# Moisture in Crawl Spaces

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**Abstract**

Crawl space foundations can be designed and built to avoid moisture problems. In this article we provide a brief overview of crawl spaces with emphasis on the physics of moisture. We review trends that have been observed in the research literature and summarize current recommendations for moisture control in crawl spaces.

**Introduction**

What does it take to design and construct a crawl space that is free of moisture problems? Crawl spaces are often historically and anecdotally associated with dampness more so than other foundation types. This article provides an overview of design factors that are critical for avoiding moisture problems in crawl spaces.

A crawl space is defined by the Merriam-Webster dictionary as "a shallow unfinished space beneath the first floor or under the roof of a building especially for access to plumbing or wiring." For the purposes of this article, we focus on foundations and exclude under-roof spaces. Britton (1948) defined a crawl space as "that enclosed space (or spaces) under the first floor of a building where there is no basement or occupancy and the first floor is some distance above the surface of the ground."

For the purposes of this article, we find it useful to distinguish three different ways of building a crawl space.

1. Open crawl space: pier-and-beam construction where the perimeter is substantially open to airflow (Figure 1)
2. Wall-vented crawl space: continuous perimeter wall that includes vents to the outside (Figure 2)
3. Closed crawl space: continuous perimeter wall with no vents to the outside (Figure 3)

Crawl space foundations primarily originated in the southern United States, where homes were commonly built on pier foundations (Rose 1994). These pier foundations were typically fully open to the outside, or had minimal skirting that allowed virtually unrestricted air movement. During World War II "basementless" houses

**Figure 1. Example of an Open Crawl Space with a Pier Foundation.**

**[USDA Forest Service Forest Products Laboratory]**

began to be constructed in the northern United States, and this was accompanied by the first requirements for minimum vent openings in crawl spaces, promulgated by the Federal Housing Administration (FHA 1942, Rose 1994). The requirements were intended to prevent moisture problems in crawl spaces, but there appears to be no technical basis for these requirements in the literature (Rose 1994).

Figure 2. Example of a Wall-Vented Crawl Space with Ground Cover.

[USDA Forest Service Forest Products Laboratory]

Recommendations to limit water evaporation from the ground by employing a vapor-resistant ground cover first begin to appear in 1949 (Britton 1949). But as early as 1946, Diller (1946) reported that ground covers significantly lowered measured moisture content in the wood floor members in the crawl space, whether the vents were open or closed. Later research affirmed the effectiveness of ground covers (Diller 1953, Moses 1954, Amburgey and French 1971, Dutt et al. 1988, Quarles 1989, Flynn et al. 1994, Stiles and Custer 1994). However, findings were sometimes confounded by opening or closing of crawl space vents at the same time that ground covers were installed or removed (e.g. Moses and Scheffer 1962, Duff 1978). Curiously, vents were adopted as a requirement in the building codes, while ground covers were not, even though the technical evidence for the benefits from the latter is much stronger.

A number of studies in various climates have shown that closed crawl spaces (without vents to the outside) can remain relatively dry with a ground cover (Duff 1978, 1980; Moody et al. 1985; Dutt et al. 1988; Quarles 1989; Samuelson 1994; Stiles and Custer 1994; Davis and Dastur 2004). These studies generally observed more stable humidity and moisture conditions in the closed crawl spaces compared with wall-vented crawl spaces. The reasons for this are discussed below.

Figure 3. Example of a Closed Crawl Space with Ground Cover.

[Advanced Energy, Raleigh, NC]

### The Physics of Moisture in Crawl Spaces

Moisture conditions in crawl spaces are determined by the balance between moisture entering the crawlspace, moisture removed, and moisture stored in various hygroscopic materials in the crawlspace, such as wood and concrete. Although moisture storage in materials in the crawlspace can provide some moderation of wide swings in moisture conditions, moisture storage is generally not sufficient to affect long term conditions. Because our concern is avoiding excessive moisture accumulation over the long-term, we therefore focus on the remaining factors in this equation: moisture entering and leaving the crawl space.

