

TechNote

Floors above Crawl Spaces: Reducing the Risk of Moisture Accumulation within Wood Floor Assemblies For Residential Buildings in Hot-Humid Climates

Floors above vented and open crawl spaces in hot-humid climates are susceptible to moisture accumulation that could lead to mold, mildew, and decay within the floor assembly, even where crawl spaces are constructed in accordance with building codes.

Water vapor generally migrates from areas of higher temperature and relative humidity to areas of lower temperature and relative humidity (vapor drive). In a humid climate, during the cooling season, the vapor drive is from the crawl space to the relatively cool and dry indoors through the floor assembly. A vapor impermeable floor covering can trap moisture in the wood subfloor. Conditions within the crawl space can lead to condensation and high wood moisture content (see **Figure 1** and **Figure 2**).

This TechNote provides design recommendations to reduce the risk of moisture accumulation within wood floors above crawlspaces in hot-humid climates – IECC climate zones 1A, 2A, and lower portions of 3A below the warm-humid line [1]. The factors that affect moisture accumulation include season, indoor temperature, types of floor insulation and floor covering, and type of crawl space (see sidebar). The focus of this TechNote is selecting floor insulation and coverings to control moisture migration and allow drying, should the floor get wet, for vented and open crawl spaces.

CRAWL SPACE FOUNDATION TYPES

Vented (traditional) crawl space: a crawl space with a continuous perimeter foundation wall (typically masonry) with ventilation openings to the outdoors intended to control crawl space humidity.

Open crawl space: a crawl space where individual piers (typically wood, masonry, or concrete) at the building perimeter support beams and floor joists.

Unvented (sealed, closed, or conditioned) crawl space: a crawl space with a continuous perimeter foundation wall that is sealed (no wall vents) to improve energy and moisture performance. Insulation is installed on foundation walls or in floors above. Humidity is controlled by a dehumidifier, exhaust venting, or HVAC system [2].

Figure 1. Vapor drive is from the crawl space to the indoors during the cooling season

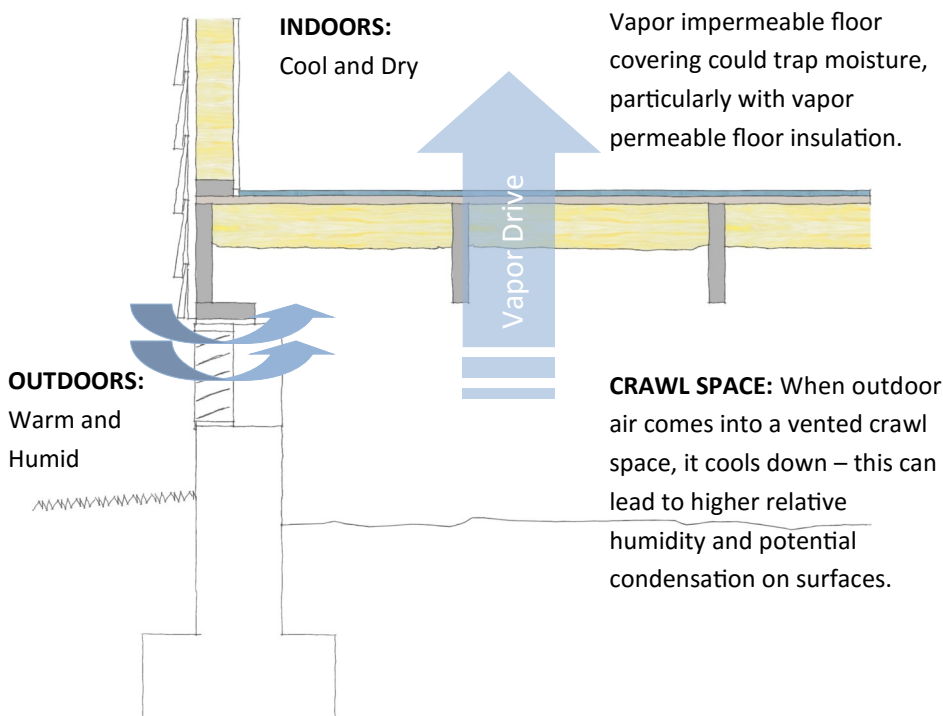


Figure 2. Subfloor with moisture damage in a house with impermeable vinyl flooring (removed) above a vented crawl space



Building Science - Moisture Dynamics

Moisture migration: water can enter the crawl space as liquid (rain or groundwater) or water vapor. Water vapor can migrate from the crawl space into the house due to air leakage and diffusion.

