. No housewrap or building paper is used. A polyethylene vapor retarder was installed on the interior; seams were not caulked. The attic insulation is R-38 blown fiberglass and R-30 fiberglass batts in the cathedral area. The windows are double-paned, vinyl, double-hung. Exterior doors are insulated steel.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Indianapolis, IN, Average Monthly Temperature, Precipitation and Relative Humidity



Problem Description:

Owners first noticed mold on several windows and at the base of an exterior French door. Investigators found mold on all windows at the frame/glazing junctures and frame/sill junctures. Investigators observed mold on the first floor at the base moulding below two northwest windows and on the base moulding and vinyl flooring in a closet.

The owners humidified the house based on their doctor's recommendation of keeping the relative humidity between 50-60% year round. The home had three aquariums, which release additional moisture into the home. All openings were covered due to the owners' light sensitivities.

Diagnosis and Prescription:

The builder plans to thoroughly wash the windows, moulding, and vinyl flooring in the areas where mold has grown. The use of a peroxide-based cleaner to remove existing mold is recommended. Some of the moulding may be replaced.

While probably not the main source of moisture, the top of all vinyl corners should be flashed or sealed.

The indoor relative humidity during winter months should be kept between 30% and 40% to prevent moisture from condensing on cool surfaces such as windows and other perimeter surfaces.

The mold on the base moulding and floor and at the bottom of the exterior door may be due to thermal bridging at the slab edge and building corners, and air leakage beneath the door. Perimeter slab insulation may prevent this problem and also keeps the wall perimeter warmer, which reduces the potential for condensation.

Gutter downspouts and splash blocks should direct water at least two feet away from the building.

Keep all HVAC supply and return registers open to ensure uniform air circulation throughout the house.

Code Issues:

The International Residential Code (IRC) does not require housewrap beneath vinyl siding (Table R703.4). However, housewrap on the exterior acts as a drainage plane and provides one more line of defense against rain water intrusion.

TOOLBASE TECHNOTES

Issue: Mold on roof sheathing

Location: Heating

Keywords: Roof sheathing, log home

Structure:

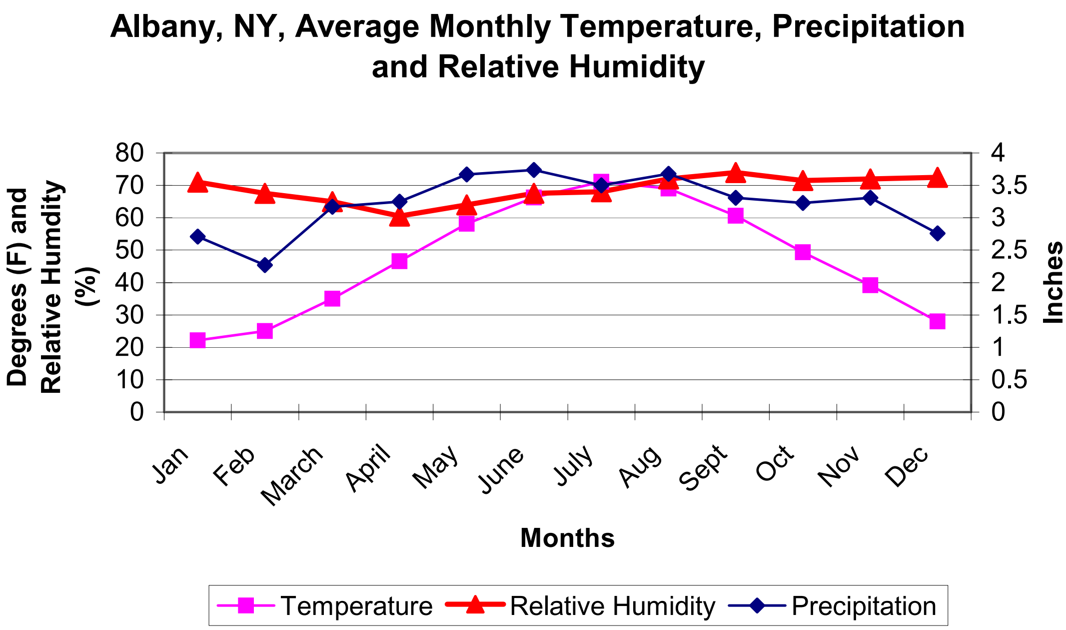
- House constructed November 2001
- Site visit January 2002
- Two-story house
- Single-family detached
- Full basement
- Engineered solid log
- Tongue and groove interlocking construction
- Lumber ceiling insulated with kraft-faced R-38 fiberglass batt insulation
- 2” x 12” lumber rafter cathedral ceiling and cathedral ceiling with scissors truss construction
- Gasketed log grooves and sealed lateral joints
- Roof sheathing is 3/8-inch OSB with building felt and 30-year architectural asphalt shingles
- Cavity areas were vented with foam-plastic baffles allowing air movement from the continuous soffit vents to the continuous ridge vents

Site Conditions:

This house was occupied in November 2001 and the owner occupants are completing the finish trim, flooring, and surface finish. The structure is of engineered solid log, tongue and groove interlocking construction with air sealing gasket material in the groove combined with sealant along the lateral joints between the logs. The logs were kiln dried, and the moisture content ranged from 7% to 12%.

TOOLBASE TECHNOTES

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

The interior surface of north-facing roof sheathing was saturated and covered with mold. The south-facing roof sheathing had low moisture content and no mold.

Diagnosis and Prescription:

Bulk air movement carrying moisture from the living spaces through the lumber ceiling into the attic is the suspected moisture source. North-facing roof surfaces have lower temperatures and may have been at or below dewpoint allowing for condensation on the sheathing.

New construction releases large quantities of water as concrete cures and lumber equilibrates to lower moisture content levels. Additionally, occupant activities such as cooking, bathing, and respiration add moisture to the air. If moisture problems persist after several months, a strategy to limit moisture movement to the attic might be warranted. Consider incorporating an air barrier just above the lumber ceiling.

Code Issues:

No code issues

TOOLBASE TECHNOTES

Issue: Construction moisture

Location: Cooling

Keywords: Construction moisture, baseboard moulding

Structure:

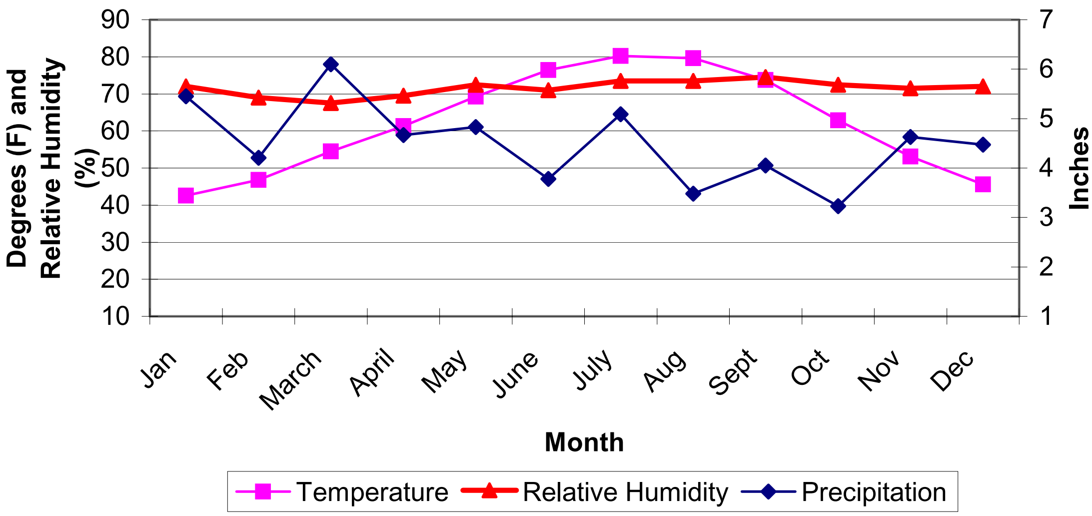
- House constructed February 2002
- Site visit May 2002
- Single-story house with a brick façade
- Single-family detached
- Slab foundation
- Wood framed
- Cellulose insulation

Site Conditions:

The property is located in Alabama about 30 miles from Birmingham. At the time of the study, the home was less than six months old. The single-story home is wood framed with a brick façade. The site visit took place in spring, just after an unusually long period of rain.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Central Alabama's Average Monthly Temperature, Precipitation and Relative Humidity



Symptom Description:

The owner noticed mild mold growth along the baseboards of exterior walls; interior walls did not appear to be affected. Upon inspection, the moisture content of the baseboard was less than 20%; the adjacent drywall had a much higher moisture content level. There was no flashing or weep holes in the brick and site grading was minimal. It is possible that the vapor retarder below the slab was omitted during construction. Because the builder described the weather during construction as unusually wet, wood and drywall may have been exposed to moisture during pre-construction and construction resulting in post construction mold growth. Another source of moisture could be the water associated with the wet-spray cellulose.

Diagnosis and Prescription:

The moisture appears to be from precipitation during construction and from poor flashing and inadequate drainage details in the wall. Corrective steps include relieving trapped wall moisture by drilling weep holes into the exterior wall and placing dehumidifiers in the living space. Additionally, allowing time for moisture to dissipate from the cellulose insulation prior to sealing with drywall may alleviate the problem. The mold will be cleaned and the condition will be reassessed after a period of time.

Code Issues:

No codes address protection of the framing from environmental elements before and during construction. Other code issues may apply to unseen building details, which may become evident upon further investigation.