### *Moisture Sources*

The main sources of water in the liquid or vapor phase are ground water or rain water intrusion, evaporation from the soil, and water vapor carried in with ventilation air. In some cases, water leaks from broken water pipes have been found as major contributors. The amount of water entering the crawl space can be very large, dominating the equation, and therefore limiting water entry should be the first priority. This can be accomplished with site grading, appropriate location and drainage of downspouts, and foundation drainage.

Evaporation from wet soil can be a significant contributor of water vapor. TenWolde and Pilon (2007) estimate that evaporation rates from wet soil can be as high as 0.2 kg/($m^2$·h) (0.05 lb/($ft^2$·h)), but greatly depend on the temperature of the soil, the humidity of the air in the crawlspace, and the amount of heat available to evaporate the water. Trethowen (1988, 1994) measured vapor release rates from soil in crawlspaces and reported an average release rate of 0.4 kg/($m^2$·da) (0.08 lb/($ft^2$·da)) from bare soil. This translates into around 0.017 kg/($m^2$·h) (0.0034 lb/($ft^2$·h)), which is less than 10% of the maximum theoretical rate cited by TenWolde and Pilon. Trethowen found that the evaporation rate varied greatly with soil temperature; the rate decreased substantially as soil temperature decreased. He also found that sources of heat in the crawl space, such as heating ducts or a furnace, can greatly increase the rate of evaporation. Of course, this rate can be drastically lowered by installing a vapor barrier (ground cover) over the soil.

### *Moisture Removal*

Moisture removal can occur by ventilation if outdoor air contains less moisture than the air in the crawl space. A simple calculation is given here for the sake of illustration. Assuming a wall-vented crawl space with no ground cover and an evaporation rate from the soil of 0.4 kg/($m^2$·da) (0.08 lb/($ft^2$·da)), a fair amount of ventilation is needed. If the incoming ventilation air is at 21°C (70°F) and 50% relative humidity (RH), and the crawl space is at the same temperature, the minimum amount of air needed to maintain the crawl space air below 80% RH is on the order of 100 L/s (about 200 $ft^3$/min) for every 100 $m^2$ (about 1100 $ft^2$) of crawlspace floor area. Providing vents in the perimeter wall does not guarantee significant, reliable ventilation. The actual amount of ventilation with outdoor air depends on wind conditions, location of the vents, location and surroundings of the building, obstructions in front of the vents, and other factors.

### *Temperature Effects*

If the dew point of the ventilation air is above the temperature of the soil in the crawl space, the air is incapable of removing moisture, and instead is a source of moisture to the crawl space. This can become an issue during humid weather in spring when soil temperatures remain cool. During summer the outdoor dew point can also exceed soil temperatures. This situation is not limited to hot-humid climates; it also commonly occurs in northern climates during summer. Table 1 lists mean dew point temperatures for the month of July in 30 U.S. locations.

An abundance of ventilation with outdoor air raises the crawl space temperature closer to that of the outdoors. Air exchange is typically much higher in open crawl spaces than in wall-vented crawl spaces. This is one reason why the old-fashioned open pier foundation with ample ventilation worked well in the past, and returning to that design is another option (see Figure 1). Temperature and absolute humidity levels in open crawl spaces generally track outdoor levels fairly closely (Glass et al. 2010). In contrast, temperature levels in wall-vented crawl spaces tend to be cooler than outdoors during warm weather. This means that during summer, relative humidity levels in open crawl spaces are typically lower than in wall-vented crawl spaces.

The majority of contemporary buildings are air-conditioned. Indoor cooling set points are frequently close to (sometimes below) outdoor dew point temperatures. In air-conditioned buildings, outdoor air can thus pose a condensation risk to subfloor sheathing or decking. In open crawl spaces and wall-vented crawl spaces, this risk may be mitigated by insulating the floor with foam insulation of low vapor permeance (Glass et al. 2010, Lstiburek 2008), or by installing a vapor retarder at the underside of vapor-permeable floor insulation (Verrall 1962). Air tightness is key in such cases so that water vapor is not carried by air leakage into the floor assembly.

Closed crawl spaces (see Figure 3) are designed with the intent of separating the crawl space from the outdoors. This type of construction requires a ground cover to minimize entry of soil moisture, air sealing at the perimeter, and either introduction of conditioned air into the crawl space or direct dehumidification to control humidity levels in the crawl space (ground covers and air sealing minimize moisture entry but may not be 100% effective).

