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Under-Slab Vapor Retarders

1.0 Terminology

The terms 'vapor retarder' and 'vapor barrier' are used relatively interchangeably. They refer to any material placed beneath a concrete slab-on-grade, typically an extruded plastic sheet, which is engineered to impede the transmission of water vapor and other soil gases (radon, methane, etc.) from infiltrating a building envelope. It should be noted, however, that materials that excel at slowing the migration of water vapor do not necessarily excel in retarding all soil gases (this is due in part to the polarity of the permeant compared to that of the film). Technically, no under-slab plastics completely stop the transmission of all gases; thus, most materials can accurately be called 'vapor retarders.' However, it is generally accepted that any material with a permeance of 0.01 perms or less is considered to be a 'vapor barrier.'[1] For consistency, this document will only use the term 'vapor retarder.'

2.0 Vapor Retarders in Dry Climates

It is commonly assumed that projects in desert regions—due to "low" water tables, relatively dry soil (i.e. low moisture content), etc.—do not require an under-slab vapor retarder. This is an unfortunate misconception that has caused many headaches over the past few decades, typically when firms have been taken to task after suffering costly flooring failures, mold issues, etc.[2] We, as an industry, now have a very good understanding of how water vapor moves; likewise, the problems associated with under-slab water vapor have been very well documented.

A water table is present in almost every region of the world. Regardless of how deep this source of underground moisture is, water vapor is constantly evaporating and diffusing up through the soil. Typically this moisture is simply a part of the natural water cycle (it rises into the atmosphere, comes down as rain, and seeps back down in the water table, starting the process anew). However, when a concrete slab is cast on-grade, this water vapor begins to accumulate beneath the slab. In fact, several investigations have shown that the relative humidity in the base and subgrade material beneath covered slabs will generally test close to 100%, even if the moisture levels of the base and subgrade materials are low.[3] This high relative humidity, coupled with a fairly constant under-slab temperature, creates a vapor pressure below the concrete slab that will tend to be approximately twice that of the vapor pressure generated in the average conditioned building space.[4] When higher under-slab soil temperatures exist, the pressure differential increases, thereby further spurring the infiltration of water vapor into and through the concrete slab where it can reach the building interior or accumulate beneath a floor covering (or any other relatively impermeable object such as certain types of furniture, mats, cargo, etc.). When this occurs, a host of moisture-related issues may ensue. These include, but are not limited to, flooring failures, mold/mildew, efflorescence, alkali-silica reaction (ASR), and issues with soil sulfates.

Liquid water and water vapor move in very different ways, and a design professional should recognize that waterproofing materials are not necessarily designed to impede water vapor. Likewise, a vapor retarder material alone may itself be waterproof but the system may not, as a whole, act as effective waterproofing. While liquid water may present less of a concern in drier regions of the world, the use of vapor retarders is not necessarily a function of geography or climate. Instead, the building application, the type of floor covering, and the negative effects moisture can have on the aesthetics and integrity of the slab itself have spurred many of the industry's experts to report that vapor retarders are a necessity under all slabs-on-grade regardless of the climate or the depth of water table.[5]

3.0 Basis of Design

There are several different standards that have been created by the American Society for Testing and Materials (ASTM) for polyethylene (plastic) sheeting. However, only a few of these standards are useful, applicable, or appropriate for an under-slab application. ASTM E 1643 – 09 *Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs*[6] provides a list of performance characteristics for a design professional to consider when specifically designing and/or selecting an under-slab vapor retarder for a given project. This standard also notes that compliance with local building codes and regulatory requirements, which generally reference the use of a 6-mil polyethylene film,[7] should be viewed as minimal levels of protection. Last, and perhaps most significantly, ASTM E 1643 acknowledges the importance of considering the recommendations of the American Concrete Institute Committee 302's (ACI 302.2R-06) *Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials*.[8]

4.0 Performance

Both ASTM E 1643 and ACI 302.2R-06 discuss which performance characteristics are desired in a vapor retarder material as well as where and how it fits into the rest of the foundation system. There are three basic categories to consider when evaluating the performance of under-slab vapor retarders. These are strength, permeance (as a function of longevity), and special conditions, and their associated test methods are outlined in ASTM E 1745 – *Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs.*[9]

4.1 Strength

All under-slab plastics are to be tested for puncture resistance and tensile strength according to ASTM E 1745. This standard classifies materials as Class A (which entails the strictest, and thus strongest, performance requirements), B, or C.[10] Materials that do not meet the minimum requirements of the Class C designation are not typically recommended under any slab due to their propensity to puncture and tear during normal installation conditions. In general, the design professional should select a material strong enough for the anticipated construction traffic. Class A materials are often recommended when construction loads exceed those of pedestrian traffic.