TOOLBASE
TECHNOTES

Issue: Condensation on windows, Mold on window sills

Location: Cooling

Keywords: Window condensation, site grading

Structure:

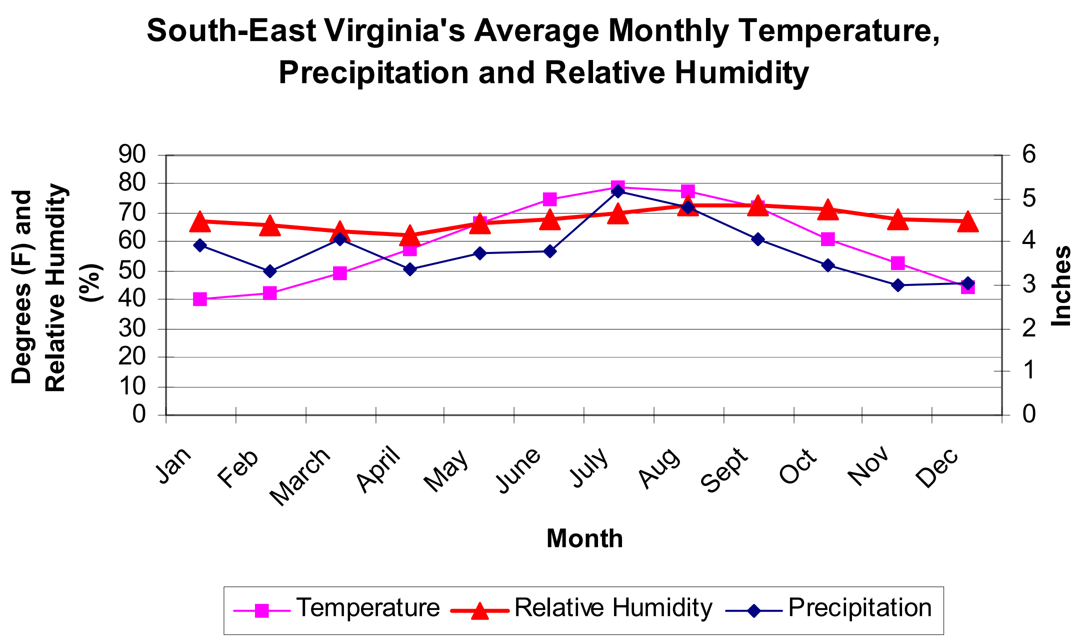
- House constructed February 2001
- Site visit May 2002
- Two-story house
- Single-family detached
- Slab foundation
- Exterior sheathing, OSB with housewrap
- Interior polyethylene vapor retarder
- 2" x 4" wood-framed walls with R-13 un-faced fiberglass batt insulation
- Double-pane, aluminum windows
- No ceiling vapor retarder present
- Soffit vents and styrofoam baffles in place

Water damage on window sill and frame

Site Conditions:

A two-story home that is approximately one year old and was completed in February 2001. The home consists of 2” x 4” wall framing with R-13 un-faced fiberglass batt insulation and an interior polyethylene vapor barrier. The foundation is an elevated slab. Exterior sheathing is OSB covered with housewrap. The ceiling is 9 feet on the first level and 8 feet on the second level. Windows are double-pane with aluminum frames. There is a lake behind the house.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

The homeowner reported condensation and mold on the windows of the upper level bedrooms and master bath. The homeowner observed that the mold appeared during the heating season and diminished in the cooling season. Investigators observed degradation of the plaster wall finish and sill around the master bath window— possible signs of water intrusion. The master bath window is metal-framed and adjacent to the shower stall. The grade on the north side of the house slopes toward the house. The downspout splash pans were either sloped toward the house or not in place at all.

Diagnosis and Prescription:

Metal-framed windows have high conductive properties and low R-values, thus condensation may result on the interior of the window frame with high indoor relative humidity and cold outdoor temperatures. Replacing windows with energy-efficient, thermally broken windows may solve the problem. Researchers advised the homeowner to clean up the mold and watch for recurrence. One temperature and relative humidity meter was placed on the second level; another meter was placed on a first-floor windowsill. Researchers found no significant level of moisture in the master bath or bedroom windowsills during the site visit. Researchers recommended that the grading be sloped away from the house and downspouts and splash pans be directed away from the foundation. Additionally, increasing the ventilation in rooms with windows showing condensation may alleviate the problem.

In some structures located in mixed or cooling climates, a polyethylene vapor retarder located on the area of framing that faces the interior may be improperly placed on the cool surface, such as during summer when air conditioning is operating. This situation can result in a buildup of moisture in the wall cavity. The use of kraft paper-faced insulation may be advisable in lieu of polyethylene to prevent this situation.

Code Issues:

No code issues

TOOLBASE TECHNOTES

Issue: Basement wall and window condensation

Location: Heating

Keywords: Moisture in wall cavity, basement frame wall, relative humidity

Structure:

- Houses started being occupied between 2001 and 2002
- Site visit January 2003
- Multi-family attached
- Basement foundation
- 2” x 6” wood-framed walls
- R-19 un-faced fiberglass batt insulation
- Vinyl or fiber-cement siding
- OSB sheathing with interior polyethylene vapor retarder


Walkout basement


Window condensation in basement

Stepped framed basement walls

Site Conditions:

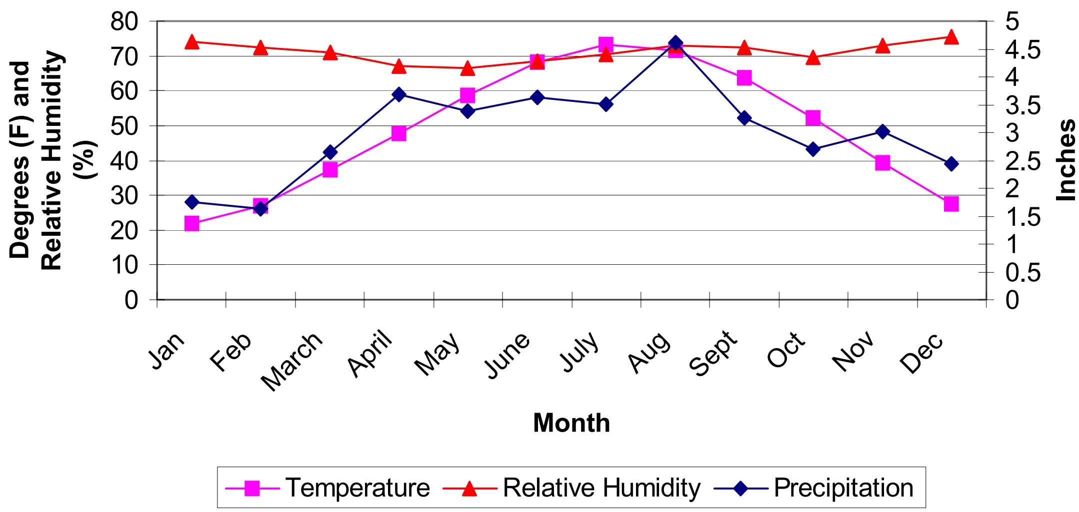
During the heating season, several Chicago area homes developed problems stemming from moisture trapped in basement and wood-framed wall cavities. One end of the basement was fully below grade, the sidewalls stepped down toward the other end wall, which was a walkout opening on grade.

The entire walkout-end wall and the portion of the sidewalls closest to the walkout-end wall were wood-framed from top to bottom. On the rest of the sidewalls, the lower portion of the walls had a stepped masonry design that followed the slope below grade; the upper portions of the walls were wood-framed and on the masonry. The framed walls were 2" x 6" with R-19 un-faced fiberglass insulation, vinyl or fiber-cement siding, OSB sheathing, and a polyethylene vapor retarder for the interior covering. The walls and ceiling were not covered with wallboard. The HVAC systems in all homes were gas fired forced air with Aprilaire humidifiers.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

TOOLBASE TECHNOTES

Chicago, IL, Average Annual Temperature, Precipitation and Relative Humidity



Symptom Description:

Moisture was developing in the wall cavities and on windows in the basements. Investigators studied three test homes. The outside air temperature on the day of the visit was 17ºF; the following measurements were obtained:

	Sheathing Moisture Content	Relative Humidity of Basement Air	Basement Temperature	Basement Dew Point
House 1	15-40%	24%	62.3ºF	25ºF
House 2	15-40%	39%	63ºF	38ºF
House 3	15-40%	42%	61ºF	38ºF

Diagnosis and Prescription:

Dew point can be reached easily in cold climates during the winter. Minimizing humidity levels will reduce the potential for condensation. Based on the following steps the builder took to remedy the problem, elevated humidity levels appear to be the source of moisture:

Builder's Remedy	Result
Replaced the fiberglass insulation and caulked polyethylene vapor retarder to the wood frame.	Moisture recurred.
Replaced the fiberglass insulation without replacing the polyethylene vapor retarder.	Moisture recurred.
Replaced the fiberglass insulation, without replacing the polyethylene vapor retarder, and set the humidifier to 15% relative humidity.	Moisture did not recur.

The builder is developing closing/walk-through procedures to educate buyers on operating the HVAC systems to avoid moisture problems.

Code Issues:

No code issues

TOOLBASE TECHNOTES

Issue: Mold in exterior wall cavities and behind vinyl wallpaper on exterior walls

Location: Mixed

Keywords: Exterior walls, masonry construction, water intrusion, vinyl-coated wallpaper

Structure:

ü House constructed June 1998
ü Site visit September 2002
ü Two-story house
ü Single-family detached
ü Basement foundation
ü 2” x 6” wood-framed walls
ü ½-inch drywall, painted and/or vinyl wall-papered
ü R-19, craft-faced, fiberglass batt insulation
ü OSB sheathing with 15 pound felt building paper
ü 6-inch stone veneer exterior

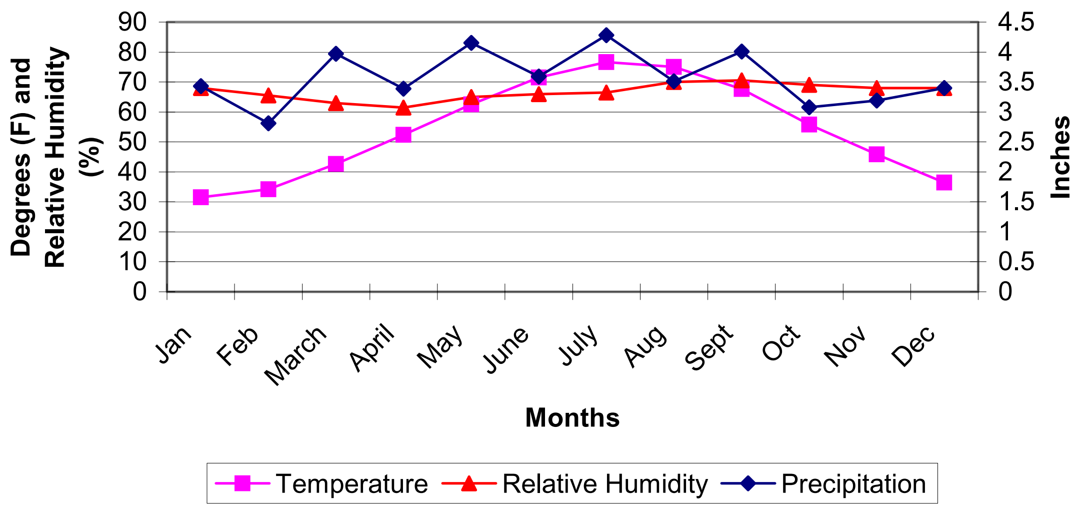
Mold on backside of vinyl wallpaper

Site Conditions:

The house was completed and occupied in June 1998, and at the time of this study the original owners occupied it. This 6,000 ft^2, two-story house has a poured concrete basement foundation. The basement is partially finished. The structure is wood-framed with 2” x 6” walls, ½-inch drywall painted and/or vinyl wall-papered, R-19 craft-faced fiberglass batt insulation, OSB sheathing, 15-pound felt building paper, and a 6-inch stone veneer exterior. The rear exterior wall of the house is covered with siding. The soil grade around the house perimeter is flat in the front, with the grade sloping to the side and rear of the lot. A landscape irrigation system for the front of the house is in place.

