Technology Assessment Report

A Field Study Comparison of the Energy and Moisture Performance Characteristics of Ventilated Versus Sealed Crawlspaces in the South

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Submitted to:
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Introduction

The purpose of this document is to assess the status and regulatory requirements for residential crawl space construction in the United States with respect to moisture control, thermal integrity, and indoor air quality. The assessment is divided into three parts. The first chapter provides background on crawl space construction in the United States. It is written by William B. Rose, research architect at the University of Illinois at Urbana-Champaign, and represents a 2001 update of his 1994 symposium on moisture control in crawl space construction. The second chapter consists of a letter to and response from the Building Officials and Code Administrator International (BOCA) clarifying various provisions of the International Regulatory Commission (IRC) with respect to crawl space construction. The third chapter offers a technical assessment of crawl space construction as of 2001 in the United States. It reviews ongoing crawl space building practices, identifies issues in the field related to moisture control, thermal performance, and indoor air quality, and offers potential solutions to these problems.

This assessment was conducted as a part of a larger project funded by the U.S. Department of Energy, and cofunded and managed by Advanced Energy Corporation. Three concurrent studies, a characterization study, a field study, and a hygrothermal study, will help complete the picture on crawl space performance for residential buildings in the Southeastern United States. The characterization study documented moisture-related problems, soil type, site drainage, materials permeance, duct leakage, pressure relationships, insulation, and the presence of radon and mold, both airborne and surface, for ten existing crawl spaces. The field study generated comparative information on the performance of closed versus wall vented crawl spaces with respect to moisture levels and indoor air quality. The hygrothermal performance study, conducted with Oak Ridge National Laboratory (ORNL), involved the development and validation of a computer program to analyze crawl space designs with respect to moisture performance. Using the model, building code officials should be able to develop design guidelines and formulate performance-based, building code provisions that will minimize moisture problems for crawl space systems. The authors hope these findings will prompt the home construction industry to employ dry construction techniques as a means of improving the performance of crawl space systems.

Reports on the pilot phases of all three studies were submitted to DOE in December 2001. Final results are now available. This project utilized the study findings and technical assessment to help commercialize and deploy improved construction guidelines and building code provisions for wall vented and closed crawl spaces. Complete project materials are located online at www.crawlspaces.org.
Chapter 1: Background on Crawl Space Regulation, Construction, and Performance

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September 25, 2001

1.1 Aim

This report seeks to provide background information on crawl space construction in the US and Canada. It combines a chronology of crawl space design, findings and regulation with a list of references.

1.2 Unregulated construction (pre-WWII)

1.2.1 Early examples

Crawl space construction appears widely throughout building construction, though patterns of its use are not well documented. A crawl space is any foundation system with a floor suspended over a space other than a basement. Crawl space construction was used whenever a floor other than a dirt floor was desired, but, for reasons of cost, speed of construction, hydrology or availability of equipment or materials, the basement was not fully excavated.

Below are listed some examples of early crawl spaces.

Lamington Church (1780s)
This Presbyterian church in Central New Jersey dates from the 1780s. A preservation effort is underway. It was constructed on a crawl space. The headroom varies from approx. 4’ at the west (entry) end to 1’ at the east end. There are three rows of piers along the east-west center. The wood framing has remained in excellent condition. There is some wetting of the soil at the low end of the crawl space, and it appears to have begun when the west end of the building was redone in the 1980s. The crawl space has never had a ground cover. No information on the soil type or condition is available. There has never been any equipment in the crawl space.

Fort Hill (1820s)
The building is a timber frame structure on the campus of Clemson University that was originally the family home of John C. Calhoun, the states’ rights advocate. The original construction was pier construction, and a skirt wall was added later. It is unclear to me how common the pier-to-crawl conversion is, especially for Southern construction.
“Michigan” basement (early 1900s)
Immigrants of the “second wave,” many from Eastern Europe, settled around the Great Lakes because of the steel industry. Many homes from this period were constructed in low-lying areas, with stem walls down to frost depth, and an excavated basement that left a bulkhead of soil at the foundation. At present, it is unclear what the sequence of construction was. It is possible that the water table was high at the time of original construction, but was lowered with community development, and once the table was lowered, the basements could be safely excavated.

Henry Ford Museum (1920s)
This museum building, 9 acres in plan, was constructed similar to the construction of assembly plants in the 1920s. The floor is a 6” reinforced slab with cast beams, all supported on piers with about 3’ of headroom. There is a center spine with full head height. There is no ground cover other than a soil treatment with gravel (basaltic?). There have been no problems except at one area that was air conditioned. Investigation of that case continues.

1.2.2 FHA warnings
The principal source of building regulation in residential construction was not the building codes, which focused on commercial and multi-family construction. Rather, builders used handbooks or guidebooks. Construction guidebooks of the first half of the 20th century describe only basement, pier and pile foundation construction.

In 1923, the National Bureau of Standards published “Recommended Minimum Requirements for Small Dwelling Construction.” [NBS 1923] Section 33 reads; “Cross ventilation shall be provided for the space inclosed (sic) by foundation walls, whether it be excavated or not (See Appendix, par. 36).” That paragraph reads as follows:

Where provision is not made for circulation of air within inclosed (sic) spaces next to the ground surface, dampness accumulates and timber decays rapidly. Openings for the admission of air help to prevent such decay and increase the life of the structure. The total area of such openings should be not less than 7 percent of the ground area inclosed (sic).

This appears to be the first call for ventilation of foundation areas. It is somewhat unclear whether the authors are referring to the area under porches or whether they acknowledge the existence at that time of residential construction that resembles current crawl space construction.

In 1935, the Federal Housing Administration (FHA) revised “Property Standards: Requirements for Mortgage Insurance under Title II of the National Housing Act” [FHA 1935] with a specific warning:

5. Where no basement is provided, the space beneath all joists, beams, and girders, of wood or metal, shall be adequately ventilated. Sufficient space shall be provided beneath such floor construction to permit access for inspection and repair.
Note: The Administration is especially insistent upon this requirement because of the great danger of decay or termite attack in wood members and corrosion of metal when such spaces are not adequately ventilated and accessible.

This rather strong language indicates that a substantial amount of decay and corrosion was being reported in areas with no basement. Ventilation of these areas was recommended. However, the FHA did not specify ventilation amounts as had the NBS.

In 1939, The Forest Products Laboratory (FPL) published “Use and Abuse of Wood in House Construction,” [Johnson 1939] which warned:

In Southern States houses commonly have partial or no basements. The South in large measure has learned the importance of unobstructed ventilation underneath the house and the advantages of barriers against termites. The North has yet to learn how to provide sufficient ventilation under houses with no basements to prevent decayed sills and still have warm floors in the winter.

A caption to a photo of a vent reads:

“Screened vents totaling 3 percent of the house area are best, with a thoroughly insulated floor. One small ventilator in each wall is hardly enough in the damp South. Adjustable windows are frequently forgotten and ventilation may thus be neglected.”

This is the first mention of northern basementless construction in the research literature.

During World War II, the Federal Agency charged with housing issues was the National Housing Agency (NHA). Its principal mandate was the allocation of materials and resources. It was also the parent organization of the Federal Housing Administration (FHA), which insured home mortgages. By 1942, the FHA published Property Standards and Minimum Construction Requirements for Dwellings. [FHA 1942] This publication became the Minimum Property Requirements in 1947, which then became the Minimum Property Standards (MPS) in 1958. The 1942 edition contains the following requirements for Basementless Spaces (Section 209-J):

1. Provide a sufficient number of foundation wall vents to assure a total ventilating area equivalent to 1/2 percent of the enclosed area plus 1/2 square foot for each 25 lineal feet of wall enclosing that area.

2. Number of vents: minimum 2.

3. Locate vents to provide cross ventilation wherever possible.

4. No vents required for basementless spaces, one side of which, exclusive of structural supports such as piers, chimney foundations, etc., is open to a ventilated basement, provided the total area of ventilating openings is 2 percent of the basement area plus the area of the basementless space.

This regulatory document predates any research on crawl space performance. Up to the 1940's regulations typically had a basis in experience and practice rather than in research results. Building research was practically unknown. Usually experience was a sufficient guide for drafting building regulations. However, crawl space construction, in the northern US, with only a small amount of vent opening area, was a construction practice with only a very short history. And that history indicated that moisture was a problem.
from the outset. Thus, there was no basis for the belief embodied in this regulation that it would be sufficient to solve the moisture problems that were known to exist.

All of the subsequent regulations regarding crawl space construction are variants of the requirements of this section. (The following section of this same document, Section 209-K, contains the first mention of a requirement for attic ventilation--1/300 of the horizontally projected roof area.)