4.2 Permeance

In order to meet ASTM E 1745, the permeance of an under-slab plastic may not exceed 0.1 perms after undergoing several mandatory permeance tests, both for the new material (unconditioned) and the material after it has been subjected to simulated under-slab conditions (conditioned). This second set of 'conditioning tests' is outlined in Sections 7.1.2 through 7.1.5 and exposes the material to cycles of wetting and drying, elevated temperature, low-temperature and bending, and contact with soils organisms. Obtaining a material's permeance after it has been conditioned according to these mandatory tests helps a design professional understand what level of protection a vapor retarder will provide in its lifetime, not just for the new material. While these tests do not represent all of the conditions a vapor retarder may be expected to encounter (contact with alkaline salts, sulfates, chlorinated solvents, petroleum byproducts, other chemicals common in brownfield sites, etc. are possible), they currently represent the best methods with which to gain an understanding of a material's permeance during the time period after it has been installed.

Typically, the permeance rating of 0.1 perms, as defined in ASTM E 1745, is treated as a minimum level of protection (i.e. materials whose after-conditioning permeance rating is above 0.1 perms, for any of the conditioning tests, do not meet any Class defined by ASTM E 1745). However, ASTM E 1643 notes that a design professional should select a permeance level for their vapor retarder based on the conditions of the slab, the building application, and the demands of the vaporproofing system in which the vapor retarder will be an integral part. Relevant considerations include the environmental variables (ambient temperature, relative humidity, etc.) that will be maintained within the building envelope, the type of flooring and how it is applied, the susceptibility of these applications/adhesives to moisture-related issues, the heat flux between the soil and the concrete slab, etc. ASTM E 1643 states that the permeance rating determined under these criteria should supersede the minimum requirements of ASTM E 1745 should that permeance rating be less than 0.1 perms.[11]

ACI 302.2R-06 recommends that the permeance value be well below the minimum requirements of ASTM E 1745 whenever low-permeance flooring or flooring with low-moisture requirements (3 lb/1000 ft2/24 hour [1.5 kg/100 m2/24 hour], 75% internal relative humidity [RH]) will be used.[12] They define moisture-sensitive floorings as: *sheet rubber, epoxy coatings, vinyl composition tile, sheet vinyl, carpet, athletic flooring, laminates, and hardwood*.[13] Due to the use of low-VOC (typically water-based) adhesives, as well as the frequency with which moisture-related problems have occurred and the costs associated with remediating such problems, specifying vapor retarders that maintain a permeance of 0.01 perms after undergoing conditioning is often recommended for all interior slabs-on-grade.

Design professionals not wishing to perform the analysis outlined in ASTM E 1643 often choose to specify 0.01 perms for all vapor retarders as this upgraded level of protection will provide the owner flexibility in selecting different flooring materials at a later point in time. This upgraded permeance rating is also typically low enough to aid in avoiding other moisture-related concerns such as efflorescence, alkali-silica reaction, sweating slab syndrome, and increased latent moisture-load on buildings utilizing a low-humidity-controlled environment (all issues that can arise without a floor covering in place). The additional cost involved in upgrading to this permeance level, when compared with the same Class of materials that simply meet the minimum recommendations of ASTM E 1745, is typically 0-10% (equating to a few cents per square foot).