**Table 1. July Mean Dew Point Temperatures for 30 U.S. Locations From 1984 to 2012 (NCDC 2012)**

| Location | °F | °C |
|---|---|---|
| Salt Lake City, UT | 49.8 | 9.9 |
| Denver, CO | 52.4 | 11.3 |
| Seattle, WA | 53.8 | 12.1 |
| San Francisco, CA | 54.0 | 12.2 |
| Portland, OR | 55.6 | 13.1 |
| Phoenix, AZ | 58.7 | 14.8 |
| Los Angeles, CA | 61.4 | 16.3 |
| Minneapolis, MN | 62.3 | 16.8 |
| Boston, MA | 62.7 | 17.1 |
| Chicago, IL | 63.4 | 17.4 |
| New York, NY | 65.6 | 18.7 |
| Philadelphia, PA | 66.4 | 19.1 |
| Washington, DC | 66.7 | 19.3 |
| Baltimore, MD | 66.8 | 19.3 |
| Louisville, KY | 67.9 | 19.9 |
| St. Louis, MO | 68.1 | 20.1 |
| Kansas City, MO | 68.2 | 20.1 |
| Atlanta, GA | 69.3 | 20.7 |
| Dallas, TX | 69.8 | 21.0 |
| Norfolk, VA | 70.4 | 21.3 |
| Memphis, TN | 71.4 | 21.9 |
| Wilmington, NC | 72.8 | 22.7 |
| Savannah, GA | 72.9 | 22.7 |
| Tallahassee, FL | 73.0 | 22.8 |
| Orlando, FL | 73.5 | 23.1 |
| Charleston, SC | 73.6 | 23.1 |
| Houston, TX | 73.7 | 23.2 |
| Miami, FL | 74.3 | 23.5 |
| New Orleans, LA | 74.4 | 23.6 |
| Corpus Christi, TX | 74.9 | 23.8 |

### Measured Moisture Conditions

In a review of measured data on in-service moisture and temperature conditions in wood-frame buildings, Glass and TenWolde (2007) observed that high moisture content (MC) values in wood floor structural members (joists, beams, sill plates, subfloor sheathing) have been measured at various times of the year, in all climate zones in the United States. Some of these readings were well over 20% MC, which is generally recognized as the moisture content at which we become concerned about mold and decay. On the basis of these historical data Glass and TenWolde (2007) make the following specific observations:

- The most extreme measured moisture contents in wood structural members above crawlspace foundations occur when the ground is not covered with a vapor-resistant ground cover. This effect is magnified for sites with poor drainage.
- Two different seasonal trends have been observed for crawlspaces:

1. Wood moisture content reached a maximum in winter and minimum in summer. This trend was observed in studies prior to ca. 1955 in crawlspaces without a ground cover in both mixed-humid and cold climates. The most likely explanation is that when the crawlspace vents either were lacking or were closed during winter, the uncovered soil supplied moisture that condensed on the coldest wood members in the crawlspace. During winter months, the coldest members are the sill plates, rim joists, and floor joists near the exterior. It should be noted that the buildings were not air-conditioned during the summer, and the floor framing therefore was probably warmer than the crawlspace soil (or below-grade portions of the crawlspace walls), for most of the time during summer months.
2. Wood moisture content peaked in summer, with a minimum in winter. This trend has been reported in hot-humid and mixed-humid climates in all studies conducted since ca. 1955 in which seasonal trends were investigated. These studies included various types of crawlspaces (both covered/uncovered and vented/closed). In many of these studies, the living space above the crawlspace was either known to be, or was probably air-conditioned during the summer. The major source of crawlspace moisture in these studies was either warm, humid outdoor air or moisture evaporating from the soil. In summer, the floor members can be cooler than the outdoor air (sometimes cooler than the outdoor dew point temperature), especially when the building is air-conditioned. Drying would have occurred during fall and winter because outdoor air would contain less water vapor and cooler soil would have a slower rate of evaporation.

### Recommendations

The following recommendations for moisture control in crawl spaces are mostly based on the 2005 ASHRAE Handbook, Chapter 24, Thermal and Moisture Control in Insulated Assemblies—Applications (ASHRAE 2005).