The following graph shows the average monthly temperature, precipitation and relative humidity over a 30-year period. The graphs were created from the National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Northern Delaware's Average Monthly Temperature, Precipitation and Relative Humidity



Symptom Description:

Homeowners reported a musty smell coming from the exterior walls of two bathrooms located on the first level of the house. Exterior walls in the bathrooms were finished with heavy, vinyl-coated wallpaper. When investigators removed the wallpaper, they observed mold on the backside of the wallpaper and on the drywall. Investigators also observed mold on the interior surfaces of the OSB sheathing and corrosion of metal surfaces in the wall cavity. Moisture readings taken of the OSB sheathing showed evidence of moisture. Mold problems were not reported in any other areas of the home.

Diagnosis:

Water intrusion testing ruled out the possibility of leaks from the window areas in the vicinity of the two mold-affected bathrooms. No significant or unusual indoor moisture sources or problems were identified. Air leakage testing indicated a tight building envelope. Moisture readings taken along a cross-section of the exterior sheathing, from the inside, indicated several areas with above normal moisture levels for studs, sheathing, and wallboard. Moisture readings of the studs were higher toward the exterior portion of the wall. HVAC supply registers cooled surfaces near the affected area creating a greater potential for condensation.

The bathroom was sealed off and a dehumidifier was placed inside. Over a period of several weeks and several rain events, the dehumidifier continuously accumulated a constant amount of moisture. Little to no air gap existed between the stone façade and the building felt/OSB layer of the exterior wall. Water intrusion testing revealed a leak through a small cavity in the mortar joint of the stone façade; investigators observed water on the interior side of the OSB sheathing. Based upon the site inspection, testing, and the accounts of the builder staff and homeowner, water intrusion through the stone veneer, direct contact of the masonry and mortar to the wall system, and vinyl-coated wall covering on the exterior walls, caused water to accumulate in the wall cavity. This created an environment conducive to mold growth.

Prescription:

Provide for an air space between masonry walls and the exterior sheathing. Use galvanized wall ties. Consider the use of waterproof rated mortar. Install weep holes on an upward angle in the mortar joint above foundation height, spaced as required. Install building paper or housewrap appropriately. Avoid using vapor-impermeable wall coverings on exterior walls.

Code Issue:

Local building code required no air gap between stone façade and sheathing.

TOOLBASE TECHNOTES

Issue: Mold on interior walls

Location: Mixed

Keywords: Fiber-cement siding

Structure:

- House constructed in 1999
- Site visit June 2002
- Three-story house
- Single-family detached
- Foundation is a piling type in sandy soil
- Wall materials: fiber-cement siding, housewrap, plywood, fiberglass batt insulation, and drywall
- Roof in good condition

Pin holes in exterior walls where moisture readings were taken

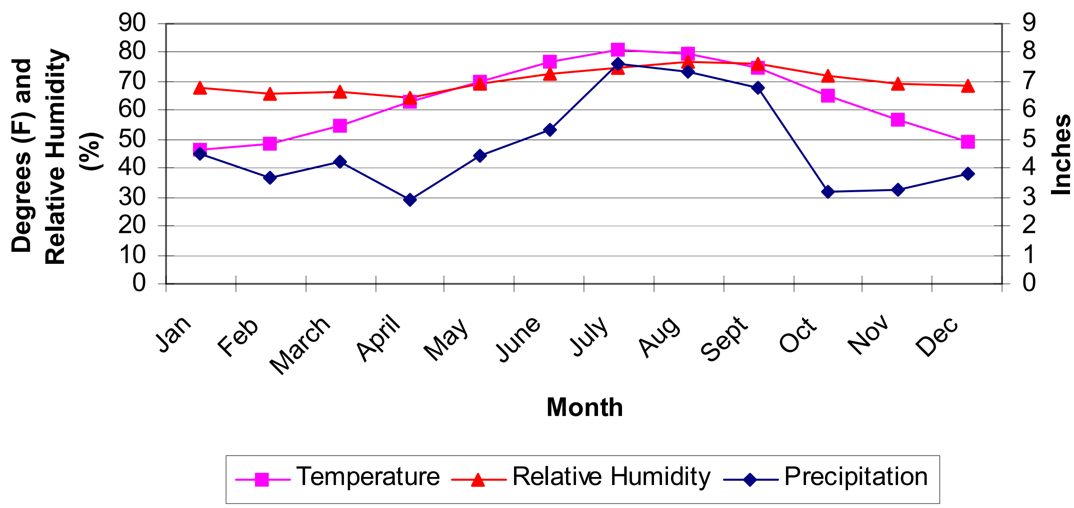
TOOLBASE TECHNOTES

Site Conditions:

The property is a coastal vacation home in North Carolina approximately 40 miles south of Wilmington. The site visit took place during a dry period for the region. The outside temperature was 88ºF with 70% relative humidity and winds were from the east at more than 20 miles per hour.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

South East North Carolina's Average Monthly Temperature, Precipitation and Relative Humidity



Problem Description:

Mold was found on interior walls near the washer/dryer unit. Moisture readings of about 15% were recorded, which is normal given the existing weather and climate conditions. Other beach-home owners reported moisture problems with the exterior walls containing similar materials.

Diagnosis and Prescription:

No mold was present at the time of the study. The homeowner will monitor the home for indications of continued problems. During a site visit, moisture levels in the exterior material appeared normal.

The original mold problem may have been a result of elevated humidity associated with the laundry. If the problem reoccurs, increasing ventilation in the laundry area is warranted.

Code Issues:

No code issues

TOOLBASE TECHNOTES

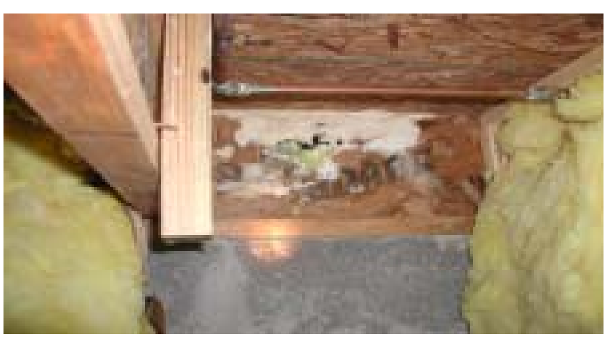
Issue: Mold in exterior wall cavities, sheathing, drywall, and interior base molding

Location: Heating

Keywords: Exterior walls, masonry construction, water intrusion, crawl space, grading

Structure:

- House constructed July 2001
- Site visit April 2002
- Two-story house
- Single-family detached
- Full basement foundation under most of the home and crawl space beneath the remainder
- 2” x 4” wood-framed walls
- ½-inch painted drywall, polyethylene vapor retarder located between drywall and studs
- R-13 un-faced fiberglass batt insulation
- OSB sheathing at outside corners and ½-inch cellulose-backed polyisocyanurate rigid insulation on the remainder
- No exterior building felt or housewrap
- Brick veneer exterior



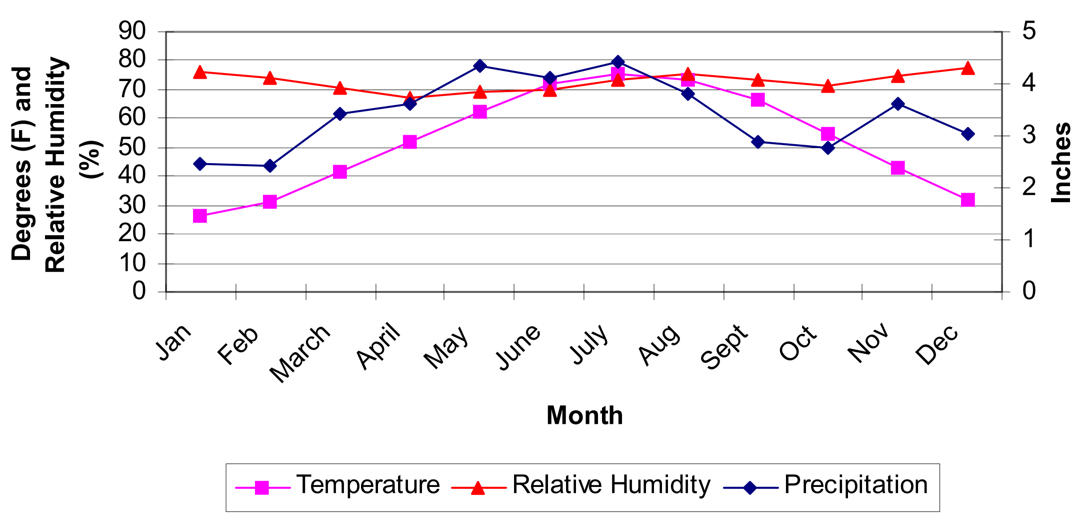
Mold on band joist below bedroom

Site Conditions:

The house was completed in July 2001, and at the time of this study the house was vacant. This 3,000 ft^2, two-story house has a basement foundation with a small crawlspace under one room. The basement wall is damp-proofed with the Rub-R-Wall system[i] and a ¼-inch protective polystyrene board. The structure is composed of 2” x 4” wood-framed walls, ½-inch painted drywall, a polyethylene vapor retarder located between the drywall and studs, R-13 un-faced fiberglass batt insulation, OSB sheathing at outside corners, ½-inch cellulose-backed polyisocyanurate rigid insulation on the remainder of the exterior walls, and a brick veneer exterior. There is no exterior felt or housewrap. The crawl space is not damp-proofed and the exterior walls are insulated on the interior with craft-faced fiberglass insulation. The floor above the crawl space is not insulated. Pea gravel and a polyethylene vapor retarder cover the crawl space soil. Both the basement and crawl space have exterior perimeter drainage at the footing. The soil grade around the perimeter is flat with several areas sloping toward the foundation.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Indianapolis, IN, Average Monthly Temperature, Precipitation and Relative Humidity



TOOLBASE TECHNOTES

Symptom Description:

Mold-like discoloration formed on interior and exterior walls on the OSB sheathing and framing members, near the base of walls along the perimeter of the house. Mold was present on the back of the base moulding and the interior face of the drywall near the floor in several rooms. Carpet, and carpet tack strips were stained indicating the presence of moisture. In the crawlspace, mold was present on the band joist in two bays. Pea gravel around the perimeter of the crawl space wall at the soil level was damp. The base of the kraft-faced insulation in the crawlspace was touching the floor and was wet.