4.3 Special Conditions

Occasionally, unique conditions will arise on-site that may spur a design professional to require further testing of a vapor retarder in order to gain an indication of its performance under those conditions. ASTM E 1745 provides three examples of possible situations that may need to be evaluated along with their corresponding ASTM evaluation standards. These are Flame Spread, Permeance after Soil Poison Petroleum Vehicle Exposure, and Permeance after Exposure to Ultraviolet Light.[14] Many manufacturers have followed suit by recognizing certain risks and carrying out tests to help determine the effectiveness of their vapor retarders in other applications. For example, many manufacturers will be able to provide an indication of their material's Radon Diffusion Coefficient and/or the Methane Transmission Rate. Design professionals are encouraged to understand what unique conditions exist on site and to include the appropriate standards, tests, and performance characteristics in their specifications. In the many cases where unique conditions do not exist, the design professional can simply continue to specify an after-conditioning permeance rating as determined by the considerations raised in ASTM E 1643 (see the previous section) while also requiring that materials conform to the performance characteristics for strength outlined in Class A, B, or C according to ASTM E 1745.

5.0 Types of Materials

Up until the past decade, the most common material used for under-slab vapor protection was 6-mil polyethylene. Both the International Residential Code[15] and International Building Code,[16] even into the 2009 versions, make reference to this type of material. However, due to the relatively high permeance of generic polyethylene (often called "visqueen"), as well as its susceptibility to puncture, tearing, and deterioration (i.e.

breakdown of the chemical structure of the plastic that can often leading to an unacceptably high post-installation permeance rating) in the below-slab environment, it often does not meet the minimum requirements of ASTM E 1745 (regardless of thickness) and is therefore generally considered to be ineffective.[17] These drawbacks in performance result from the predominant use of recycled resins as the raw materials for manufacturing. The recycling process changes the physical structure of the polymers themselves which can lead to non-homogenous characteristics along a single length of the membrane and inferior or unacceptable performance characteristics.

Multi-layer and reinforced polyethylene materials were also somewhat common until recently. The internal reinforcing, usually comprised of nylon skrim or craft paper, helped to increase the strength of the vapor retarder material. Other manufacturers chose to assemble their membranes by weaving or laminating them. In many of these cases, the materials have failed to resist deterioration or provide an acceptably low permeance rating. As a result, many of the slabs-on-grade that were placed prior to the past decade are now "feeling" the effects of a vapor retarder that was damaged during installation or that has subsequently deteriorated significantly.

Today, a wide range of types of materials are able to call themselves vapor retarders. Most common among these products are extruded polyolefins (plastics). The suffix 'olefin' refers to a general class of plastic monomers, under which ethylene is one very common example. However, the term 'polyolefin' is most often used in the industry to describe a new generation of extruded plastics that utilize higher-quality resins than those that make up generic polyethylene (again, often called 'visqueen'). These new-generation polyolefin vapor retarders are typically much stronger, have a lower permeance, and are much less susceptible to deterioration than generic polyethylene. Furthermore, because they are extruded, rather than being woven or reinforced, these materials maintain their characteristics uniformly over their entire area. Even among the polyolefin vapor retarders, there is a significant range of quality and performance; thus, design professionals are advised to be very familiar with the products they specify.

Still other vapor retarders utilize an inner layer of aluminum between layers of polyethylene, some adhere/bond to the bottom of the slab, and a few are made of semi-rigid bituminous board (the latter being governed by ASTM E 1993[18] instead of ASTM E 1745). These materials are less common than the extruded plastics, and have a wide range of performance characteristics as well. Regardless of the type of materials available, a product's performance characteristics (in terms of strength and after-conditioning permeance) are what should govern whether or not it is appropriate for a given project.

6.0 Location of the Vapor Retarder

ACI 302.2R-06 recommends that the slab-on-grade be placed directly on top of the vapor retarder whenever a vapor-sensitive flooring will be installed. The same is true in situations in which the slab will lie below a humidity controlled environment. A "blotter" layer, often composed of 3 or 4 inches of trimmable, compactable, self-draining granular fill and located between the vapor retarder and the slab, is only recommended when a vapor-sensitive flooring will not be used and both the fill and slab will be placed with a water-tight roof system already in place.[19] Refer to Figure 1 below for details.[20]