#### *Accessibility*

One of the principle reasons that problems occur in crawl spaces is that owners or occupants do not regularly inspect the crawl space. By inspecting regularly, problems with standing water or plumbing leaks are discovered and corrected sooner, hopefully before major damage occurs. Inspection can also uncover problems with water entry from outside, allowing timely corrective action. The crawlspace therefore needs to be easily accessible, well illuminated, and clean. Although a minimum clearance of 18 inches (0.46 m) between the soil and the bottom of the floor joists is often recommended, it is advisable to increase this to 40 inches (1 m) for easier access.

### *Water Entry*

The soil in the crawl space should be kept as dry as possible, and therefore water entry into the crawl space should be prevented. It is recommended that the crawl space floor level not be below the exterior grade. Proper site drainage is also critical. Gutters and downspouts should carry rain water away from the foundation, and the site should be sloped away from the foundation to allow water to drain away. If this is not possible, berms, retaining walls, and other means may be used to guide the water around and away from the building. In case of high ground water levels, installing sump pumps may be useful.

If a building is to be constructed on a site with poor grading and drainage or where the water table is close to the surface, an open pier foundation with substantial grade clearance would be the most viable option. With wet soils, capillary rise through stem walls may be an issue. This issue is largely side-stepped with open-pier foundations.

### *Ground cover*

Measurements have consistently shown that ground covers can significantly lower moisture conditions in the crawl space. Recommendations usually call for ground cover material with a water vapor permeance of no more than 1 perm, and the material must be strong enough to withstand foot and knee traffic. Polyethylene with a minimum thickness of 6 mil (0.006 in, 0.15 mm) is commonly used. A concrete slab may be poured over the ground cover to keep out rodents. Debris must be removed and the soil leveled before installing the ground cover. The seams of the ground cover should be lapped 4 to 6 in (100 to 150 mm), and no sealing is required.

Open pier-and-beam construction generally does not require a ground cover because the amount of air flow under the floor is sufficient to carry away excess moisture (Glass et al. 2010).

### *Vents*

The 2006 International Residential Code (IRC) (ICC 2006) contains a standard requirement for minimum vent openings of 1 $ft^2$ per 150 $ft^2$ of crawlspace floor area (1 $m^2$/150 $m^2$). As noted earlier, there is no known technical basis for these requirements, and providing vents does not guarantee actual airflow. Research has also shown that with warm humid outdoor conditions, providing 1/150 vents can be counterproductive. However, the 2006 IRC does allow omitting the vents in a crawl space with perimeter insulation if a) a ground cover is installed (sealed and taped), with the cover extending 6 inches (150 mm) up the side walls; and b) the crawlspace has a continuously operated exhaust fan, or conditioned air is supplied to the crawl space, or the crawl space is used as a plenum.

If local codes require vents or vents are desired, one should consider going well beyond the minimum requirement of 1/150 to ensure that there is enough air movement to raise the crawl space temperature above the dew point of the outside air during summer.

### *Other Considerations*

From the perspective of energy use, it is best not to locate ducts for heating and cooling in unconditioned spaces. Locating ducts in a crawl space with vents in the perimeter walls will also complicate air sealing and insulating of the floor over the crawlspace. If it is necessary to locate ducts in a crawl space that is vented with outdoor air, air sealing and insulating those ducts is very important. Poorly sealed supply ducts often fail to deliver adequate conditioned air to locations where it is desired. Poorly sealed return ducts may introduce crawlspace air into the living space. If the crawlspace air is humid or contains contaminants (soil gases, mold spores, mold metabolites, or volatile chemicals), the humidity or the contaminants (or both) will be introduced into the living space. Properly insulating the ducts limits energy losses and reduces the chance of condensation on the ducts when the air-conditioning is running. If it is necessary to locate ducts in a crawl space, it may be viable to construct a closed crawlspace and to insulate the walls (Davis and Dastur 2004). This, of course, assumes that water entry into the crawlspace is controlled, that there is a functioning soil cover, and that volatile substances (e.g., gasoline or gasoline-powered tools) are not stored in the crawlspace.

It is of paramount importance to vent clothes dryers outdoors (not into the crawlspace), and to repair any leaking water pipes.

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