1.3 Britton and the post-war boom (1940s)

1.3.1 Ralph Britton

Technical Bulletin No. 38, from January 1946, contains “Preliminary Report on Soil Evaporation Experiment.” The author was undoubtedly Ralph R. Britton, Structural Engineer of the Technical Division Staff. It begins:

During World War II and immediately prior to it when many basementless houses and apartments were constructed, experience indicates that confined areas of untreated or untopped soil under the first floors in crawl spaces are large contributors of moisture within the structure.

Realizing that in many instances these crawl spaces do not contain the present generally recommended amount of ventilation in the outside walls (two square feet of free area per 25 lineal feet of outside wall or two square feet of free area per 100 lineal feet of outside wall plus one-half of one percent of the floor area) and yet in many instances no trouble from moisture is experienced, the National Housing Agency is conducting experiments on the amount of evaporation that may be expected from soil under various conditions.

General Scope

Six experimental cans or containers, one containing water only, have been set up in the basement of a residence in Arlington, Virginia, and are being observed daily....

This article speaks as though recommended amounts of crawl space ventilation were known at the time. However, to date it has been impossible to find any reference or source for the guidelines that the soil experiment author (Britton) cites. The article gives a brief history of crawl space construction, indicating its rapid growth during the war years. And the article points to moisture problems that can result from “untreated or untopped” soil. This article thus contains the first reference in the literature to suitable ground covers (or soil treatments) and to crawl space ventilation.

A 30” high container had 1 sq. ft. exposure at the top. Water was maintained at a somewhat constant level at the bottom of the can. The amount of water needed to maintain the constant level was equal to the rate of evaporation into the basement air. The initials “RRB” appear at the bottom of the page of a figure. The author sought to study topped or treated soil in the crawl space. His study was of untreated soil, compared to:

- water
- weak solution of calcium chloride and sodium silicate
- 2” of pea gravel
Vinsol NVX. (Note: Vinsol was a binder used in fiberglass insulation. It was an abbreviation for “very insoluble”. Personal communication Mike Lacher, CertainTeed Corporation)

Throughout the study, the pea gravel case showed substantially less evaporation than all of the others. During the second study period, it was noted that untreated soil allowed for a greater amount of water evaporation (13.20 gallons per 1000 sq. ft. per 24 hours) than free water (12.42 gallons per 1000 sq. ft. per 24 hours).

Two formulas were given for calculating the required vent area:

- 2 sq. ft. per 25 lineal feet of foundation (presumably the length of the side of a house), or
- 2 sq. ft. per 100 lineal feet of foundation (the approximate perimeter of the house) plus one half of one percent of the floor area (a 1/500 ratio).

A 25' x 40' (1000 sq. ft.) house would thus require about 11 sq. ft. of vent area by formula 1, or about 5 sq. ft. by formula 2.

In January 1948, Ralph R. published “Crawl Spaces: Their effect on dwellings – an analysis of causes and results – suggested good practice requirements.” This article is the seminal article in the research literature. His aim was to address the concerns about moisture problems in crawl spaces and to provide literature in support of appropriate recommendations.

The article begins with a definition of this new term “Crawl Space” and with a warning:

A Crawl Space is 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. The space may be only a foot, or two, or it may be several feet in height. It must be suitable for the installation and maintenance of mechanical lines and equipment when they are placed below the first floor. The walls enclosing the crawl space may be of masonry or they may be of wood siding, asbestos cement board, metal sheets of other similar materials supported on light framing. No matter what the details are, the result is an area or areas enclosed within the confines of a building which can be a serious constant supply of moisture and, therefore, potential trouble.

He studied closely what was happening in a group of 72 apartment houses on crawl spaces. Among his findings are the following:

- 32 to 45 gallons of water were left in the apartment structures in 24 hours,
- the relative humidity in the crawl space was 90%,
- warm, humid air rises up through the furred spaces and condenses on the underside of the roof,
- wood moisture content in the floor framing members in the crawl space was up to 50%
- the plywood roof sheathing was delaminated, due directly to the wet conditions in the crawl space,
• “...maintenance crews closed the vents in winter.”

• Crawl space moisture can be modified by changing the type of attic ventilation:

  When ventilation was added to the walls of the loft spaces of a test building of the 72-apartment project and, therefore, the suction effect of the roof ventilators to the crawl spaces was eliminated, it was noted that the crawl spaces rapidly became wetter and damper.

• Moisture problems in crawl spaces can be relieved:

  When ventilation to the extent of approximately 1/1500 of the building area was cut into crawl spaces walls, in conjunction with ventilation of approximately 1/500 of the building area in the loft space walls and the covering of the crawl space ground with 55# mineral surfaced roofing, all trouble was apparently eliminated. It is to be noted that these corrective measures are the ones adopted for the entire 72-apartment project. They are apparently successful as no trouble during the winter of 1946-47 has been reported.

From these findings he was able to draw several recommendations:

• The crawl space should have more ventilation than the attic space.

• Crawl space ventilation should amount to 2 sq. ft. per 100 ft. of building perimeter plus .5% of building area (same rule as Property Standards 1942).

• Crawl space ventilation and attic ventilation are linked:

  “When the roof slope is more than 3" in 12" and there is no effective vapor barrier in the top story ceiling, install ventilation in the gable ends as high as possible with free access to all other enclosed spaces between the living quarters and the roof in the total amount of 1/300 (free area) of the reflected roof area.”

  Note: Where an effective vapor barrier is assured in the top-story ceiling, loft or attic space ventilation specified above may be greatly decreased. Such decrease may well be as much as 90% where controlled construction is assured and walls or crawl space do not contribute to moisture supply in the attic or loft space.

  Note: Where crawl space floors are covered with 55# mineral surfaced roll roofing in an effective manner, the specified wall ventilation may well be reduced as much as 90% for controlled construction.

• Regarding attic ventilation:

  Loft or attic spaces should not be ventilated through the roof only as Drawing No. 1 indicates. It is understood that existing building codes and even Model Basic Codes now being written are not clear on this subject and are being interpreted to prohibit ventilation in side walls of loft spaces. Such practice is dangerous.

• Regarding ground covers:

  Attention is directed to other possibilities in guarding effectively against prolonged condensation. Crawl spaces may be vented by ducts through the roof, opening directly into the crawl space below the first floor. Treatments of soil other than covering with roofing in crawl spaces show promise. Sufficient data, however, have not been gathered and analyzed as yet to allow good practice recommendations to be set forth on their use.

• A warning:

  Trouble should not be invited by providing closing devices for needed ventilation. The closing of ventilation openings is a dangerous practice.
With these recommendations in place he drew the principal conclusion:

“The design (of the crawl space) shall be such as to reasonably assure lack of prolonged condensation on any surface either exposed or enclosed (and including equipment) of any part of the dwelling or building.”

“We are reasonably sure of one way of accomplishing the desired result. That is by adequate ventilation as described above. However, as we go ahead in development, other means of doing the job adequately are bound to be perfected.”

It is important to note that in the finding above, moisture problems were solved with the increase in ventilation combined with the addition of a 55# roll roofing ground cover. There is nothing in the findings which distinguishes the effect of ventilation from the effect of the ground cover. In the 1940's it was known that 15# roofing felts deteriorated quickly from ground contact. It was feared that 55# roll roofing might do the same. Thus it makes sense that a researcher would not want to insist that a moisture control strategy hinge on the performance of a membrane whose continued performance was not assured. For this reason, it makes some sense that the focus of a moisture control strategy would be on ventilation, which, under normal circumstances, would remain in place. However, there were no findings that would support that conclusion that ventilation is a sufficient moisture control strategy. Britton expressed the hope at the end of his conclusion that other means of doing the job be perfected.

1.3.2 Vapor barrier materials

The theory of moisture diffusion in building envelope assemblies was first promulgated by Frank Rowley in 1938. At that time techniques for measurement of vapor permeance were undertaken by the National Bureau of Standards, the University of Minnesota and the Armstrong Cork Company. These efforts resulted in ASTM Standard E96. The history of vapor barrier materials has been described by Rose (1997). Materials used for ground covers were the same materials as those used for wall and ceiling vapor barriers.

1.3.3 Condensation Control

Small Homes Council, University of Illinois

Britton's work was widely publicized, as it was done within the framework of the Housing and Home Finance Agency and the Federal Housing Authority. Less well known was the work of the Small Homes Council, founded at the University of Illinois in 1944, with the purpose of translating wartime technology to improvements in residential construction. In 1946 they published their first “Short Course” and it contained a significant contribution on crawl spaces, then called "basementless spaces.”

Morrisett, the Chief Construction Examiner for the Springfield IL HFA was the speaker:

The elimination of this (condensation) hazard which so definitely shortens the life of the structural frame of homes has been dealt with lightly, or overlooked, in a large percentage of small homes in the past. However, in recent years small home construction has had the advantage of some scientific study and today an effort is being made to solve this problem. Study has been made mostly by organizations interested in large projects—that is, group housing. The Department of Agriculture and the National Housing Agency have been carrying on intensive study. The war
housing projects in the mid-west and in the vicinity of Washington have been the object of this study. Bulletins are not available on those recent studies. However, I am at liberty to disclose that studies have shown the seriousness of the problem of moisture in crawl spaces. Briefly, the moisture problems in crawl spaces resolves itself into the following:

Water is constantly evaporating from the ground into this space. The temperature varies greatly from day to night, in this space, but not enough to stop fungus growth. Relatively high humidity exists in this space.