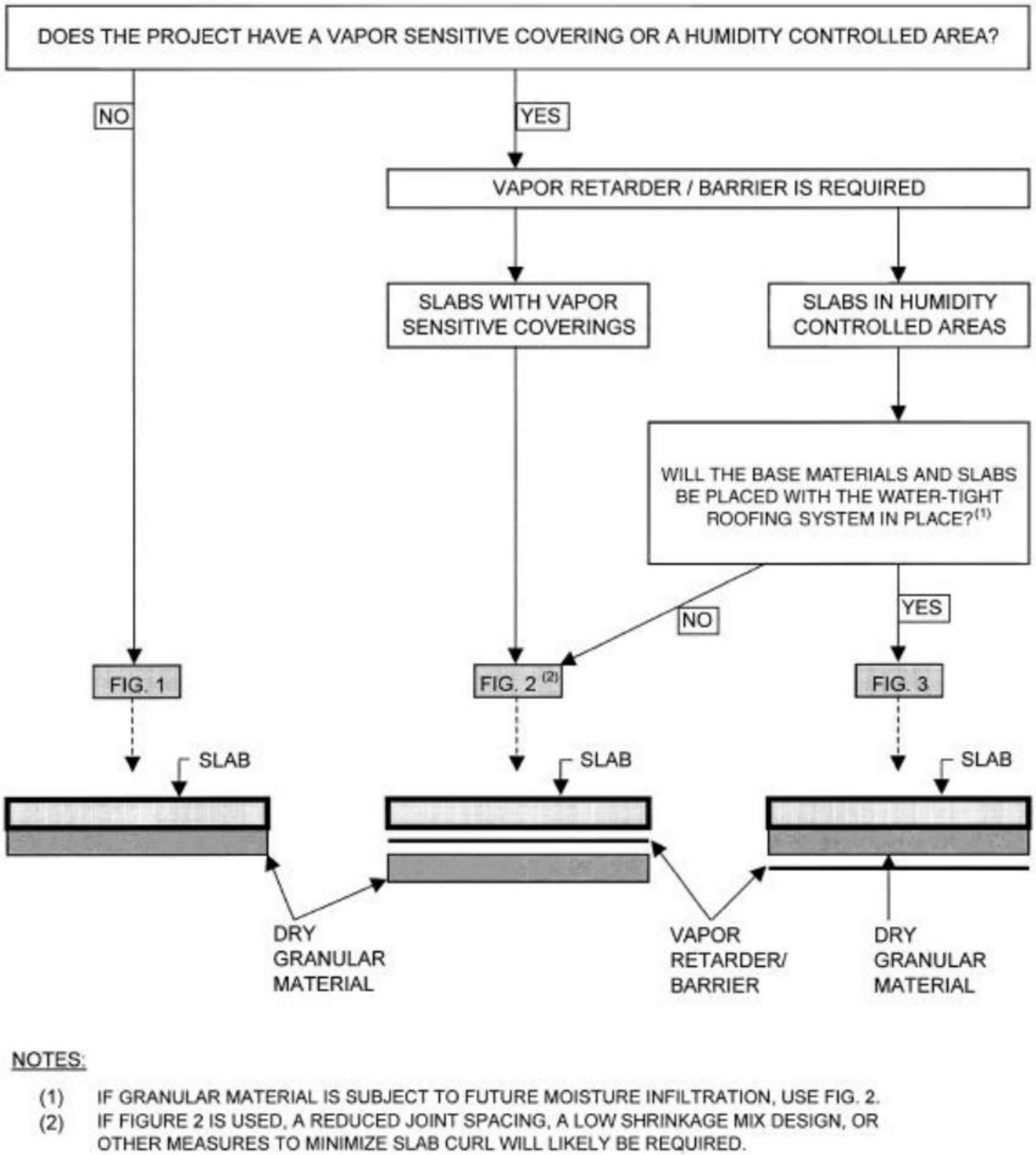

Figure 1: Note that footings are not illustrated in this configuration. Whether or not the vapor retarder should be placed beneath the footings, interior or exterior, is an issue that should be addressed by the design team while considering the general installation standard, ASTM E 1643 (refer to Section 7.0 for more information).