Diagnosis:

Investigators removed several sections of brick from around the perimeter of the house. These areas revealed that no building paper had been installed and that the air space between the brick and sheathing was obstructed with mortar, resulting in direct contact between the brick, mortar, and sheathing. The mortar was also blocking the drainage path to the weep holes at the base of the wall. Although there were weep holes at the bottom of the wall, they were at grade or below grade, preventing adequate drainage and allowing pooled water to enter the wall system. There were no weep holes at brick windowsills or heads. Flashing was also not present at either the windowsills or near the weep holes. Air leakage testing indicated a tight building envelope. Moisture and water vapor from the exterior became trapped behind the wall. With no capillary break between the masonry and sheathing, no drainage path or flashing, and no air gap to allow circulation as a means of drying, the moisture/water vapor was likely to have migrated or wicked-up through the wall and condensed on the cooler exterior polyethylene vapor barrier. Also, the crawlspace had no vapor barrier and straw on the floor, contributing as a moisture source for that area and the room above it. Ductwork in the crawlspace was not sealed or insulated.

Prescription:

Provide an air gap between masonry veneer and the exterior sheathing. Weep holes and proper flashing should be installed at the base of the brick wall as well as at the lintels and sills of windows and doors. Install a secondary weather barrier. Install building paper and housewrap appropriately. Back-fill the area around the house with gravel and/or soils that have good drainage characteristics. Ensure that the grade slopes away from the house. Damp-proof exterior foundation walls. Make sure the foundation is properly elevated above the finished grade. Anticipate that homeowners will add mulch to the areas around the home. Consider the use of kraft-faced fiberglass batts as opposed to continuous polyethylene vapor retarder on exterior walls. Caulk or seal polyethylene vapor retarder to the base of the crawl space wall or bring the polyethylene up the side of the wall and fasten it to the sill plate. Ensure that multiple pieces of poly have sufficient lap. Insulate plumbing supply lines in the crawl space.

Code Issues:

Section R703 of the International Residential Code (IRC) requires a weather-resistant asphalt-saturated felt between the brick veneer and any sheathing that is not water-repellent. The IRC also specifies a 1- to 4½-inch air space between the brick veneer and exterior wall sheathing. Weep holes and non-corrosive flashing are also required at lintels above windows and doors, at windowsills, and at the base of veneer walls. Figure R403.1 in the IRC shows a 6-mil poly vapor barrier covering the floor of the crawl space in a wood foundation. Although not specifically mentioned in relation to a concrete stem wall, this is advisable practice. Section R408.4 of the IRC specifies removing vegetative and organic material from the crawl space area. Section 603.8 of the International Mechanical Code (IMC) refers to the International Energy Conservation Code with respect to sealing of ductwork. Section 603.11 of the IMC also specifies that provisions shall be made to prevent condensation on the exterior of all ductwork.

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[1] A liquid rubber, spray-applied foundation water-proofing membrane.

TOOLBASE TECHNOTES

Issue: Condensation in crawlspace

Location: Mixed

Keywords: Crawl space moisture

Structure:

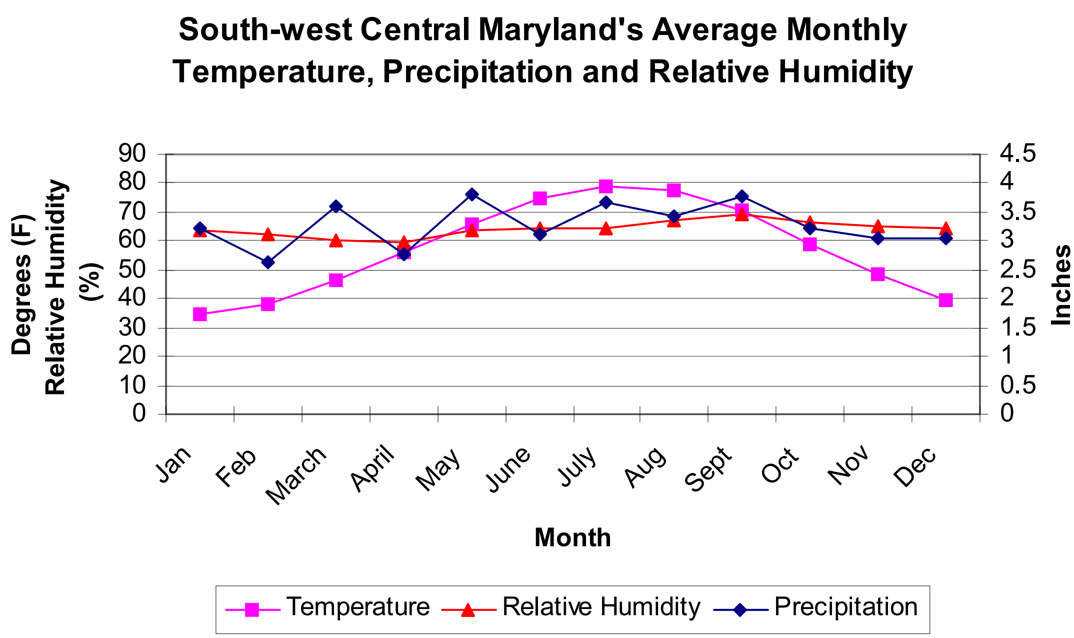
- Site visit June 2001
- Two-story house
- Single-family detached
- Crawlspace foundation
- Insulation installed between the floor joists
- Engineered wood floor joists
- OSB sub-floor


Perimeter grade sloping away from structure

Site Conditions:

The property is located in Maryland. During the visit in June 2001, the outdoor air conditions were 81°F with 57% relative humidity, and a dew point of 66°F. The area of concern, the crawl space, was 71°F with 80% relative humidity, and a dew point of 64°F. The crawlspace did not appear to have surface water problems—the house is situated on a hill, with perimeter grade sloping away from the structure, roof gutters and downspouts were properly maintained, and grade in the crawl space slopped to a sump pump, which has never operated according to the owner.

The following graph shows the average monthly temperature, precipitation, relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Problem Description:

The bottom side of the insulation between the floor joists was dripping wet. The moisture range of the bottom plate of the floor joists was 20% to 24%. Below grade sections of the foundation wall surfaces were visually wet. Pools of water were observed on the vapor barrier ground cover. Water was dripping off the HVAC supply plenum insulation covering. Two fans, each running at approximately 100 cubic feet per minute were actively venting the crawlspace and the grills of the passive vents were open.

Diagnosis and Prescription:

Ventilating the cool crawlspace with humid outdoor air introduced moisture which condensated in the crawl space. Field personnel placed air temperature and moisture sensors in the basement. They also disabled the crawl space ventilation fans, closed the crawl space passive vent grills, placed a dehumidifier in the crawl space, and sealed perimeter wall vents with insulation.

A second visit to the site showed that remedial measures were effective. The thermal insulation between the floor joists was dry as were the floor joists. The concrete block foundation walls showed no evidence of visible moisture unlike the first visit.

Code Issues:

While the structure met code requirements for crawl space ventilation, ventilation appears to be a poor practice for this structure due to its location in a mixed, humid climate zone.

TOOLBASE TECHNOTES

Issue: Condensation on sheathing and roof leaks

Location: Heating

Keywords: Roofing system, attic venting

Structure:

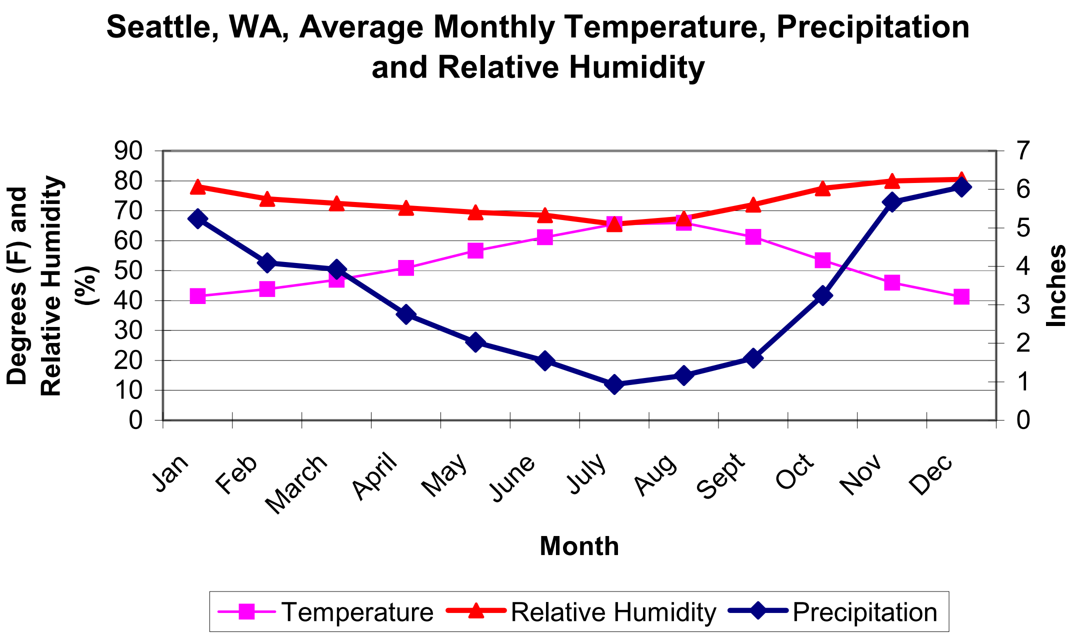
- House constructed in 2001
- Site visit April 2002
- Two-story house
- Single-family detached
- Roof trusses sheathed with OSB
- Rock wool insulation above the ceiling
- Roof, gable, and soffit vents were present
- Bathroom ceiling uses a light well design between two trusses


OSB roof sheathing with evidence of high moisture

Site Conditions:

The property is located in north of Seattle, Washington. The site visit took place during the wet/rainy period for the region, where the outside temperature varied from 40º to 60ºF with relative humidity between 60% and 100%.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for years 1972 through 2002.