...The solution lies in stopping the evaporation, but until a successful method of stopping evaporation from the soil is developed adequate ventilation of this area is absolutely necessary.

When crawl space is ventilated much heat is lost unless the floors are insulated. In case the floors are insulated and a vapor seal is used, the humidity is increased in the crawl space as this vapor seal prevents moisture from diffusing through the super-structure. Humidity may become so high in this space when it is sealed by a complete vapor barrier under the floor that any plumbing chases, or openings, extending from the crawl space to the attic may act as vent flues and conduct this moisture laden atmosphere into the attic, resulting in a serious moisture problem in the attic.

The studies conducted by the organizations above mentioned indicate that a probable cure for the moisture in the crawl space lies in the field providing a sealing coat which will prevent moisture in the soil from being transferred to the air. The most successful treatments so far observed are: covering the soil with about 2” of pea gravel; and laying roofing felt loosely on the ground. Either of these methods cause very great change in the rate of evaporation from the soil to the air. In some of the experiments the roofing paper treatment has been found to be effective enough so as to reduce the water content of the wood joists over the crawl spaces to the point where fungus growth is inhibited. The unknown factor about the roofing felt is how long it will remain in good repair when in contact with the soil. The gravel treatment seems to be more promising as far as lasting quality is concerned. I wish to reiterate at this point that until a successful method is developed to stop the water from evaporating out of the soil, the ventilation of crawl spaces, and the insulation of the floors over such area, is necessary.

Clearly, Morrisett was aware of Britton’s work, published two years later. He neatly expresses the state-of-the-art for the immediate postwar period:

- Crawl space moisture is a serious problem
- Preventing evaporation from soil is the principal strategy
- However, permanence of ground covers has not as yet been sufficiently established.
- So, meanwhile, crawl spaces should be vented and floor systems insulated.

There was considerable interchange of information between the University of Minnesota, the University of Illinois, the Forest Products Laboratory and the National Housing Agency in Washington. In January 1947, the SHC published the 8-page circular, *Moisture Condensation,* the author was Frank B. Rowley who, eight years before, had conducted experiments in a climate-controlled chamber at the University of Minnesota, which quantified condensation rates in walls and attics. This publication contained a three-paragraph section titled “The Problem of Basementless Houses,” as follows:

The basementless house built over a 3- or 4-foot excavation (crawl space) is likely to have a serious condensation problem if there is considerable rainfall and ground moisture. Such moisture tends to rise through the house (through floors and open stud spaces). In some cases, it rises as high as the attic and condenses there.
The solution for this problem has not been definitely determined. According to the best building practices known today, such houses should have a vapor barrier beneath the floor boards; rot-proof subfloor and joists (concrete or pressure treated lumber); screened vent openings in the foundation sidewalls above the ground to allow circulation of air; and a layer of crushed rock, cinders or gravel on the ground to retard the rise of vapor. Good ground drainage is essential.

It is believed best to have the vents open all-the-year-round. If this is done, then it is necessary to insulate below the first floor. (Insulation should be wrapped around all pipes if they are not above the floor insulation.) When insulation is used, the vapor barrier should be placed above the insulation for all practical purposes since the possibility of condensation in the summer is slight (the ground temperature is usually less than the floor temperature.) It is only necessary to have a vapor barrier under the insulation when the house is to be left unheated in the winter.

That section appears to be the first reference to the use of gravel as a vapor retarder. There is no mention of a ground cover and no specification of venting requirements.

**HHFA “Condensation Control”**

The most influential document of the period was the booklet “Condensation Control” (HHFA 1949). It contained the following description of ventilation and ground cover as approaches to crawl space moisture control:

*Condensation Control by ventilation*

Where there is no other means of effective condensation control, and in the absence of a definite determination that the soil is not a large supplier of moisture to the crawl space, the total net amount of ventilation should be 2 square feet per 100 lineal feet of building perimeter plus one-third of 1 percent of the crawl space ground area...

*Condensation control by ground cover*

Since in many northern areas it is not practical to allow a free sweep of cold air below a dwelling floor, an alternate method of condensation control in crawl spaces has been developed. This consists of stopping moisture from the ground from entering the air in the confined space by covering the ground with a vapor-resistant durable material. A good water-proofed concrete slab or heavy roll roofing has been shown to be effective...Generally the lap joints need no cementing material. Where a good cover is applied over the entire surface of the ground in the crawl space, very little ventilation is needed. However, to be on the safe side, it is recommended that at least 10 percent of the ventilation indicated by the two plus one-third formula be provided.

*Other crawl space recommendations*

In crawl space construction the following good practice requirements for taking care of matters other than the condensation problem under discussion are recommended:

1. Adequate headroom for the purpose of maintenance of equipment
2. Proper slope of outside grading away from the building.
3. Possible drains in the crawl space if the ground level is below outside grade and of a soil composition not allowing seepage of water through it.
4. Full 18-inch clearance between ground and bottoms of wood framing or other materials subject to attack by termites.
5. Ready access to all parts of crawl spaces for inspection against deterioration and termites.
1.3.4 Building Codes

Minimum Property Standards

The Federal Housing Administration (a part of the HHFA) developed the Minimum Property Requirements to “set forth minimum planning and construction requirements to apply to a residential property...which is offered or proposed to be offered to the Federal Housing Administration as security for an insured mortgage loan.”

The Minimum Property Requirements contain Planning Requirements (Section 301-K) and Construction Requirements (Section 403-B).

In 1947, Section 301-K read:

1. Where the floor construction above is of wood or metal provide at least two foundation wall vents to assure a total ventilating area equivalent to one square foot for each 15 lineal feet of wall enclosing that area.

2. Locate one vent at or near each corner to provide through ventilation wherever possible. No vents are required for a basementless space adjoining a basement where the common wall below the joists is at least 50 percent open, provided the total area of ventilating openings in the basement space is not less than 2 percent of the combined basement area and basementless space.

3. In each vent opening install corrosion-resistant screening, mesh not less than 8 per inch.

In 1947, crawl spaces were still largely foundations for spaces adjoining buildings with basements. In 1951, Section 301-K read:

1. No foundation wall vents are required for ventilating a basement space one side of which, exclusive of structural supports, is open to a ventilated basement, provided the total area of ventilating openings in the exterior walls of the basement is at least 1/50 of the combined area of the basement and basementless space.

2. When the floor construction above a basementless space is of wood or metal, and the space is not open to a ventilated basement as described above, provide:
   a. At least four foundation wall vents located near the corners of the basementless space, having an aggregate free ventilating area equal to 2 square feet per 100 lineal feet of wall enclosing the space plus 1/300 of the ground area of the basementless space in square feet, or,
   b. Ground surface treatment in the form of a layer of smooth asphalt roofing weighing at least 55 pounds per 108 square feet lapped a minimum of 2 inches plus at least two foundation wall vents, located for effective cross ventilation, having an aggregate free ventilating area of not less than 10% of that required in 2a above.

3. In each vent opening install corrosion-resistant screening, mesh 4 to 8 per inch.

This was clearly derived from the recommendations of Britton. Section 403-B dealt with maintaining 18” of clearance, positive drainage and the removal of debris. In 1956, the requirements of 301-K and 403-B were the same, except for the addition under 403-B of the following:

4. “Unless otherwise acceptable to the Chief Underwriter, the entire ground surface shall be covered as required in 301-K-2-b.”
Evidently, by 1956, concerns for the durability of ground covers had been sufficiently addressed.

The Minimum Property Requirements were reissued in 1958 as the Minimum Property Standards FHA no. 300. Section 604-3 Basementless spaces (Crawl spaces) reads:

604-3.1 At least 4 foundation wall ventilators shall be provided, one located close to each corner of the space, having an aggregate net free ventilating area not less than 1/150 of the area of the basementless spaces; or

604-3.2 Ground surface treatment in the form of a vapor barrier material complying with 713-5 plus at least 2 foundation wall ventilators having an aggregate net free ventilating area not less than 1/1500 of the area of the basementless space.

604-3.3 Foundation wall ventilators are not required for ventilating a basementless space one side of which, exclusive of structural supports, is completely open to a basement; except that basementless spaces having a greater area than the basement shall be separately ventilated.

604-3.4 Where a crawl space is used as a plenum comply with 1003-14.3c.