There are several advantages cited by ACI 302.2R-06 for systems that utilize a blotter layer, most notably a reduction in slab-curling during drying (others include shortened period of bleed-water settling and less cracking caused by plastic or drying shrinkage).[21] As concrete hydrates (a necessary process in which water is consumed in a chemical reaction with cementitious particles) and dries (free water in the concrete seeps or evaporates out) it tends to shrink. Often, when a slab is cast directly on a vapor retarder, a drying differential will exist when one area of the concrete (in this case, the top of the slab) loses moisture more quickly than another (in this case, the bottom of the slab). As a result, the slab can tend to shrink unevenly and thus curl

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(and, if tension in the slab becomes too high, subsequently crack). Although all slabs can experience curling to some extent (regardless of whether or not a vapor retarder is in place), a blotter layer placed between the vapor retarder and the slab may help to allow the top and bottom of the slab to dry at a similar rate, thereby decreasing the effects of slab-curl. A wet-cure process can also help to reduce this drying differential initially, although this alone should not be relied upon to eliminate curling.

However, moisture trapped in the blotter layer in this process has been linked to many failed floors, mold issues, and other under-slab moisture-related problems. For this reason and others, ACI 302.2R-06 does not recommends the use of a blotter layer unless the slab is protected by a watertight roofing system during construction. ACI 302.2R-06 also identifies several advantages unique to systems that omit the use of a blotter layer. These include: reduced costs due to less excavation and no need for additional granular material; better curing of the slab bottom as the vapor retarder minimizes moisture loss; and less radon gas infiltration.[22] ACI 302.2R-06 has also identified several strategies to reduce the effects of differential drying when a blotter layer is not advisable; design professionals can consider the use of continuous or strategic reinforcement of the slab, correct joint-spacing, and a well-engineered concrete mix.[23] A successful mix-design will likely utilize well-proportioned water and cement contents, larger top-size aggregate, and well-graded aggregate while also potentially employing water-reducing agents, plasticizers, and/or supplemental cementitious materials. It is important to know the pros and cons of using or omitting the blotter layer; however, removing the vapor retarder is typically not considered to be a cost-effective approach to alleviating the issues of differential drying and/or slab-curling and cracking.

7.0 Installation

Under-slab vapor retarders should be installed according to the general guidelines of ASTM E 1643 along with the specific recommendations of the manufacturer. Generally, the installation should follow these guidelines[24] unless other details are identified by the design professional:

1. Level and compact base material.
2. Install vapor retarder material with the longest dimension parallel with the direction of concrete pour and face laps away from the expected direction of the concrete pour whenever possible.
3. Extend vapor retarder over footings and seal to foundation wall or grade beam at an elevation consistent with the top of the slab or terminate at impediments such as water stops or dowels.
4. Seal around penetrations such as utilities and columns in order to create a monolithic membrane between the surface of the slab and moisture sources below the slab as well as at the slab perimeter.
5. Lap joints minimum 6 in. (150 mm), or as instructed by the manufacturer, and seal laps in accordance with the manufacturer's recommendations.
6. Extend vapor retarder over the tops of pile caps and grade beams to a distance acceptable to the structural engineer and terminate as recommended by the manufacturer.
7. Take precautions to protect vapor retarder from damage during installation of reinforcing steel, utilities and concrete.
8. Inspect and mark all areas of damage and insufficient installation of the vapor retarder sufficiently in advance of concrete placement such that deficiencies may be corrected before concrete is placed.
9. Repair vapor retarder damaged during placement of reinforcing or concrete with vapor retarder material or as instructed by manufacturer.
10. Lap beyond damaged areas a minimum of 6 in. (150 mm) and seal as prescribed for sheet joints.

From time to time, the proper installation of the vapor retarder may conflict with the structural design of the foundation. In these instances, the design team should collaborate to attempt to eliminate the conflicts and reach a balance between maximizing the effectiveness of the vaporproofing system while maintaining the structural integrity of the building itself.

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8.0 Commissioning

Most manufacturers will guarantee that every inch of their material will have the performance characteristics noted on their data sheet when that material arrives on the jobsite and is installed (for further validation that a material has the performance characteristics that its manufacturer reports, ASTM E 1745 allows a design professional to specify verification of test results through an independent third party laboratory). Some manufacturers will also provide support in the field to help facilitate an efficient and successful installation. However, in terms of testing how well a material is performing once the slab is in place, there are only indirect methods. Typically, a Moisture Vapor Emission Rate (MVER) can be obtained that will give the design professional and/or contractor an indication as to how much moisture (typically measured in pounds of water per one thousand square feet per twenty-four hours) is being released from the top of the slab. Different flooring and adhesive manufacturers will make different recommendations as to the maximum MVER allowable before their flooring system should be installed; thus, design professional and contractor should allow enough time between the placement of the slab and the installation of the floor covering to make sure the slab is sufficiently dry.