Problem Description:

The bathroom ceiling uses a light well design between two trusses. The mold problem originated from this bathroom skylight area, and extends into the attic space. This elevated area tends to trap hot, humid air with no means of ventilation. In addition, poor sealing and insulation around the light well in the attic space promoted condensation by lowering the dew point. While a mechanical vent was available in the bathroom, the flow rate and location were not sufficient to prevent condensation or mold growth in the skylight area.

In the attic, building paper covered a third of the gable vent and a truss member restricted another third. Holes for the roof vents were cut too small and the vent cover was not placed correctly over the opening. Nails driven through the roof system caused water leakage into the attic, which saturated the insulation and drywall.

Diagnosis and Prescription:

Moisture generated in the bathroom is condensing on cool bathroom and attic surfaces. Roof leaks are introducing additional moisture into the attic. To correct the problem, the homeowner sealed the skylight and around the light well. Insulation was reinstalled correctly around the light well, and attic ventilation was improved. Additionally, penetrations through the roofing system were repaired.

Code Issues:

International Residential Code (IRC) 2000 regulates skylights and their construction in section R308.6. However, the issue of the light well construction in a bathroom area is not specifically addressed. Instead, it becomes part of the building envelope without necessarily meeting the full definition of an exterior wall.

Attic ventilation is regulated in section R806 and requires "net free ventilation" of at least 1 to 150 unless at least 50 percent and not more than 80 percent of the ventilation occurs in the upper portion of the roof at least three feet above the soffit. This case study home had a vent area of less than 3.5 ft^2 where the 1/150 stipulation would require about 8.7 ft^2. In other words, the case home had less than half of the code required ventilation area for attics.

TOOLBASE TECHNOTES

Issue: Construction moisture

Location: Mixed

Keywords: Shaft wall, moisture exposure

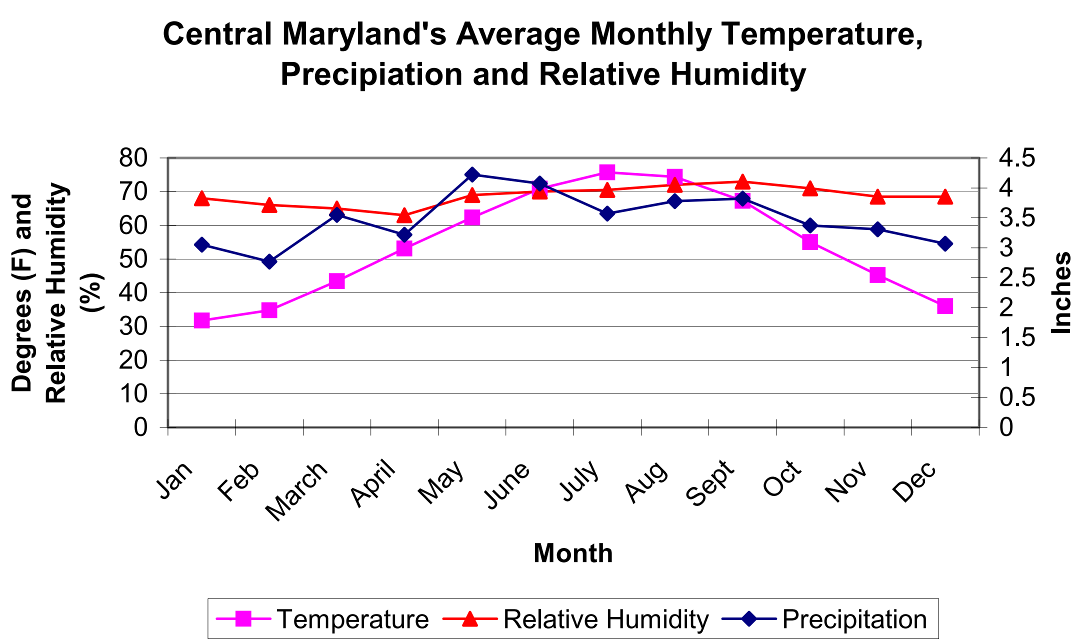
Structure:

ü Site visit September 2001
ü Multi-family and retail commercial property
ü Shaft wall uses a 1-inch thick, green fire rated drywall, with a metal "H" channel retaining assembly
ü 5/8-inch, type X drywall mounted on the core gypsum and screwed to the channel
ü Fire rated assembly extends from the basement to the attic roof

Site Conditions:

This three- and four-story townhouse project is a retail commercial property with office and dwelling space above. The project was still under construction during the investigation. The shaft wall uses a 1-inch thick, green fire rated drywall with a metal “H” channel retaining assembly. A 5/8-inch type X drywall is mounted on either side of the core gypsum and screwed to the channel. This fire rated assembly extends from the basement to the attic roof.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



TOOLBASE TECHNOTES

Problem Description:

The shaft walls exhibited active mold growth. The shaft- or firewall is typically exposed to the weather for eight or more weeks before protected by roof sheathing. The wall assembly absorbs considerable moisture. The basement receives little ventilation once the first floor is set. There are no proactive steps (e.g., fans, dehumidifiers, sump pumps) taken to dry the basement and the soil has poor drainage.

Diagnosis and Prescription:

Precipitation is the primary source of moisture. Severely molded material was removed and replaced. The remaining affected material was cleaned with X-14 (a mildew stain remover) and painted with Kilz brand primer. Dehumidifiers were added in the basement area and plastic sheeting was used to cover the assembly. On remaining projects, a 10-inch masonry stem wall was added to lift the wall assembly off of the floor to prevent standing water from wicking into the construction materials.

Several drywall manufacturers offer mold-resistant products specifically designed for shaft wall applications. Generally, these products replace the paper faces with fiberglass or other materials that do not support fungal growth. An added measure of mold resistance might be gained from using these products.

Code Issues:

No code issues

TOOLBASE TECHNOTES

Issue: Water stains around window.

Location: Mixed

Keywords: Baseboard molding, water-stained carpet

Structure:

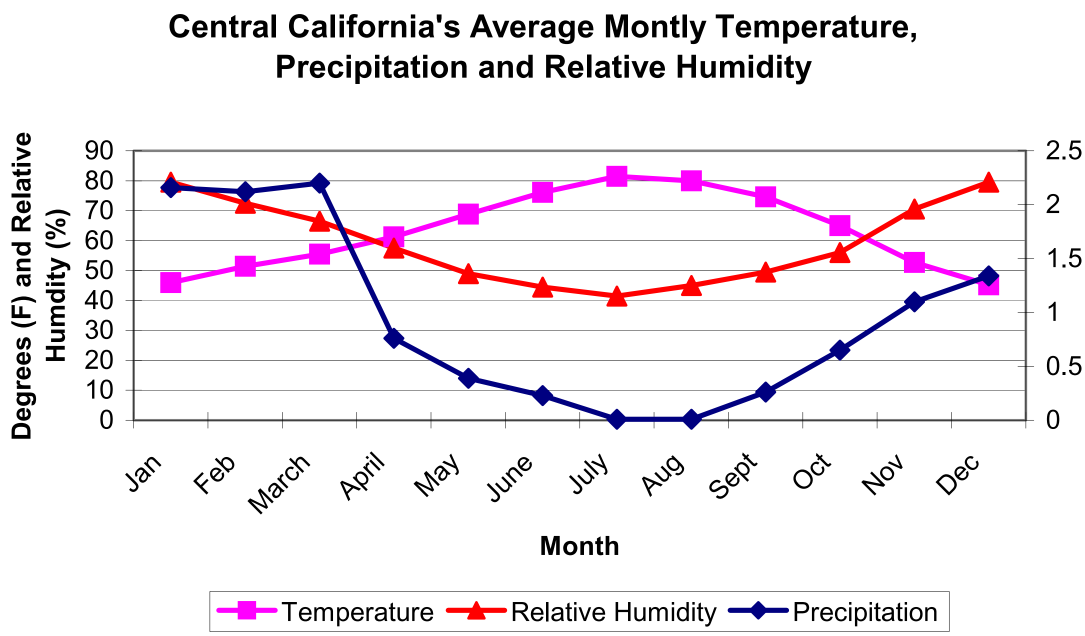
ü Owner occupied in 2001
ü Site visit June 2002
ü Two-story house
ü Single-family detached
ü Slab-on-grade foundation
ü Stucco cladding was replaced in 2001

Water staining on floor below window

Site Conditions:

The property is located in California. Building representatives reported water intrusion and mold growth. Employees of the builder previously documented moisture and mold problems. One episode occurred in 2001 and the other in 2002.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

The sealant failed around the window trim and stucco. There was a cohesive sealant failure within the sealant bead. The flashing was negatively sloped. Cracks between the window frames and the stucco were not caulked. Dormant mold was evident on the baseboards. The carpet had water stains, especially near windows. No mold was evident on framing, sheathing, thermal insulation, or drywall.

Diagnosis:

The water intrusion was determined to be from sources unrelated to the home's construction. One leak site is attributed to a lack of maintenance. It is likely that rain is entering through open windows.

Prescription:

Replace aged sealant around windows. Clean and repaint affected surfaces. There is no need for major repairs.

Code Issues:

No code issues

Issue: Construction moisture

Location: Heating

Keywords: Brick veneer, site drainage

Structure:

ü House constructed July 2001
ü Site visit May 2002
ü Two-story house
ü Single-family detached
ü Crawl space foundation
ü 2" x 4" wood-framed walls
ü ½-inch painted drywall, polyethylene vapor retarder located between drywall and studs
ü R-13 unfaced fiberglass insulation
ü OSB sheathing at outside corners and ½-inch asphalt-impregnated fiberboard sheathing on the remainder
ü Housewrap
ü Brick veneer and vinyl siding

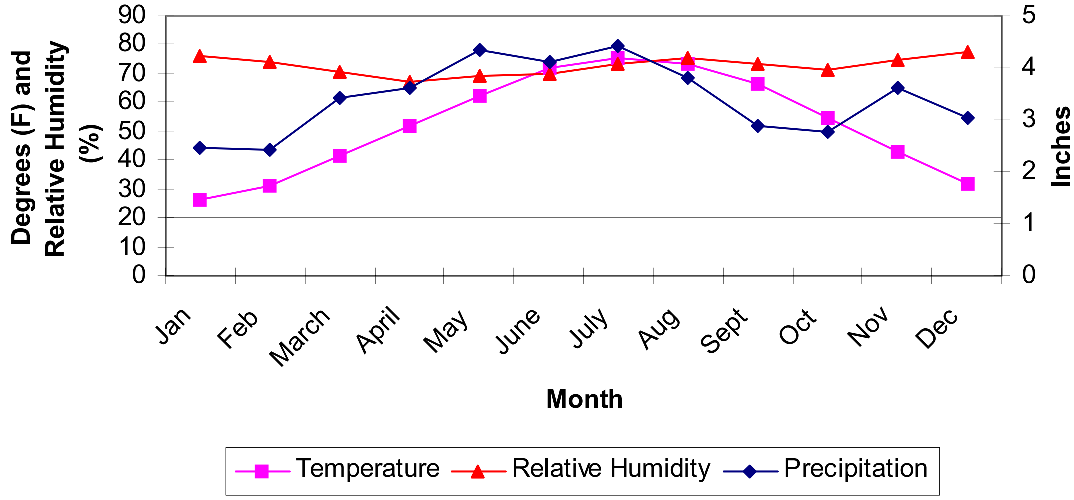
Housewrap over sheathing.