Section 713-5 requires a 1 perm rating for the ground cover. Section 1003-14.3c requires (d) “the perimeter construction enclosing the crawl space shall be sealed above the level of the crawl-space ground elevation against air leakage”, and (g) “provide two vent openings in the perimeter wall complying with 604-2.3. The vent openings shall be equipped with closures operable from the outside and be screened in accordance with 604-2.3.” It is little wonder that confusion should arise over whether vents should be opened or closed.

1.4 Ground covers and ventilation (50s and 60s)

1.4.1 Ground covers

The concern over the durability of ground covers was addressed in HHFA's Housing Research, October 1952 in an article titled “Durability of Moisture-resistant Membrane Materials in Contact with the Ground.” This was the result of research sponsored by HHFA and conducted at FPL by C. S. Moses. The samples of 15# felt paper were seen to disintegrate from fungal attack within 3 years. Samples of 55# roofing were found to be still effective vapor barriers after 8 and 10 years. The recommendation was for placement of 55# membrane in all crawl spaces. Under the section “New Membrane Developments,” no new materials were named.

The HHFA published in April 1954 Housing Research Paper No. 28 “Moisture Migration From the Ground.” No author was cited. The research is similar to that conducted by Britton and recorded in NHA Technical Bulletin #38. It includes the chart from Britton's article
“Crawl Spaces.” The results were surprising. This series of tests showed that the greatest amount of evaporation occurred in the case with 4 inches of gravel over the soil. Indeed, **twice as much evaporation occurred in this case than in the case of exposed soil with no gravel.** This is in sharp and direct contrast to the results found by Britton, where the sample with pea gravel showed substantially less evaporation than any of the other samples. Evidently there were flaws in the methods that seriously affected the reproducibility of the results. It can be speculated that the soil in the containers was not well characterized for its capillary potential.

This document began the exploration of some questions that remain controversial, for example, whether or not to seal the seams in the ground vapor retarder:

Sealing or cementing of the laps of crawl space membranes is not recommended. Many crawl spaces are below the grade of the surrounding yard, where they are subject to occasional flooding during heavy rains, and the open laps permit this water to drain off before it causes damage to the house.

Most notably, the first recommendation for closing crawl space vents appeared in this document:

When a durable and effective ground cover such as 55-pound roll roofing has been placed in the crawl space, the vents provided in the foundation walls to ventilate the crawl space may safely be closed during cold winter months. This will provide a more comfortable floor during cold weather, and will reduce fuel costs.

1.4.2 Small Homes Council

The first reference to “closed” crawl space construction appeared in 1959, in the Small Homes Council brochure *Crawl Space Houses* [SHC 1959]. The circular was widely distributed. It contains the following (the emphasis is in the original):

**Closed Crawl Spaces**

The moisture control provided by ground cover is so effective that crawl-space ventilators can usually be kept closed during the heating season. This “closed” crawl space construction is recommended except under severe moisture conditions since it provides maximum floor comfort with a minimum of expenditure for insulation. Insulation around water pipes and heat ducts and pipes is not needed; furthermore, a closed crawl space can also serve as a plenum for a warm-air heating system.

1.4.3 National Academy of Science

In 1962, the Building Research Advisory Board, under the auspices of the National Academy of Sciences-National Research Council, put forth recommendations regarding ground covers and ventilation for crawl spaces. Their recommendations were based on the authority of the experts on the panel.

Until the quantitative data needed for precise determination is developed, the Committee recommends that:

1. Ground cover be required in residential crawl spaces in locations where the average January mean temperature is 45 degrees Fahrenheit or below, and the average annual precipitation is 20 inches or more.
2. In all cases where the crawl space is used as a heat plenum, regardless of geographical location or environmental conditions, ground cover be provided, and

3. All crawl spaces, except those used as heat plenums, be ventilated. The number and size of the vents to continue to be determined on the basis of current FHA minimum Property Requirements, or alternatively… the formula appearing in ASHRAE Guide.

BRAB asked for more research, which was never carried out, specifically for a determination of facts regarding the incidence, nature and extent of crawl-space moisture and its effects “also, the interrelationships of moisture, ground cover, and ventilation.”

1.4.4 Other work

Moses (1954) found that minimal ground cover (50%) could help control high moisture content conditions in crawl space framing.

In 1963, Ev Shuman of Penn State, under contract to the FHA conducted “A survey of the durability of vapor barrier materials in contact with the ground (1963). To the question “What existing information is available that relates directly to the length of time vapor barrier materials remain effective?” he discovered that “none which was specific was found.” He recommended stockpiling old samples.

1.5 Energy crunch (70s and 80s)

Duff of the US Forest Products Laboratory (1978, 1980) found that, with 90% ground cover coverage, wood moisture content was in an acceptable range even with vents closed. A study from Princeton (Dutt et al 1988) concluded from temperature and moisture measurements in crawl space homes in New Jersey, that with ground covers in place, walls can be insulated and vents closed, resulting in energy savings and “no moisture problems.”

Moody et. al. in 1982 reported that crawl space wall insulation is 2 to 3 times more cost effective than floor insulation. They stated that the effect of removing crawl space ventilation did not detrimentally affect the structure and, in fact, reduced moisture content to a more acceptable value. Moody et. al. in 1985 reported that closing crawl space vents did not result in excessive wood moisture content.

Shipp (1982) showed that the thermal performance of foundation areas, including crawl spaces, could be estimated satisfactorily with simple material property values and boundary conditions as inputs.

Jennings and Moody in 1984 summarized the recommendations arising from their studies and those of others:

1. Crawl space ventilation appears to be a key element in residential moisture problems in areas with hot/humid climates… Ventilation rates addressed by national code or standards do not adequately consider local climatic conditions, soil characteristics, or local construction practices… An effort should be initiated to reevaluate the techniques for calculating crawl
space ventilation requirements and further research should continue on alternative approaches to conventional floor insulation.

2. If sufficient heat cannot enter the crawl space to maintain a temperature above the outdoor dew point during the summer, then the moisture laden air entering through the foundation vents can increase the percent moisture content up to a level above the fiber saturation point. In these cases, it is safer to leave the foundation vents closed during the summer months.

3. Crawl space wall insulation is a superior method for reducing heat loss through the floors in winter months.

4. A great deal of misinformation exists within the residential community of builders, contractors, architects, building inspectors, pest control operators, and homeowners on the importance of and techniques for residential moisture control.

However, a close reading of their document reveals that their finding in (1) above is in contrast to their recommendation for code-level venting, given in Appendix A of their report. Thus, they contribute unwittingly to misinformation on the subject.

Labs (1988) summarized the conflicting information in *Building Foundation Design Handbook* as he described both vented and unvented construction for crawl spaces without guidance on how a designer would select one over another.

Rose (1988) conducted a survey of homes in Champaign County IL and determined that the one moisture problem that was both widespread and severe was wetness in the crawl space. He noted that attic moisture problems occurred only in homes with severely wet crawl spaces.

1.6 Reassessment (90s)

1.6.1 Continuing challenges

**CMHC**

Under contract to Canada Mortgage and Housing Corporation, Sheltair Inc. (1991) concluded for houses in British Columbia:

To some extent the use of crawl space vents in B.C. Housing has been an attempt to compensate for inadequate or ineffective drainage systems and moisture barriers. Field surveys and test results indicate that the crawl space vents are not being installed and operated in a manner consistent with building codes, and that even where vents have been used correctly they are ineffective as a moisture control strategy. It is likely that a better approach would be to eliminate the vents, and apply the capital and operating costs associated with the installation and use of crawl space vents toward improving drainage systems and moisture barriers.

The greatest single factor influencing the generation of moisture in B.C. crawl spaces is the presence (or absence) of an effective moisture barrier.

Quarles (1989) concluded from measured data that several approaches led to acceptable moisture content: standard 1/150 venting (even without ground cover), reduced venting (1/1500) with both 90% and 100% ground cover coverage, and no venting with 100% ground cover coverage. He also noted that soil and wood moisture contents can vary significantly even within a single small crawl space.
1.6.2 ASHRAE Crawl Space symposium

An ASHRAE symposium on “Recommended Practices for Moisture Control in Crawl Spaces” was held in January 1994. From all of the available sources—the previous literature as well as the recent research—several results are prominent:

1. Crawl spaces are dangerously wet. Estimates of the water contribution were made first by Britton, then later by other researchers including Trethowen [1994]. Their results were similar. According to Britton, untreated soil can allow for water evaporation at the rate of 13.2 gallons per 1000 square feet per 24 hours, or 58kg per 100m² per 24 hours. In a survey of homes in Illinois [1987], Rose found that most moisture problems occurred in crawl space houses.

2. Ventilation should not be considered a sufficient moisture control strategy. Samuelson [1994] and Fugler [1994] describe heated crawl space construction where venting is not appropriate or desirable. Tsongas [1994] recommends against venting crawl spaces in the Pacific Northwest as long as a ground cover is in place.