Water vapor migration due to air leakage: the transport of water vapor carried within moving air through air leaks in the floor assembly. Can be controlled with effective air barriers and air sealing.

Water vapor migration due to vapor diffusion: the migration of water vapor through permeable building materials. Can be managed using vapor retarders.

Vapor permeance: a measure of the rate of water vapor diffusion through materials. A lower “perm” rating indicates the material is less vapor permeable (see **Table 1**).

Relative humidity (RH): the amount of water vapor in air relative to the maximum amount air can hold at the same temperature. RH increases if air gets colder without losing moisture because warm air can hold more moisture than cold air.

Dew Point (DP): the temperature at which water vapor condenses into a liquid on surfaces (100% RH).

Moisture content (MC): the weight of moisture contained in wood expressed as a percentage of the wood’s dry weight.

The upper limit for **wood moisture content (MC)** is about 20% to protect against decay. Wood MC increases and decreases with RH: approximately 10% MC at 50% RH, and 13% MC at 70% RH. Wood MC also varies somewhat with temperature. Additionally, wood expands and contracts with MC. Wood (and some other building products such as Kraft paper) becomes more vapor permeable as RH increases.

Table 1. Water Vapor Retarder Classifications

Vapor Retarder Classification	Vapor Permeance (grains/hour/sq.ft./in.Hg)	Common Description	Examples (typical perm ratings)
Class I	0.1 perm or less	Vapor impermeable	Sheet polyethylene, 6 mil (0.06 perms)
Class II	0.1 < perm ≤ 1.0 perm	Vapor semi-impermeable	Kraft-faced fiberglass insulation (0.3 perms)
Class III	1.0 < perm ≤ 10 perm	Vapor semi-permeable	OSB (1-2 perms); Grade D building paper (5 perms)
	Greater than 10 perms	Vapor permeable	Fiberglass insulation (unfaced)

Research shows that in hot-humid climates during the cooling season [3]:

- The MC of a subfloor above a crawl space generally decreases with: higher indoor air conditioning set points; more vapor permeable floor covering; and less vapor permeable under-floor insulation.

- Within an **open crawl space**, air temperature and DP differ only slightly from outdoors, so the RH in the crawl space is about the same as outdoors. A ground vapor retarder has no measurable effect on the wood subfloor MC above an open crawl space.
- Within a **vented crawl space**, the DP is about the same as outdoors, but the air and surface

temperatures can be considerably cooler than outdoors and indoors – potentially leading to higher RH, condensation, and increased wood MC compared to an open crawl space [4].

- Building an unvented crawl space effectively controls RH and prevents moisture accumulation within the floor [2].

Design Considerations for Hot-Humid Climates

Vapor retarders are intended to prevent assemblies from getting wet due to water vapor diffusion, but these can also trap moisture and prevent drying:

- Vapor retarders, if installed, should be located toward the exterior of the floor insulation (facing the crawl space)
- Interior vapor retarders are generally unnecessary (similar to walls). Floor coverings should ideally allow for upward drying.

Table 2 shows common floor coverings and underlayments. Flooring underlayment products (installed between the subfloor and floor covering) can be selected to provide a smooth, comfortable, and durable surface and to help control moisture.

- The least vapor permeable component may determine the upward drying potential of the floor covering assembly.
- Perm ratings for many flooring products are not readily available from manufacturers.

Table 3 provides three types of recommendations for example insulation and flooring combinations to help reduce the risk of moisture accumulation within floors in hot-humid climates.