Several standards exist to help determine if a slab is dry enough to receive a floor covering. These tests can be qualitative or quantitative, and can provide different indications of a slab's moisture content or emissions rate. The two most common tests are ASTM F 1869 – 98 *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride*[25] and ASTM F 2170 – 02 *Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.*[26] Before a slab is to receive a resilient floor covering, it is typically prepared according to ASTM F 710 – 05 *Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring*[27] which outlines several tests and procedures (including the two aforementioned standards) as well as recommended limits to help promote successful floors in the absence of a flooring manufacturer's recommendations (for example, an upper limit on MVER of 3 lb/1000 ft2 per 24 h if employing ASTM F 1869 and 75% relative humidity [obtained at 40% depth from the top of the slab assuming it is drying from one side] if employing ASTM F 2170).[28]

These tests provide an indication as to when a slab has reached a drying profile deemed appropriate by a floor covering manufacturer to install their product. While this number is certainly affected by the quality of the vapor retarder, there are several other factors that impact this value. It should be understood that the purpose of a vapor retarder is to help reduce the amount of subsequent under-slab moisture that can enter a slab-on-grade. Doing so will help to maintain a low internal relative humidity (and thus low MVER) within a slab that initially tested within the limits of the aforementioned tests. Thus, while it is important to get a slab "dry" initially, a vapor retarder is an absolutely necessary part of making sure a slab stays "dry." Again, a material's permeance (and specifically its permeance after being subjected to the required conditioning tests within ASTM E 1745), is perhaps the design team's best indication as to how well a vapor retarder will perform during the lifetime of their project.

Additional Information:

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[1] Howard M. Kanare, Concrete Floors and Moisture, Second ed. (Portland Cement Association and National Ready Mixed Concrete Association, 2008), 62.
[2] Peter Craig and Monica Rourke, "Take the Ground out of Play!" RCI-Online [USA], July 2008, http://www.rci-online.org/interface/2008-07-craig-rourke.pdf
[3] Peter Craig, "Vapor Barriers: Nuisance or Necessity" Concrete Construction, March 2004, 34.
[4] Craig, 34.
[5] Kim Basham, "Vapor Retarders," Concrete Contractor, 14 May 2009.
[6] ASTM E 1643 – 09 Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs.
[7] The 2009 International Building Code, in Section 1805.2.1, and the 2009 International Residential Code, in Section R506.2.3, both refer to the use of 6-mil polyethylene film lapped no less than 6 inches, or other approved material and/or method. Refer to endnotes 14 and 15 for document citation.
[8] ACI Committee 302, ACI 302.2R-06 Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials (Farmington Hills, MI: American Concrete Institute, 2006).
[9] ASTM E 1745 – 09 Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs.
[10] ASTM E 1745, Table 1.
[11] ASTM E 1643, Section 5.3.2.3.
[12] ACI Committee 302, Section 9.3, 36.
[13] ACI Committee 302, 1.
[14] ASTM E 1745, Sections 7.4.1-3.
[15] International Code Council, 2009 International Residential Code (ICC, 2009), from 19 April 2010, http://publicecodes.citation.com/
[16] International Code Council, 2009 International Building Code (ICC, 2009), from 11 May 2010, http://publicecodes.citation.com/
[17] Howard Kanare, "Why Are We Still Having Problems and Concrete Floor Slabs?" Concrete Construction, 15 November 2007, 3.
[18] ASTM E 1993 – 98 (Reapproved 2002) Standard Specification for Bituminous Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs.
[19] ACI Committee 302, Section 7.2, 29-30.
[20] ACI Committee 302, Figure 7.1, 31.
[21] ACI Committee 302, Section 7.2.1, 29.
[22] ACI Committee 302, Section 7.2.2, 29.
[23] ACI Committee 302, Section 7.2.4, 30-31.
[24] ASTM E 1643, Sections 6-9.
[25] ASTM F 1869 – 98 Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride.
[26] ASTM F 2170 – 02 Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.
[27] ASTM F 710 – 05 Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring.
[28] ASTM F 710 Table 1.