3. Ground covers are the principal element in any strategy of moisture control in crawl spaces. Polyethylene was introduced in the 1950's and has been shown to be effective at reducing the rate of moisture evaporation from crawl space soil. Loosely-laid polyethylene ground covers have been shown to be quite effective. Improved methods of laying ground covers should include taping and sealing the ground cover to the structure and accommodating the inevitable traffic associated with inspection and repair. Flynn et al. [1994] found that a ground cover membrane provided sufficient moisture protection to reduce dangerously high moisture levels in crawl space framing members.

4. Crawl spaces should be inspected regularly. They should be designed for regular inspection, with easy access, good lighting, no debris, and neatly laid and fastened ground covers. The inspection should be to look for any puddling of water on top of the crawl space, for leaks from plumbing or air conditioner condensate, and to assure the structural sufficiency of the floor framing. Crawl spaces should also be inspected for insect pests, termites and vermin.

5. All of the literature, past and present, emphasizes the importance of good drainage around the house. The soil surface should slope outward with a 5% fall for the first 10’ (3m) away from the house, and there should be no basins where water can collect near the house [21]. This is especially important in areas where there are concentrations of water discharge, such as at the discharge of downspouts. If water is allowed to saturate the soil that is in contact with the foundation, it may leak inward and puddle on top of the ground cover. This is to be avoided.

The following conclusions were presented in Rose & TenWolde (1994) for the ASHRAE Crawl Space Symposium:

The reference literature which regulated crawl space construction predates any research in the field. The common experience with crawl space construction has been that crawl spaces are dangerously wet. Ventilation is not a sufficient moisture control strategy in crawl space construction.

All crawl spaces should have ground covers. Ground covers effectively prevent the evaporation of moisture from the soil. Ground covers should cover 100% of the soil, and they should not be covered with gravel or any topping which would tend to hide water puddles.

The soil area around the building that is in contact with the foundation is critical to the proper performance of a crawl space. It should act as a drainage surface that propels surface rainwater away from the foundation and prevents saturation of the soil that is in contact with the foundation.
1.6.3 Modeling

Crawl spaces may be considered in simplified form, thus lending themselves to analytic (computer) modeling. Hagentoft (1986, 1988) of Lund, Sweden took this process forward. His work was used by International Energy Agency Annex 24 on modeling. ASHRAE has participated in the development of Neutral Model Frameworks (NMF), which seeks to provide a uniform language for building modeling such that any analytic engine can be applied to solve the equations. Matilainen and Kurnitski have applied NMF to Nordic crawl spaces in an, as yet unpublished, manuscript.

1.6.4 Recent work

**ICC (Final Draft 1998)**

The following draft language and commentary illustrates the state-of-the-art of moisture control in crawl spaces as it affects code language.

1202.4 The space between the bottom of the floor joists and the earth under any building except such space as is occupied by a basement or cellar shall be provided with ventilation openings through foundation walls or exterior walls. Ventilation openings shall be provided with corrosion-resistant wire mesh, with the least dimension being 1/8 inch (3.2mm). The minimum net area of ventilation openings shall not be less than 1 square foot for each 150 square feet of crawl space area. One such ventilation opening shall be within 3 feet of each corner of said building.

**Exceptions:**

- Ventilation openings may be vented to the interior of buildings where warranted by climatic conditions.

- The total area of ventilation openings may be reduced to 1/1,500 of the under-floor area where the ground surface is treated with an approved vapor barrier material and one such ventilation opening is within 3 feet of each corner of said buildings. The vents may have operable louvers.

- Ventilation openings may be omitted on one side.

- Ventilation openings may be omitted when continuously operated mechanical ventilation is provided at a rate of 1.0 cfm for each 50 square feet of crawl space floor area and the ground surface is covered with an approved vapor barrier.

**Proposal:**

Ventilation openings may be omitted when the ground surface is covered with an approved vapor retarder, the perimeter walls are insulated and the space is conditioned in accordance with the International Energy Conservation Code.

**Proponent:** Ronald W. Clements, Jr. C.B.O. County of Hanover VA on behalf of the Virginia Building and Code Officials Association;

**Reason:** In a number of counties in Virginia, we have allowed as an alternate method crawl spaces to be constructed as unvented conditioned space. This method was proposed to combat a problem found in areas like Virginia with very humid summer months. The problem is that the vents, required by the code, provide a path for moisture to get into the crawl space. Warm humid air from outside comes into the crawl space, where the temperature is cooler, at which point the water in the humid air condenses on the cool surfaces under the house and a moisture problem develops. In essence, the vents do not provide a method for water to vacate the crawl space, they provide a way for it to get into the crawl space. The vapor retarder keeps moisture from the soil out of the space so the only way for water to get in is through the vents. To further improve performance, supply
air from the home’s HVAC system is introduced into the crawl space and the perimeter walls are insulated per the MEC turning the area into conditioned space and in essence you have a short basement that outperforms vented crawl spaces.

Our office receives a substantial number of complaint calls about wet crawl spaces. We have never received a complaint about an unvented conditioned crawl space. No technical data has ever been produced which supports the use of vents in crawl spaces (ASHRAE 1994, 1987) and a number of studies have concluded what we have found in our experience: that unvented crawl spaces outperform vented crawl spaces. The International Energy Conservation Code and the Model Energy Code already address the insulation requirements of unvented crawl spaces. The 1997 edition of the ASHRAE Handbook of Fundamentals, Chapter 23, supports the use of unvented conditioned crawl spaces and the section discussing these concepts has been included for review. A study was conducted by Lynn Stiles of Stockton State College which put vented crawl spaces head to head against unvented crawl spaces. A brief report about the Stiles study has also been included for review.

1.6.5 Cold-climate crawl spaces

Crawl spaces are used in cold climates. Tobin in 1992 showed for crawl spaces in Sweden that ground insulation may be necessary to provide a sufficiently warm crawl space to prevent moisture problems. Such crawl spaces, he noted, should be airtight. Two unfinished works, George (2001) from Alaska and Matinainen (2001) from Finland appear to indicate that temperate zone advice may not pertain to extreme climates. Matinainen shows the value of placement of insulation on the soil surface. George shows from data that no ventilation leads to problems in cold climates.

1.7 Reference works

1.7.1 Model Building Codes

All of the model building codes require venting of crawl spaces, with certain exceptions. The exceptions noted below are those which permit exemption rather than reduction in natural venting requirements.

- **BOCA 1999 1210.2.1:** “…vents shall have manually operable louvers.” 1210.3 Alternative mechanical ventilation: “Enclosed attic rafter and crawl spaces which are not ventilated as herein required shall be equipped with a mechanical ventilation system conforming to the requirements of the mechanical code listed in Chapter 35.”

- **UBC 1994 2317.7:** “Where moisture due to climate and groundwater conditions is not considered excessive, the building official may allow operable louvers…provided the under-floor ground surface area is covered with an approved ground cover.”

- **Standard Building Code 1991 1302.6.3 (4):** “An operable vent louver shall be permitted only where an approved vapor barrier is installed over the ground surface.”

- **CABO One and Two Family Dwelling Code 1995 409.1:** “(1) Ventilation openings may be vented to the interior of the buildings where warranted by
climatic conditions… (4) Under-floor spaces used as supply plenums for distribution of heated and cooled air shall comply with the requirements of Section 2104. (5) Ventilation openings may be omitted when continuously operated mechanical ventilation is provided at a rate of 1.0 cfm for each 50 square feet of crawl space floor area and ground surface is covered with an approved vapor barrier material.”

- **Model Energy Code 1992 602.2.5:** “The exterior walls of crawl spaces below uninsulated floors shall have a thermal transmittance value not exceeding the value given in Table No. 502.2.1 or 502.3.1.” Such transmittance values imply avoidance of air flow through the wall.

1.7.2 **ASTM Moisture Control in Buildings**

Guidance was provided in the ASTM Manual *Moisture Control in Buildings*, (Trechsel, ed., 1994). A contribution by Rose summarizes practice thus:

**Crawl Spaces**

Crawl spaces should be dry. Keeping them dry depends on site surface drainage, described above. Crawl spaces should be inspected seasonally. To encourage seasonal inspection they should be constructed and maintained to be pleasant: access should be relatively easy, light fixtures with an accessible switch should be provided, clearance requirements (usually 18” or 0.5m) should be respected, the soil surface should be level and free of debris.

All crawl spaces require a ground cover over the entire soil surface. This is often a layer of medium strength (6 mil) polyethylene sheeting, although ground covers can be of asphalted felt or concrete. Roofing felts may become brittle with time; concrete can crack if too thin, is more permeable than polyethylene, and is less comfortable on knees than soil or gravel. The ground cover should be strong enough to resist tearing during inspection or repairs. There is no need for ballasting ground covers in crawl spaces; in fact, unballasted ground covers are able to float above rising water in crawl spaces and to resettle in place with minimum evaporation. If a ground cover is damaged, or becomes embedded in soil or buried beneath gravel, a second ground cover can simply be added on top. (The “double vapor barrier” concern does not apply.)