Generally:

- Vapor impermeable flooring is not recommended over vapor permeable insulation.
- Vapor impermeable insulation allows a greater selection of flooring (but combined

with vapor impermeable flooring poses the risk of a double vapor barrier that could trap moisture from a plumbing leak or overflow).

The effect of the limited use of vapor impermeable flooring in wet areas (e.g., bath rooms) above vapor permeable floor insulation, where the rest of the flooring is permeable, is not well understood – trapped moisture may be re-distributed, or if there is moisture at the sub-floor, it can be difficult to determine if that is due to interior spills, initially wet subfloors, or seasonal accumulation.

Table 2. Common Interior Floor Coverings and Typical Range of Vapor Permeance

Interior Floor Covering	Floor Covering Vapor Permeance	Underlayment Type and Vapor Permeance
Carpet	Commonly permeable (backing may not be)	Pads range from impermeable to permeable
Wood (hardwood, softwood, engineered wood)	Generally semi-permeable	Common Grade D asphalt-saturated Kraft paper underlayment is semi-permeable
Tile (ceramic)	Ranges from impermeable to semi-permeable	Cement board, mortar, and grout are commonly semi-permeable. Grade B asphalt-laminated Kraft paper is semi-impermeable. A polyethylene membrane is impermeable.
Resilient (vinyl, linoleum, cork, rubber)	Vinyl ranges from impermeable to semi-impermeable. Cork and linoleum are typically semi-permeable. Rubber is generally impermeable.	A wood panel substrate (e.g., 1/4" plywood) is semi-permeable.
Laminate (multi-layer synthetic)	Ranges from impermeable to semi-permeable	Underlayment is commonly an impermeable foam.

Table 3. Recommendations for Example Combinations of Insulation and Flooring^A

Common Insulation Options ^{B,C}	Typical Water Vapor Permeance (Perms)	Floor Covering & Underlayment			
		Permeable	Semi-permeable	Semi-impermeable	Impermeable
Un-faced fiberglass batt, 3.5" (R-13)	Permeable (34 perms)	OK	D	NR	NR
Open cell (polyurethane) spray foam, 3.5" (R-13)	Permeable (25 perms)	OK	D	NR	NR
Expanded polystyrene (EPS) rigid foam, 1" (R-4)	Semi-permeable (2.0-3.8 perms)	OK	OK	D	NR
Closed cell (polyurethane) spray foam, 1" (R-6) + fg batt	Semi-permeable at (1.6-2.0 perms)	OK	OK	D	NR
Kraft-faced fiberglass batt (sealed seams)	Semi-impermeable (0.3 perms ^D)	OK	OK	D	NR
Extruded polystyrene (XPS) rigid foam, 1" (R-5) + fg batt	Semi-impermeable (0.8 perms)	OK	OK	OK	D
Closed cell (polyurethane) spray foam, 2.5" (R-15)	Semi-impermeable (0.8-1.0 perms)	OK	OK	OK	D
Foil-faced (non-perforated) fiberglass batt (sealed seams)	Impermeable (0.05 perms)	OK	OK	OK	D
Polypropylene-faced (non-perforated) XPS, any thickness	Impermeable (<0.1 perms)	OK	OK	OK	D
Foil-faced polyisocyanurate rigid foam (R-5.7/in), any thickness	Impermeable (0.06 perms)	OK	OK	OK	D

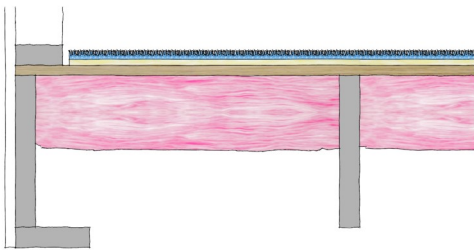
^A General recommendations: **OK** indicates recommended; **NR** indicates not recommended; **D** indicates discretionary – consider all design variables

^B Minimum floor insulation (energy code prescribed) R-value: R-13 in climate zone 1-2 and R-19 in climate zone 3

^C For fire safety, spray foam and rigid foam in crawl spaces must generally be fire retardant or covered with a thermal barrier (e.g., 3/8" gypsum, 1/4" plywood) or ignition barrier (e.g., a foil-faced product or approved spray applied coating). Kraft-faced products may also require a thermal or ignition barrier.