Inadequate air space between wood sheathing and brick veneer.

Site Conditions:

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Indianapolis, IN, Average Monthly Temperature, Precipitation and Relative Humidity



Symptom Description:

Mold was found on the sub-floor, framing, sheathing, and drywall located on the front and west side of the home. The raised patio was built directly against the band joist with no moisture drainage or water protection. There was inadequate air space between the wood sheathing and the brick veneer; the mortar obstructs gaps. Weep holes at the base of the walls too close to grade. Crawlspace vents are just at grade level. The base of the walls had no flashing. There were no weep holes at windowsills or lintels and no flashing at windowsills. The ductwork located in the crawlspace was not insulated. Observers found evidence of water intrusion through the cinder block walls.

Diagnosis and Prescription:

Moisture causing problems could have come from many sources. Wetted brick can provide a moisture source using solar energy to drive water into the wall cavity as the sun heats the masonry wall. Having adequate space between the brick and sheathing can prevent this phenomenon. Provide an air space, properly flash, and correct weep hole locations on the brick veneer to limit moisture intrusion through the cladding.

Intrusion through foundation walls and from the soil may also contribute substantial quantities of water to building elements. Make the crawlspace moisture barrier continuous by lapping seams at a minimum of 8 to 12 inches. An option to consider is to extend the polyethylene up the wall and caulk at the sill plate, however provisions to keep bulk water from penetrating the block foundation is paramount.

Crawlspace vents should be above grade, not at-grade. Seal the sump pump cover and verify it is working. Insulate and seal the ductwork in the crawlspace. Insulate water lines to prevent condensation. Damp proof crawlspace walls. The installation of exterior perimeter drainage and grading the soil to slope away from the structure will further reduce soil moisture in the crawl space. The patio should be flashed where it meets the band joist.

Code Issues:

The IRC specifies a 1- to 4½-inch air space between the brick veneer and exterior wall sheathing. Weep holes and non-corrosive flashing are also required at lintels above windows and doors, at windowsills, and at the base of veneer walls.

TOOLBASE TECHNOTES

Issue: Construction moisture

Location: Heating

Keywords: Weather exposure, rafters, surface mold

Structure:

ü House constructed October 2001
ü Site visit April 2002
ü Two-story house
ü Single-family detached
ü Full basement
ü In-law suite above garage
ü Wood-framed, rafter roof
ü Sheathed in OSB
ü Ridge and soffit vents
ü Ceiling insulated between joists and sheathed with OSB

Attic and trusses with mold growth

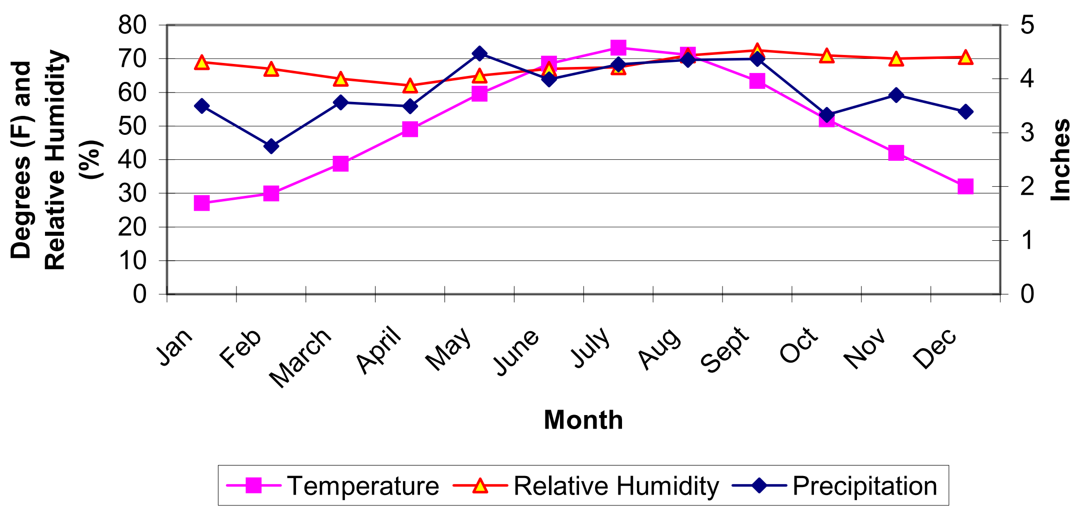
Trusses with mold growth

Site Conditions:

The site is a very low-density, wooded lot with varied terrain located near the Pocono Mountains in Pennsylvania. During a site visit, the outside air temperature was unseasonably warm at 70.1ºF with 37.4% relative humidity and winds less than 10 miles per hour.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.

Poconos Area, PA, Average Monthly Temperature, Precipitation and Relative Humidity



Symptom Description:

Mold was reported on the rafters and described by the homeowner as being active growth affecting the "vast majority of rafters" although investigators detected only a small number of rafters affected. Lumber exhibited no signs of structural moisture damage or other signs of decay. Moisture readings on all wood surface areas in the attic registered less than 10%.

Diagnosis and Prescription:

Site inspectors did not believe that construction design contributed to the presence of mold. No active mold growth was identified. Wood may have been exposed to moisture resulting in mold growth during the construction or pre-construction phase. The owner was advised to clean future mold growth as recommended by local environmental consultants.

Code Issues:

None

TOOLBASE TECHNOTES

Issue: Water leakage through windows

Location: Heating

Keywords: Flashing, multi-family, stucco

Structure:

ü House constructed in 1978
ü Site visit March 2002
ü Three-story condominium complex
ü Multi-family attached
ü Originally clad with a traditional stucco cladding system over chicken wire mesh


Untreated wood sill plate

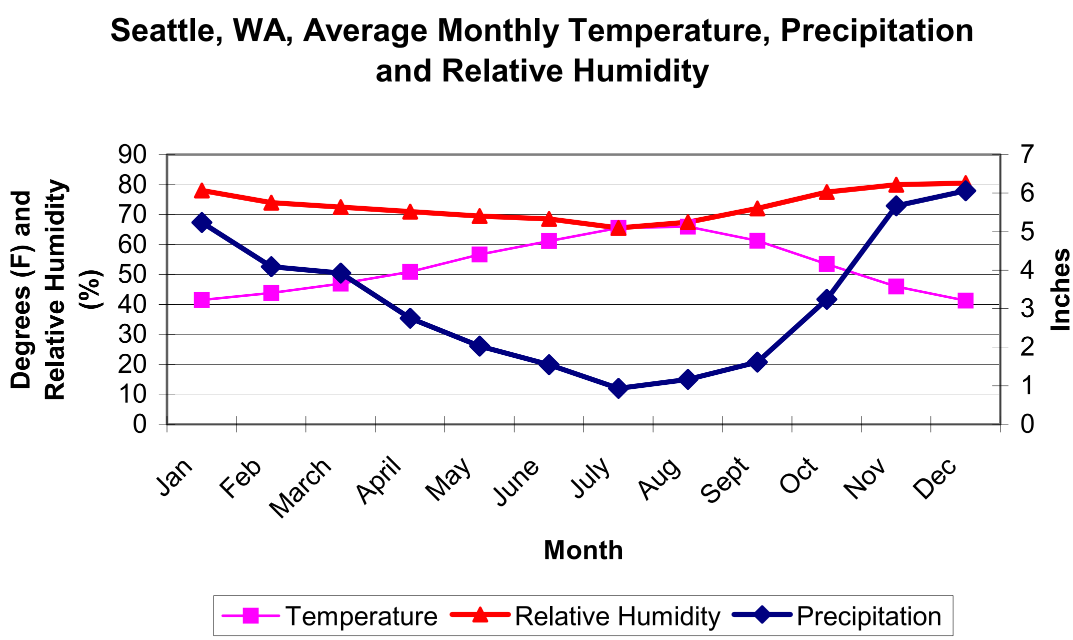

Water intrusion around window frame

TOOLBASE TECHNOTES

Site Conditions:

The site is a three-story condominium located in Seattle. The 10-unit building was constructed in 1978, and was originally finished with a traditional stucco cladding system over chicken wire mesh.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

Water is seeping through and around windows following rain events. A micro-laminated wood beam supporting a tuck-in garage was wet and substantially rotted. Bulk water leakage is evident at penetrations in the stucco cladding. Untreated sill plates are subjected to poor drainage and grading conditions that lead to water-based degradation of the structure. Moldy materials were present in the structure. Minimal flashing was incorporated around windows and other penetrations.

Diagnosis and Prescription:

The primary sources of moisture intrusion are bulk water entering through the building exterior then exiting through walls around windows and doors, and from poorly directed ground water.

The condominium association replaced approximately 75% of the stucco cladding with a fiber cement lap siding system. Z-channel flashing was installed around windows. Builders caulked joints and flashing details. The fiber cement and silicone caulk were finished with an exterior-grade primer.

Conventional stucco would have performed well if window and door openings were properly flashed and the site was graded to direct water away from the structure.

Code Issues:

Section 2306.4 of the Uniform Building Code (1997) states that sill plates should be of pressure treated wood or Foundation redwood if in areas of high risk for termite attack. For areas of moderate risk, Foundation cedar or No. 2 Foundation redwood is allowed. The sill plates found during this investigation do not appear to be of this material, which is resistant to rot.