Crawl spaces should be inspected regularly. The inspector should look for exposed soil, puddles of water on top of the ground cover (which may be due to seepage through the foundation walls, plumbing leaks or air conditioner condensate), and mold, mildew or fungal growth on the floor framing overhead. Even dry crawl spaces may show signs of having had puddling and water accumulation. The source of any water should be located and corrected. Crawl space inspections for mobile homes should include an inspection for any possible water accumulation in the bottom board or belly paper. A crawl space inspection may also include a check of ductwork and other mechanical systems.

The living space should be insulated from the outdoors at the crawl space. There are two common insulating strategies: insulating the crawl space walls, and insulating the floor framing. Table 2 gives the advantages and disadvantages of each approach.

An additional concern for floor-insulated crawl spaces occurs in areas with high ambient (outdoor) humidity and cold soil temperatures. In this case, insulated floor joists may be chilled by radiant exchange with the cooler soil. If the bottoms of the joists are cooled below the dew point temperature of outdoor air, then the moisture provided by ventilation may keep the floor joists near saturation. A review of local soil temperatures and ambient humidities should indicate whether or not this is a local problem.

The band joist is the outside perimeter floor framing member. In cold weather it may be a site for moisture condensation within wet crawl spaces. Frequently, insulating materials are applied to the
band joist from the inside, which has the effect of lowering the surface temperature of the band joist, and increasing the likelihood of moisture damage. Obviously, the band joist must be protected from humid air. The first step is to keep the crawl space dry. Further protection may be afforded to the band joist by covering the band joist insulation with a vapor-retarding material.

Building codes require that crawl spaces be provided with ventilating openings [CABO R-309.1]. The ventilation openings of wall-insulated crawl spaces are often closed in the interest of energy conservation. This strategy appears workable, provided the crawl space remains dry.

Crawl spaces should not be used as a plenum in any recirculating heating or cooling system. Problems with such an approach include not only moisture but also radon and soil treatment chemicals. Some designers successfully use the crawl space as an exhaust plenum in a mechanical house ventilation system. Such a design provides some protection against the movement of crawl space gases (including possibly moisture, radon and soil treatment chemicals) into the living space.

1.7.3 ASHRAE 2001 Handbook of Fundamentals

The guidance provided by ASHRAE 2001 Handbook of Fundamentals Chapter 24 is as follows:

Crawl Spaces

Moisture problems generally occur when improper drainage or grading around the house lead to wet soil or even standing water in the crawl space. Evaporation of moisture then causes high humidity in the crawl space and often in the rest of the building, and sometimes leads to high moisture content in wood framing members in the floor and in the band joist (header joist). Any source of subfloor warmth (heating ducts, furnaces) is likely to seriously increase the evaporation from wet subfloor soil (Trethowen and Middlemass 1988, Trethowen 1988). Providing proper drainage of water away from the foundation is critical for moisture control (ASHRAE 1994). Dewatering techniques, including sump pumps, drain tiles, etc., should be used to keep the soil in the crawl space as dry as possible. Ground covers that restrict evaporation of water from the soil into the crawl space provide an effective way to prevent moisture and humidity problems. It is important to seal any ducts in the crawl space, to avoid venting clothes dryers into the crawl space, and to repair any leaking water pipes. A minimum clearance of 18 in. between the crawl space soil and the underside of any wood framing members is recommended and often required. Good access into and around the crawl space is very important.

Whether or not to ventilate a crawl space has been a controversial issue. Most building codes require installation of vents to provide ventilation with outside air, but a symposium on crawl space design concluded that there is no compelling technical basis for crawl space ventilation requirements (ASHRAE 1994). There must be a distinction between conditioned and unconditioned crawl spaces. Conditioned crawl spaces have insulated perimeter walls and may contain plumbing and heating runs. Conditioned crawl spaces should not be ventilated with outdoor air. If air circulation is desired, indoor air should be used. One way to accomplish this is by exhausting indoor air through the insulated crawl space, which may be done in conjunction with an air-to-air heat exchanger for energy efficiency (Samuelson 1994). Unconditioned crawl spaces have an insulated floor above the crawl space. Ventilation with outside air is permitted but not always necessary. Unvented crawl spaces must have a ground cover, which should cover 100% of the crawl space soil. Ground cover treatments for conditioned and unconditioned crawl spaces are similar.

The ground cover material should have a permeance of no more than 1.0 perms and must be rugged enough to withstand foot and knee traffic. The most commonly used material is 6 mil (0.006 in.) polyethylene. The membrane ground cover may be covered with a thin slab of concrete to prevent entry of rodents. Before laying the membrane, all debris must be removed and the soil leveled. Edges need only be lapped 4 to 6 in., and no sealing is required. The membrane need not be carried up the face of the wall.
If control of entry of radon or other soil gases is desired, a minimum 6 mil (0.006 in.) polyethylene ground cover is recommended. Some have recommended that the ground cover should be weighted down and sealed at the perimeter and overlaps to retard radon entry, but others argue that weighting and sealing may lead to water ponding on top of the ground cover. If radon control is not of primary importance, the ground cover may be cut in several low spots to help drainage should ponding occur. The primary intended function of the ground cover (i.e., moisture control or radon control) should govern the decision on this issue.

1.7.4 Moisture Control Handbook

Lstiburek has illustrated crawl space construction practice in the Moisture Control Handbook (Lstiburek and Carmody 1994) and in the series of Builders Guides (Lstiburek 2000). His guidance is direct: “Constructing vented crawl spaces [in mixed humid climates] is a bad idea…Venting a crawl space with exterior, humid air during summer months leads to the wetting for crawl space assemblies…Crawl spaces should be constructed like mini-basements.”

1.7.5 International Building Code and International Energy Conservation Code

2000 International Building Code

1202.3 Under-floor ventilation. The space between the bottom of the floor joists and the earth under any building except spaces occupied by a basement or cellar shall be provided with ventilation openings through foundation walls or exterior walls. Such openings shall be placed so as to provide cross-ventilation of the under-floor space.

1202.3.1 Openings for under-floor ventilation. The minimum net area of ventilation openings shall not be less than 1 square foot for each 150 square feet of crawl space area.

Ventilation openings shall be covered for their height and width with any of the following materials, provided that the least dimension of the covering shall not exceed ¼ inch.

1. Perforated sheet metal plates not less than 0.070 inch
2. Expanded sheet metal plates not less than 0.047 inch thick.
3. Cast iron grills or gratings
4. Extruded load bearing vents
5. Hardware cloth of 0.035 inch wire or heavier.
6. Corrosion resistant wire mesh, with the least dimension not exceeding 1/8 inch.

1202.3.2 Exceptions. The following are exceptions to sections 1202.3 and 1202.3.1:

1. Where warranted by climatic conditions, ventilation openings to the outdoors are not required if ventilation openings to the interior are provided.
2. The total area of ventilation openings is permitted to be reduced to 1/1,500 of the under-floor area where the ground surface is treated with an approved vapor retarder material and the required openings are placed so as to provide cross-ventilation of the space. The installation of operable louvers shall not be prohibited.
3. Ventilation openings are not required where continuously operated mechanical ventilation is provided at a rate of 1.0 cfm for each 50 square feet of crawl space floor area and the ground surface is covered with an approved vapor retarder.
4. Ventilation openings are not required when the ground surface is covered with an approved vapor retarder, the perimeter walls are insulated and the space is conditioned in accordance with the International Energy Conservation Code.

5. For buildings in flood hazard areas as established in Section 1612.3, the opening requirements of ASCE 24 are authorized to be satisfied by ventilation openings that are designed and installed in accordance with ASCE 24.

1208.1 Crawl Spaces. Crawl spaces shall be provided with a minimum of one access opening not less than 18 inches by 24 inches.

1806.1.2 Underfloor Space. The finished ground level of an underfloor space such as a crawl space shall not be located below the bottom of the footings. Where there is evidence that the ground water table rises to within 6 inches of the ground level at the outside building perimeter or where there is evidence that the surface water does not readily drain from the building site, the ground level of the underfloor space shall be as high as the outside finished ground level, unless an approved drainage system is provided. The provisions of Sections 1802.2.3, 1806.2, 1806.3 and 1806.4 shall not apply in this case.


502.2.1.3 Crawl space walls. If the floor above a crawl space does not meet the requirements of section 502.2.3.2 and the crawl space does not have ventilation openings which communicate directly with outside air, then the exterior walls of the crawl space shall have a thermal transmittance value not exceeding the value given in Table 502.2. The U-value of the wall shall be determined by selecting the U-value for the wall section from Appendix Table 502.2.3.5. Where the inside ground surface is less than 12 inches below the outside finish ground level or the vertical wall insulation stops less than 12 inches below the outside finish ground level, crawl space wall insulation shall extend vertically and horizontally a minimum total distance of 24 inches linearly from the outside finish ground level [see Appendix Details 502.2.1.5(1), 502.2.1.5(2), and 502.2.1.5(3), and the DOE Foundation Design Handbook.]