^D The permeance of Kraft paper can increase to 1.8 perms at higher RH levels.

Example Floor Assemblies in Hot-Humid Climates



Example Assembly 1:
Vapor Permeable Insulation and Flooring

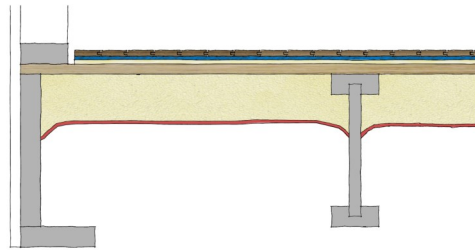
Insulation: un-faced fiberglass batts (vapor permeable)

- Kraft-faced or foil-faced would improve moisture control and can be secured with staples
- Open crawl spaces may require rigid sheathing below the joists to protect the insulation
- Open-cell spray foam (also vapor permeable) could be substituted and provides air sealing

Flooring: carpet and carpet pad (above subfloor)

- Select vapor permeable products to allow upward drying

Floor joists and subfloor: treated wood may be recommended



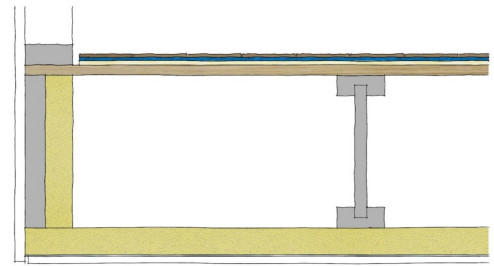
Example Assembly 2:
Vapor Semi-impermeable Insulation

Insulation: closed-cell spray foam (semi-impermeable)

- Closed-cell spray foam also provides air sealing
- The bottom of floor joists could be encapsulated to protect those from moisture
- Install thermal barrier or ignition barrier as required

Flooring: Hardwood, Grade D asphalt-saturated Kraft paper, 1/4" plywood substrate

- Vapor semi-permeable flooring will allow upward drying



Example Assembly 3:
Vapor Impermeable Insulation

Insulation: foil-faced polyisocyanurate rigid foam (vapor impermeable)

- Insulated and air sealed perimeter rim area
- Foil facing must be sealed at all exposed edges, seams, and penetrations (e.g., using foil tape)
- The bottom of floor joists are protected from moisture in this configuration
- Thermal barrier or protective board sheathing over rigid foam, as required

Flooring: laminate, foam underlayment, 1/4" plywood substrate (alternative: ceramic tile, mortar, cement board, Grade B asphalt-laminated Kraft paper)

- Ideally, select flooring that is vapor semi-impermeable or more permeable to allow upward drying

Note: The air gap between the insulation and subfloor in this configuration is not allowed by the 2012 IRC and earlier versions, but will be permissible for 2015. Substituting foil-faced (non-perforated) fiberglass batts, stapled to the bottom of the floor joists, and protected with sheathing, may be permissible as well. See sidebar in Building Code section.

Building Code

The International Residential Code (IRC) does not require or prohibit the use of vapor retarders in floor assemblies in climate zones 1, 2, or 3. The 2012 IRC does address crawl space construction requirements regarding insulation and moisture control:

- DEFINITIONS – VAPOR RETARDER CLASS and corresponding permeance (outlined in Table 1 of this TechNote; example vapor retarder materials in R702.7.2)
- DEFINITIONS – VAPOR PERMEABLE: a vapor permeance of 5 perms or greater
- R316.5.4 – Thermal/ignition barrier requirements for foam plastic insulation in crawl spaces

- R408.1 – Foundation vents and ground vapor retarder for vented crawl spaces
- R408.3 – Unvented crawl space requirements
- R408.7 – Crawl spaces are permitted in flood hazard areas if the finished grade of the crawl space is equal to or higher than the outside finished grade on at least one side, or for crawl space construction that meets FEMA Technical Bulletin TB-11 requirements [5]
- Table N1102.1.1 – Prescriptive floor insulation: R-13 in Climate Zone (CZ) 1-2, R-19 in CZ 3
- Table N1102.4.1.1 – Floor insulation, air barrier, and air sealing requirements

- N1102.2.7 – “Floor insulation shall be installed to maintain permanent contact with the underside of the subfloor decking.” (See sidebar.)