TOOLBASE TECHNOTES

Issue: Construction moisture

Location: Heating

Keywords: Flashing, multi-family, pre-treatment products, material storage

Structure:

- Construction started December 2001
- Site visit March 2002
- Multi-family attached
- Five-story apartment complex
- Wood framed
- No flashing and weep holes in brick
- OSB panels, and micro-lam beams
- Site grading was minimal

Unroofed, exposed construction

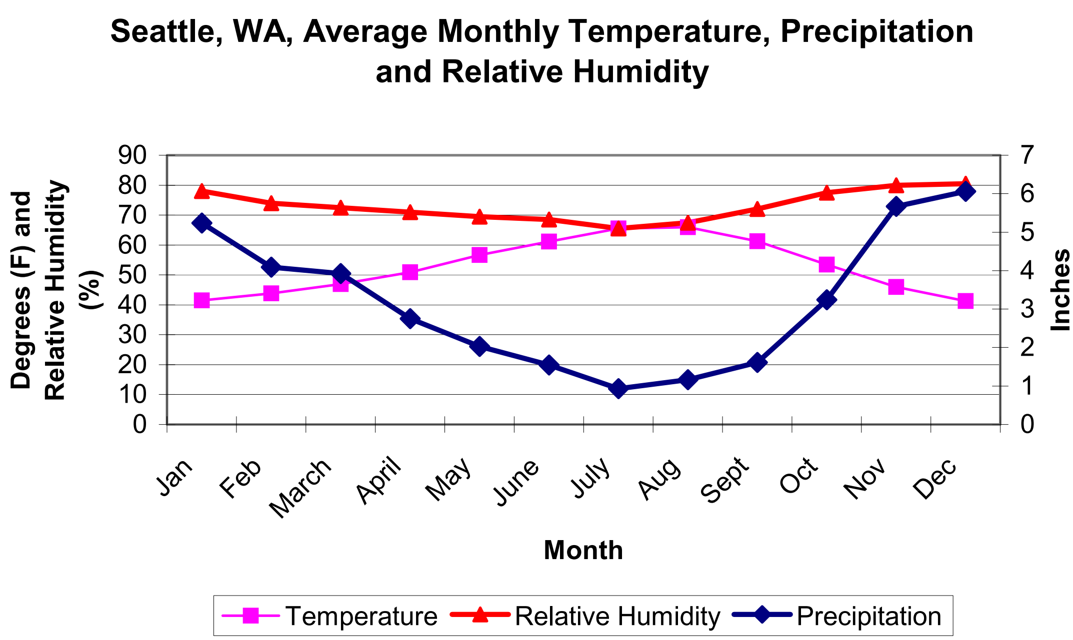
Wall panels exposed to weather

TOOLBASE TECHNOTES

Site Conditions:

The site is a two building, 200-unit apartment complex located in Seattle. Each building contains approximately 100 high-end, luxury apartments ranging in size from 800 to 1,600 ft^2. At the time of the inspections, the apartments were in various stages of construction ranging from rough framing to finishing.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

Panelized wall sections were exposed to rain for about three months. Wall sections were subjected to precipitation during assembly, pre-construction storage, and construction. The builder showed diligence in reviewing their construction processes and inspecting and treating mold problems. Very little evidence of mold was found on framing lumber or other materials.

TOOLBASE TECHNOTES

Diagnosis and Prescription:

The builder recommended measuring moisture content of wood framing materials before the drywall close-in construction phase. The builder's plan also includes on-site testing of window installations for water intrusion performance and a separate framing inspection for mold. That plan also includes treatment, when necessary, using a microbial agent or bleach solution.

Code Issues:

No code issues

TOOLBASE TECHNOTES

Issue: Mold in wall cavity and rotted base plate

Location: Mixed

Keywords: Vapor barrier, fiber cement siding

Structure:

- Constructed in 1996
- Site visit March 2002
- Three-story house
- Single-family detached
- Foundation is a piling type
- Roof with a two foot overhang
- Wall cross section consists of fiber cement siding, housewrap, plywood, fiberglass batt insulation, vapor retarder, and drywall

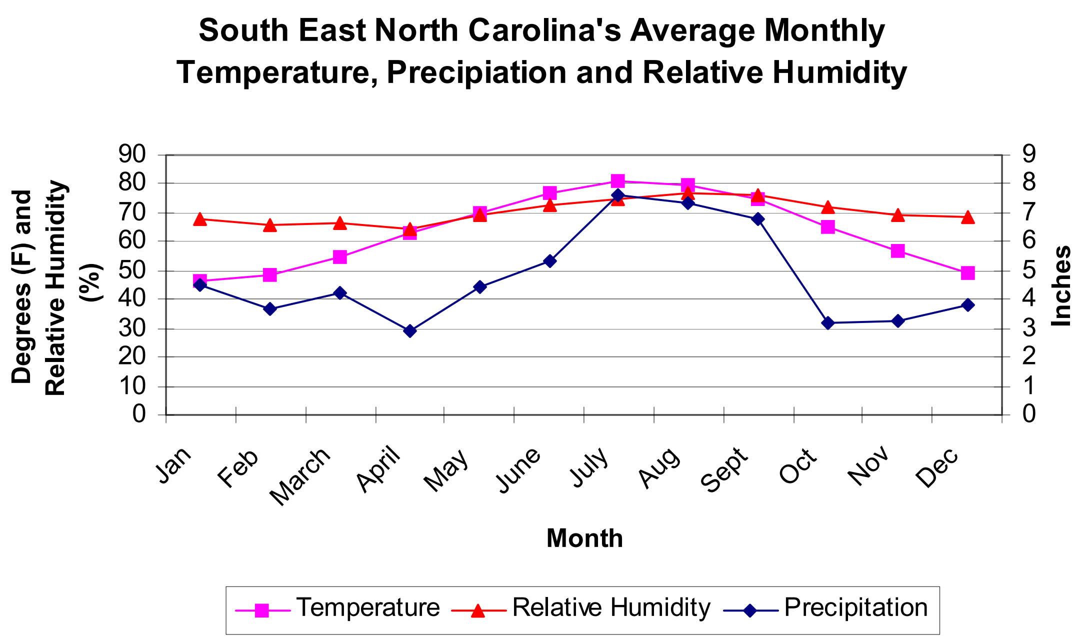
Moisture stains conform to the lap spacing in the exterior siding. Areas where the vapor barrier was breached (e.g., electrical outlets, staples, and drywall nails) show little sign of damage.

TOOLBASE TECHNOTES

Site Conditions:

The property is a coastal vacation home in North Carolina and at the time of the study, was approximately six years old. The foundation is a piling type in sandy soil. Two vented garage spaces on the first floor are below the main living spaces. The second floor contains mostly sleeping and bathing space and exhibits the majority of the mold problems. The kitchen, family room, and one bedroom are located on the third floor. With the exception of the southeast corner, there is little moisture damage on the third floor.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Symptom Description:

Mold was present in most of the second floor wall cavities with extensive rotting of the base plate and the bottom of the wall studs. The third floor had much less moisture damage except in the south corner. The first floor exterior garage wall did not contain insulation or gypsum although the painted sheathing had visible moisture stains. Thermally insulated walls between this outdoor space and the conditioned interior did not show much damage on the first floor.

Diagnosis and Prescription:

The vapor retarder was installed on the wrong side of the wall, although it conformed to local code at the time of construction. The issue of improper vapor retarder installation coupled with a large temperature gradient between the conditioned and unconditioned spaces, moisture condensed on the wall cavity side of the vapor retarder. The owner rebuilt a portion of the front wall before discovering mold and rot damage throughout most of the exterior second floor walls, which forced him to abandon the home.

Installing the vapor retarder on the exterior portion of the wall, sealing uncontrolled air infiltration, and ensuring adequate insulation around the perimeter of the exterior walls will prevent condensation within the wall cavities and will prevent conditions that lead to mold and decay.

Code Issues:

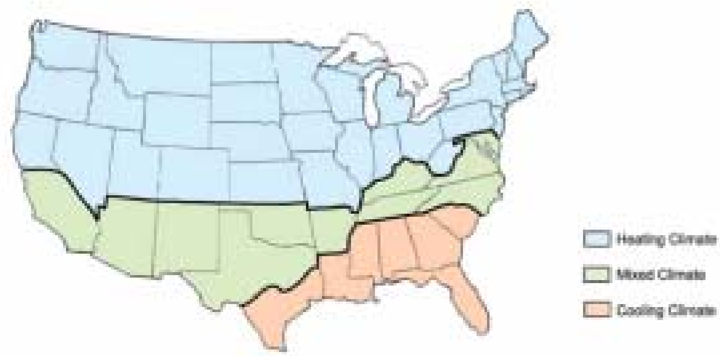
BOCA 1996: “All vapor retarders, whether integral or applied separately, shall be installed on the warm side of the building element, and shall have a permeance not exceeding 1 perm.”

TOOLBASE TECHNOTES

Issue: Sealed and unsealed crawlspaces

Location: Mixed

Keywords: Crawlspace study



Structure:

ü Site visit April 2002
ü One-story duplex house
ü Multi-family attached
ü Crawlspace foundation
ü Steel floor joists
ü Composite of styrofoam and steel studs
ü R-19 fiberglass batts installed between the floor joists

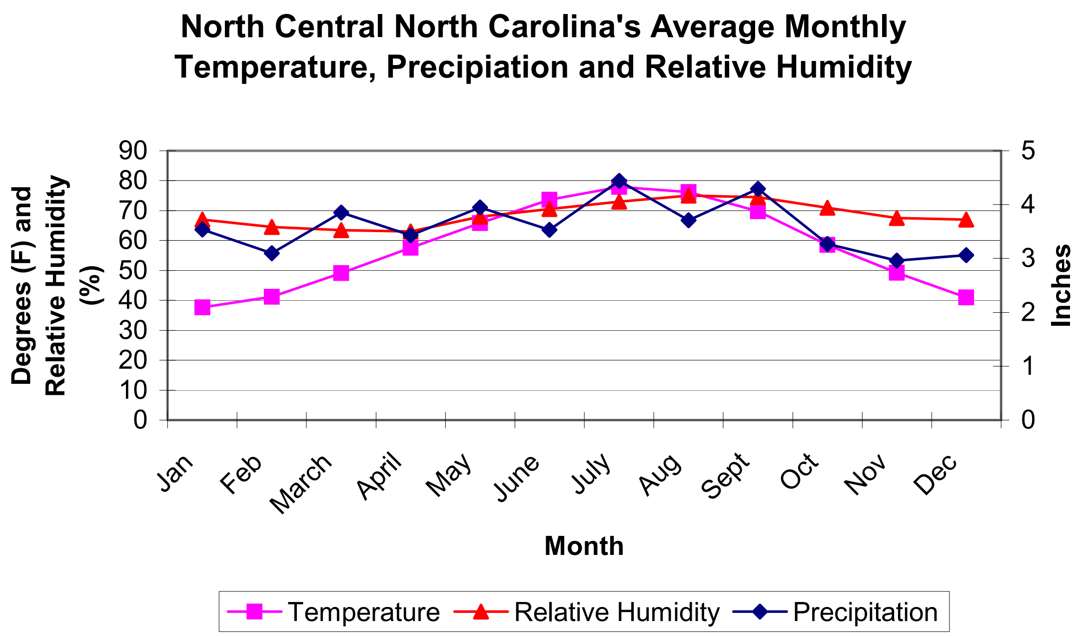
A duplex unit with identical crawlspaces was used to determine the effects of venting or not venting crawlspaces in mixed climates.