502.2.1.5 Crawl space walls. (Similar to 502.2.1.3)

These citations of the International Building Code 1202.3.2 (1) and (4) introduce the possibility of crawl spaces with no vents in two cases: 1) where “ventilation openings to the interior are provided” and 2) where the ground surface is covered with an approved vapor retarder, the perimeter walls are insulated and the space in conditioned in accordance with the IECC. It is unclear what is meant by “openings to the interior”, though one may presume it refers to air exchange between the conditioned space and the crawl space sufficient to condition the space. More interesting is exception (4) in which it appears that a crawl space with a ground cover and particular insulation levels may be exempt from the ventilation requirement. The appropriateness and sufficiency of this code provision deserves careful study.

1.8 Conclusions

The aim of this report has been to survey the history of crawl space ventilation regulation. A timeline of the significant events is included at the end of this report.

There has been very little research on the performance of crawl spaces. The research that has been done has been summarized in this report. There has been no collection of baseline data (despite the 1962 call by BRAB for such data), so there is not means of
determining whether practices improve performance or not. Most of the writing on crawl spaces has been derived from anecdote or professional investigation, and it involves guidance to professionals through interpretation and rewording of previous writings.

Research on crawl space performance is greatly hampered by the inherent difficulty of quantifying the principal determinants of performance. These include:

- **Rates of water evaporation from soil.** These have been addressed only by Britton (1948) and Trethowen (1994).

- **Effectiveness of ground covers.** Moses and others have recorded permeance values for ground cover materials. However, no researchers have measured the effect of sealing seams and edges. Likewise, no researchers have addressed the likelihood of water accumulation on the top of the ground cover.

- **Air change rates.** DeWitt has characterized flow rates under pressure regimes for vent devices used in crawl spaces. However no one has developed or applied methods of measuring air change rates for crawl spaces. No one has characterized the rates of air change between the outdoors and the crawl space, nor between the living space and the crawl space.

- **Pressure regimes.** No one has characterized the pressures acting on crawl spaces (from outside and as part of house stack flow), so the driving forces for air flows are not known.

- **Effect of rainwater management.** No one has studied the effect of rainwater management on the water contribution to the crawl space. No one has studied the common observation that vents installed near, at or below grade level serve as conduits for the influx of surface rainwater.

- **Mold.** Outside of individual case studies, no one has quantified mold growth in crawl spaces, nor correlated mold growth with measured values of temperature and humidity.

- **Variability of findings.** No one has succeeded at this point of demonstrating that construction and soil conditions can be of such uniformity that similar conditions are demonstrated.

- **Energy Analysis.** While research has been done on the various energy components (insulation, duct leakage, air leakage, etc.) that are found in crawl space systems, no one has conducted a comprehensive modeling study of energy performance.

Those who model crawl space performance appear to be able to arrive at parameters of water contribution and air exchange that match measured data sets within certain limits (Shipp 1982, Matinainen 2001). New research could make a significant contribution, but research planning must be cognizant of the difficulties presented above.

The most commonly-used measure of crawl space moisture performance is the moisture content of exposed wood material. Many researchers use wood moisture content of 20%
as a threshold between acceptable and unacceptable moisture performance (Duff, Quarles).

The first regulation that addressed crawl spaces were those of the Federal Housing Administration. They predated dependable ground covers and they called for venting. Several exceptions appeared over time.

- In the earliest appearance of venting regulations, crawl spaces which were adjacent to basements were permitted exemption for any exterior venting requirements, provided there were openings between the crawl space and the basement.
- Reductions to 10% of the previous values with a ground cover in place appeared in Minimum Property Requirements documents of 1947.
- Where a crawl space is used as a plenum, exemption of venting was permitted under 1958 Minimum Property Requirements.
- Operable vents are permitted by the model building codes.
- Mechanical ventilation of crawl spaces is an allowed alternative to natural venting under CABO, BOCA and IBC.
- Conditioning with indoor air provides exemptions from venting requirements under CABO and IBC
- Insulation, ground cover and compliance with IECC form an exemption under IBC.

Changes to building codes should begin with an assessment of their perceived mission. Should building codes seek to achieve moisture control in buildings? On the one hand, their “health, safety and welfare” mission might indicate that they must assume moisture control responsibility. If so, that carries the obligation to make moisture control effective and not symbolic. On the other hand, building codes might recognize that effective moisture control does not lend itself to prescription, and thus they might admit that moisture control is the proper domain of the design and construction professionals. If that is the case, they should recognize that current moisture control provisions are unhelpful and troublesome and should be dropped.

Measured data on crawl space temperatures and humidity conditions have been presented. Most of the pertinent data has been collected and published in ASHRAE Technical Data Bulletin Vol. 10, no. 3. Recommended Practices for Controlling Moisture in Crawl Spaces. Measurements from large numbers of buildings have not been conducted. There has not, as yet, been published research on large data sets regarding pressure relationships, air leakage rates for crawl spaces, or air quality conditions associated with crawl spaces.
### Timeline, crawl space vent regulation:

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1920</td>
<td>1923 FHA recommends “7%” of footprint size be vented.</td>
</tr>
<tr>
<td>1930</td>
<td>1935 FHA recommends venting of basementless spaces, warns of possible moisture problems.</td>
</tr>
<tr>
<td>1940</td>
<td>1942 FHA specifies venting ratio for “basementless spaces”.</td>
</tr>
<tr>
<td></td>
<td>1947 Britton (HHFA) compiles investigation of findings on “crawl spaces”.</td>
</tr>
<tr>
<td></td>
<td>1948 BOCA Basic Building Code adopts crawl space venting ratio requirement.</td>
</tr>
<tr>
<td>1950</td>
<td>Early 1950s Polyethylene sheet is introduced into construction industry.</td>
</tr>
<tr>
<td></td>
<td>1954 HHFA introduces concept that vents may be closed</td>
</tr>
<tr>
<td></td>
<td>1959 Small Homes Council recommends “closed” construction for crawl spaces.</td>
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<td>1960</td>
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<tr>
<td>1970</td>
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<tr>
<td>1980</td>
<td>1980s Research by FPL.</td>
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<tr>
<td>1990</td>
<td>1994 ASHRAE Symposium finds no justification for current venting requirements.</td>
</tr>
<tr>
<td>2000</td>
<td>2000 IBC and IECC include provisions for crawl spaces without ventilation.</td>
</tr>
</tbody>
</table>
1.9 References


FHA. 1935. Property Standards: Requirements for Mortgage Insurance under Title II of the National Housing Act, U.S. Federal Housing Administration, Washington DC, revised February 1935.


SHC. January 1959. Crawl space houses. Small Homes Council, University of Illinois, Urbana, IL.


Moses. C.S. October 1952. Durability of moisture-resistant membrane materials in contact with the ground. Housing Research, No. 4, Housing and Home Finance Agency, Washington DC.


Quarles, S.L. 1989. Factors influencing the moisture conditions in crawl spaces. Forest Products Research Society. vol. 39 no. 10


Published in *Recommended Practices for Controlling Moisture in Crawl Spaces*, ASHRAE Technical Data Bulletin volume 10, number 3.


Chapter 2: Residential Building Code Inquiry

2.1 Overview

Central to any campaign designed to improve crawl space construction is a strong focus on the building code provisions that regulate this foundation system. The technology assessment of existing building code regulation revealed many flaws that need corrections. Chapter 2 presents the culmination of this inquiry. The contents of which are a letter to and response from the Building Officials and Code Administrator International (BOCA) clarifying various provisions of the International Regulatory Commission (IRC) with respect to crawl space construction.

The immediate benefit of the BOCA inquiry response is the clarification of several confusing code provisions and resulting field interpretations pertaining to approved vapor retarders, crawl space ventilation requirements and the use of foam plastic insulation.

Beyond these needed clarifications, the inquiry lays the groundwork for the preparation of code change proposals that would address the results and findings of ongoing project research. As is pointed out strongly in Chapter 1, current crawl space regulation for moisture control is not based on definitive research. This assertion is supported by the BOCA response, which traces the source of current crawl space wall venting requirements to a 1979 opening hearing of the Board of Cooperation of the Model Codes (BCMC). The technical basis given in the attached BCMC report from this meeting is that the 1979 wall venting provisions are simply “state-of-the-art”.