Regarding section N1102.2.7, for 2015 (N1102.2.8) a new exception will permit an air space above the cavity insulation where the insulation is in contact with the topside of sheathing or continuous insulation installed on the bottom side of floor framing, and where insulation at the perimeter floor framing (rim joist area) meets the wood frame wall R-value requirements.

Recommendations for Assuring Consistent Quality of Moisture Control Measures

Crawl Space Construction

- Control bulk moisture, with proper grading, drainage, foundation dampproofing, capillary breaks, and flashing, to keep rain and groundwater out of the crawl space, including during construction.
- Control vapor migration due to air leakage, from the crawl space to the house through the floor, with effective air sealing – seal all floor penetrations, rim areas, and insulation seams, as required.
- Consider treated wood for floor framing and subfloors to improve moisture resistance – particularly in a vented crawl space with permeable insulation and where floor joists are exposed below the insulation.
- Consider building an unvented crawl space – floor covering permeability does not matter because the space is conditioned.

Floor Component Selection for Vented and Open Crawl Spaces in Hot-Humid Climates

- Select the R-value of floor insulation to meet building code or above-code energy program requirements.
- Select vapor impermeable or semi-impermeable insulation to minimize vapor diffusion into the floor assembly.
- Ensure that under-floor insulation does not impede pest inspection, where applicable.
- Avoid installing vapor impermeable flooring and underlayment products where the insulation is vapor permeable.

- Generally, select more vapor permeable interior flooring and underlayment to allow upward drying to the interior.

Design HVAC Systems to Control Indoor Humidity to Allow for Occupant Comfort at Higher Air Conditioning Set Points (e.g., 78F)

- Ensure the HVAC trade partner does not over-size air conditioning systems.
- Install a dehumidifier in the house – central or stand-alone – for supplemental RH control during milder swing-seasons.
- Install heating and cooling ducts within conditioned space – leaky return ducts could draw humid air indoors, and leaky supply ducts could depressurize the house and increase infiltration.

General

- Install all products in accordance with manufacturer’s specifications (e.g., underlayment requirements; do not enclose products with high MC), local building codes, or specifications established by the licensed design professional.

Occupants

- Raise indoor air conditioning set points to decrease the risk of condensation within floors
- Use bath and kitchen exhaust fans to control humidity at the source
- Don’t rely on “super-cooling” the house to dehumidify.

Notes and Resources

- [1] See climate zone map (right): Figure C301.1 Climate Zones. Excerpted from 2012 International Energy Conservation Code. Copyright 2011. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved. www.ICCSAFE.org
- [2] NAHB Research Center TechSpec. The Closed Crawl Space: Making the Transition. Upper Marlboro, MD: Home Innovation Research Labs. (January 2013), and companion videos: www.homeinnovation.com/trends_and_reports/featured_reports/techspec_-_the_closed_crawlspace_making_the_transition
- [3] Glass, S., Carll, C., Curole, J., Voitier, M. (2010). Moisture Performance of Insulated, Raised, Wood-Frame Floors: A Study of Twelve Houses in Southern Louisiana. Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference: ASHRAE.
- [4] See also: Lstiburek, J. (2008). BSI-009: New Light in Crawlspaces. Westford, MA: Building Science Corporation.
- [5] FEMA Technical Bulletin TB-11: Crawlspace Construction for Buildings Located in Special Flood Hazard Areas (2001; updated 02/28/2014).

