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

**INDOORS:** Cool and Dry

**OUTDOORS:** Warm and Humid

**Vapor Drive**

**Vapor impermeable floor covering could trap moisture, particularly with vapor permeable floor insulation.**

**CRAWL SPACE:** When outdoor air comes into a vented crawl space, it cools down – this can lead to higher relative humidity and potential condensation on surfaces.

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

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 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].

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.

Design Considerations for Hot-Humid Climates

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., bathroom areas) 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 1. Water Vapor Retarder Classifications

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

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

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

**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

**Typical Water Vapor Permeance (Perms)**

<table>
<thead>
<tr>
<th>Common Insulation Options</th>
<th>Permeable (34 perms)</th>
<th>Permeable (25 perms)</th>
<th>Semi-permeable (2.0-3.8 perms)</th>
<th>Semi-permeable at (1.6-2.0 perms)</th>
<th>Semi-impermeable (0.3 perms)</th>
<th>Impermeable (&lt;0.1 perms)</th>
<th>Impermeable (0.06 perms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-faced fiberglass batt, 3.5” (R-13)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Open cell (polyurethane) spray foam, 3.5” (R-13)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Expanded polystyrene (EPS) rigid foam, 1” (R-4)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Closed cell (polyurethane) spray foam, 1” (R-6) + fg batt</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Kraft-faced fiberglass batt (sealed seams)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Extruded polystyrene (XPS) rigid foam, 1” (R-5) + fg batt</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Closed cell (polyurethane) spray foam, 2.5” (R-15)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Foil-faced (non-perforated) fiberglass batt (sealed seams)</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Polypropylene-faced (non-perforated) XPS, any thickness</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Foil-faced polysisocyanurate rigid foam (R-5.7/in), any thickness</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

* General recommendations: OK indicates recommended; NR indicates not recommended; D indicates discretionary – consider all design variables
* Minimum floor insulation (energy code prescribed) R-value: R-13 in climate zone 1-2 and R-19 in climate zone 3
* 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.
* The permeance of Kraft paper can increase to 1.8 perms at higher RH levels.

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Example Assembly 1: Vapor Permeable Insulation and Flooring

**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

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Example Assembly 2: Vapor Semi-impermeable Insulation

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Example Assembly 3: Vapor Impermeable Insulation

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**Insulation:** foil-faced polysisocyanurate 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.
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., 78°F)
- Ensure the HVAC trade partner does not oversize 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