Vented crawlspace with ground vapor retarder and fiberglass batt insulation between joists

Site Conditions:

The site is a duplex housing unit on a masonry unit crawlspace foundation. The crawlspace under each unit is separated from the adjacent crawlspace by a block wall. The floor joists in each unit are Dietrich Trade Ready steel floor joists. The house is framed with a system called ThermaSteel™, a composite of styrofoam and steel studs.

The following graph shows the average monthly temperature, precipitation, and relative humidity over a 30-year period. The graphs were created from National Oceanic and Atmospheric Administration data for the years 1972 through 2002.



Problem Description:

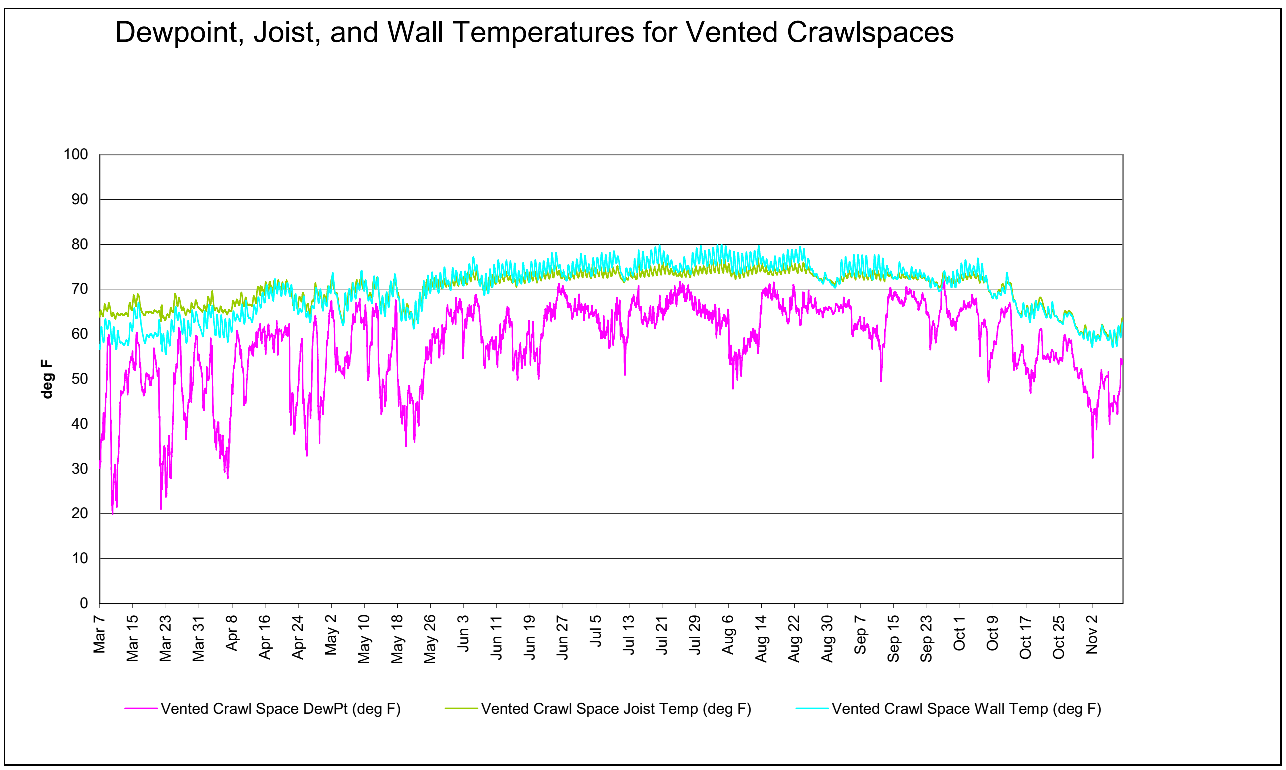
These residences have no current or previous mold problems. This case study examines the issue of venting or not venting crawlspaces in mixed climates.

The crawlspaces under each unit are identical in size and are separated by a block wall. One crawlspace is vented and the other is not. The vented crawlspace has temperature-activated, louvered vents, a 6-mil ground cover vapor retarder that overlaps the wall, and R-19 fiberglass batts installed between the floor joists. The non-vented crawlspace has a 6-mil ground cover vapor barrier that overlaps the wall and the perimeter wall is insulated with a fiberglass blanket held onto the wall with stickpins and clips (“button" system).

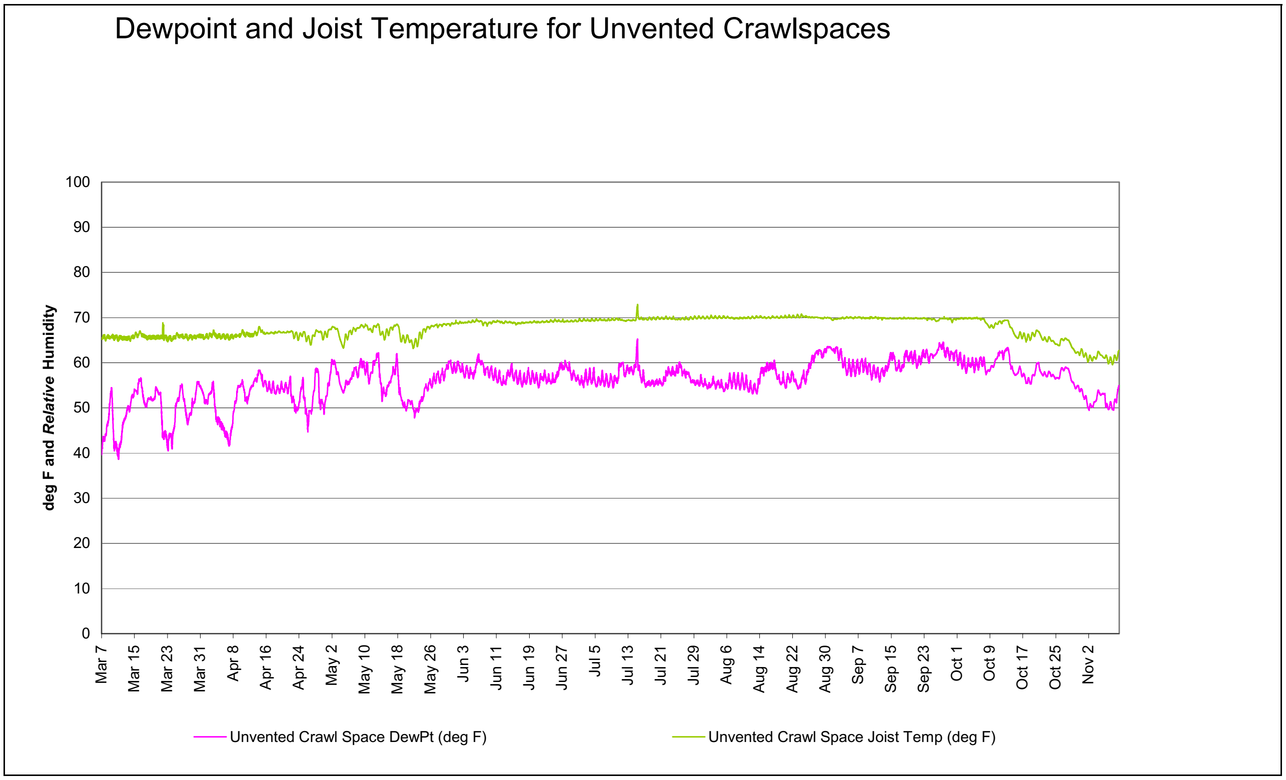
Diagnosis and Prescription:

A duplex with two equal-sized crawlspaces was selected for evaluation because it presented an opportunity for a side-by-side comparison using similar building materials and expertise, similar site characteristics, and similar building dimensions.

Each crawlspace was outfitted with sensors to record temperature and relative humidity of the air near wall surfaces, floor joists, and general ambient conditions of the space. The following graphs represent the conditions for vented and unvented crawlspaces respectively.



Readings for temperature and relative humidity were taken every fifteen minutes for about 8 months.



Dew point is the temperature where air can no longer hold water; water condenses on surfaces that are at or below the dew point. Therefore, surfaces that are near or below the dew point are suspect for condensation formation and subsequent mold problems.

The vented crawlspace has several areas where the joist or wall temperatures were near or at the dew point, a condition that promotes mold growth. The unvented crawlspace showed joist temperatures consistently above the dew point indicating a low probability for condensation and mold. Wall temperatures for the unvented crawlspace are not shown due to the inability of this experimental design to obtain dew point temperatures for air under the fiberglass insulation and near the masonry block wall. It is likely, however, that the condensation potential for the walls is also reduced.

The data were analyzed on a per reading basis and the number of occurrences where mold potential was high is recorded in the following table.

Sensor Location	Condensation Probable: Number of 15-minute events where surface temperature is less than dew point.	Condensation Possible: Number of 15-minute events where surface temperature is within 2ºF of dew point.
Vented Joist	1	12
Vented Exterior Wall	32	749
Unvented Joist	0	0
Unvented Exterior Wall	N/A	N/A

Condensation Risk Based on Dew Point and Surface Temperature

Based on the results of this study, the use of unvented crawlspaces for mixed climates appears to be a good practice in the reduction of mold potential. The dew point temperatures for the unvented crawlspaces show reduced variation and are consistently below joist temperatures. No readings indicated potential for condensation for the unvented crawlspace.

Code Issues:

Many jurisdictions within the mixed climate zone require crawlspace ventilation. For the prevention of mold, crawlspace ventilation may not work as intended for this climate zone.