Much of the key element in the debate regarding crawl space moisture control is reflected in the concluding statement made on the third page of the BOCA response letter:

“*We recognize that there is a considerable amount of dispute among the building science, academic, and design communities regarding the role of exterior venting in keeping crawl spaces dry. In some climates, such vents may add moisture to crawl spaces by allowing entry of warm and moist exterior air into the crawl space and increasing moisture through condensation. Most building codes do call for natural ventilation by way of screened crawl space vents meeting minimum opening requirements or alternatively mechanical ventilation of these under floor (crawl) spaces.*”

While BOCA acknowledges the crawl space air moisture load physics, the impact is made conditional by the use of the qualitative phrase, “*In some climates, such vents may add moisture to crawl spaces...*”. Ongoing project research is directed at providing a clear understanding of the range of climates affected and the extent of moisture and related causes introduced by wall vents.

The BOCA response also confirms the existence of a significant thermal performance problem. Builders that seek to build thermally improved wall insulated crawl spaces, are significantly impacted by the fire and termite protection provisions that limit the use of foam plastic insulation. Further work must be done in this area that will allow builders to construct code approved, thermally efficient, wall insulated crawl spaces.
2.2 Letter to BOCA

November 21, 2001

Mr. Darren Meyers
Building Officials and Code Administrators, Inc.
4051 West Flossmoor Road
Country Club Hills, IL 60478

Reference: Code inquiry on residential crawl space building code provisions

Dear Mr. Meyers:

This letter follows our phone conversation on November 19. I write to seek clarifications of intent for residential building code provisions regarding crawl space construction. This inquiry is part of a technology assessment being performed for the crawl space project, a research and commercialization effort designed to improve the moisture, indoor air quality and thermal performance characteristics of residential crawl space construction. This project is primarily funded by the U.S. Department of Energy. The project is being conducted and co-funded by Advanced Energy, a nonprofit organization that works to improve industrial process and building performance (www.advancedenergy.org).

PERTAINING TO THE 2000 INTERNATIONAL RESIDENTIAL CODE (2000 IRC)

1) With reference to Section R408.1 and 2
   a. Neither of these 2 provisions calls for the use of a vapor retarder on the ground surface. Does this omission mean that a wall vented crawl space (constructed to the 1/150 sizing requirement) can be built without any vapor retarder barrier being installed on the ground surface? Are there any other provisions in the 2000 IRC that require a vapor retarder on the crawl space ground surface?
   b. What is the technical basis for the 1/150 sizing requirement?
   c. The first 2 sentences of R408.2 are a virtual restatement of the last 2 sentences of R408.1. For the sake of clarity, could the first 2 sentences of R408.2 be deleted?

2) With reference to Section R408.2, Exception 1:
   a. Please define what the opening sentence phrase “Where warranted by climatic conditions” means. What climatic conditions allow ventilation openings to the outdoors to be deleted by instead providing ventilation openings to the interior?
   b. What constitutes “openings to the interior”? Are these registers, doorways, air leakage holes through the floor, etc?

3) With reference to Section R408.2, Exception 2:
   a. What is the technical basis for the 1/1,500 sizing requirement?
   b. Relative to the 1/1,500 sizing requirement, is the intent of the phrase “cross ventilation” to require that at least 2 crawl space wall vents be installed on crawl spaces that are less than 1,500 sf?
   c. What materials can be used as an “approved vapor retarder material”?
   d. Are there any requirements for the percentage of ground surface that must be covered with the vapor retarder material?

4) With reference to Section R408.2, Exception 4:
   a. Which of the following ventilation strategies meet the intent of providing “mechanical ventilation”?
      i) A supply fan that pressurizes the crawl space with make-up air from the house, attic or outside.
ii) An exhaust fan that depressurizes the crawl space with make-up air from the house, attic or outside.

iii) A circulating fan in the crawl space

iv) Supply air to and/or return air from registers in the house duct distribution system.

5) With reference to Section R408.2, Exception 5:
   a. What is meant by the phrase “supplied with conditioned air”? Is this heated, cooled, dehumidified, and/or filtered air?
   b. Does the air have to be supplied from the house air or can just the air in the crawl space be conditioned, such as by installing a dehumidifier in the crawl space?

6) With reference to Section N1102.1.7 and R324.4, Exception 3, regarding the installation of interior crawl space wall insulation.
   a. N1102.1.7 calls for interior wall insulation to be installed “downward from the sill plate to the exterior finished grade level; whereas R324.4, Exception 3 does not list crawl space walls as an exception to the 6” clearance gap between exposed earth and foam plastic insulation. Can plastic foam insulation be installed continuously on the interior of crawl space walls in contact with the crawl space ground surface?
   b. Are there any other 2000 IRC provisions that require the installation of a termite view strip or other forms of termite protection regarding the installation of any type of insulation on the interior walls of a crawl space?

BEYOND THE 2000 IRC:

This crawl space project covers states in the U.S. census South region. These states are:

   South Atlantic: DE, DC, FL, GA, MD, NC, SC, VA, and WV
   East South Central: AL, KY, MS, and TN
   West South Central: AR, LS, OK, and TX

Are you aware of any state or local municipal provisions in these states that differ from the provisions in the 2000 IRC regarding crawl space ventilation, moisture control and wall insulation termite protection?

Thank you very much for your assistance in this matter. Please contact me by phone (919/933-8151) or email (warrenb@nc.rr.com) if you have questions or need more information to respond to this inquiry.

Sincerely

Bill Warren
warrenb@nc.rr.com
Project Manager
Crawl Space Research and Commercialization Project
BWES Building Science Consulting
6214 Lance Street
Chapel Hill, NC 27514
919/933-8151 fax: 919/933-6300
2.3 BOCA Response

December 7, 2001

Mr. Bill Warren, Project Manager
Crawlspace Research and Commercialization Project
C/o Advanced Energy
909 Capability Dr., Suite 2100
Raleigh, NC 27606-3870

RE: Sections R202, R324, R408, R506 and R1102 of the ICC International Residential Code/2000 (IRC)

Mr. Warren,

This letter is in response to our telephone conversation of November 19th, 2001 and your subsequent letter of November 21st, 2001, wherein you posed several questions regarding the provisions of the IRC. In the interest of clarity, we may have consolidated and rephrased some of your questions. Our answers to your questions are as follows:

Q1? Your first question asks whether a crawl space can be built without a vapor retarder, and asks for the basis of the 1/150 sizing requirement?

Conditionally, No. Sections R408 and N1102.1.7 of the IRC contain requirements specific to under-floor (crawl) space construction. As such, Section N1102.1.7 would require the installation of a vapor retarder only where crawl space foundations feature an "exposed earth" condition. Certainly there exist innovative crawl space construction practices which do not feature an "exposed earth" condition. Even so, where a nominal “scrim-slab” is poured to serve as the floor of the crawl space, the construction requirements of Section R506.2.3 dictate the omission of the vapor retarder only in specific circumstances. So in all but the most remote circumstances, a vapor retarder is required for under-floor (crawl) space construction.

The 1/150 sizing requirements can be traced back to the open hearings, oral testimony and written comments received by the Board for Coordination of the Model Codes (BCMC) during their July, 1979 open hearing. An excerpt of the salient points from BCMC’s July 15th, 1979 Open Hearing Report as applicable to ventilation of underground spaces is attached for your utility.

Q2? In your second question, you request that we describe the “climatic conditions” that would permit opening the underfloor (crawl) space to the interior, and exactly what those “openings to the interior” might be?

Simply stated, the exception gives the authority having jurisdiction the latitude to establish whether moisture condensation is likely in underfloor (crawl) spaces based on geographic location, climatic conditions unique to specific areas within a jurisdiction or other localized experience derived from valid experimental evidence or observation. Through reasonable interpretation of the code, the phraseology, “openings to the interior,” means any opening in the building thermal envelope that communicates with or connects the underfloor (crawl) space to the conditioned space.

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Q3? Your third question asks for the intent behind the phraseology, "cross ventilation" as found in Section R408.2, the material performance characteristics of "approved vapor retarders," and the percentage of ground surface that must be covered by a vapor retarder where required? For the technical basis of the 1/1,500 sizing requirement please see our answer to Q1? above.

Note that where terms are not defined through the methods authorized by the IRC or in other code publications of the ICC, such terms shall have ordinarily accepted meanings such as the context implies. However, through reasonable interpretation of the code, the phraseology, "cross ventilation" could be defined as follows: The natural or mechanical circulation or flow of air through openings, such as doors, windows, or supply, exhaust or return openings that are on opposite sides of a room or space.

The performance requirements for vapor retarders can be located by reference to the definition of a VAPOR RETARDER (see Section 202).

Mindful of our response to Q1?, and through reasonable interpretation of the provisions found in Sections R506.2.3 and N1102.1.7, one-hundred percent (100%) of the ground surface would be required to be covered by the vapor retarder.

Q4? Which of the following ventilation strategies meet the intent of providing "mechanical ventilation," that is consistent with Exception 3, 4 or 5 to Section R408.2?

i) A supply fan that pressurizes the crawlspace with make-up air from the house, attic or outside; or

ii) an exhaust fan that depressurizes the crawlspace with make-up air from the house, attic or outside; or

iii) a circulating fan in the crawlspace; or

iv) supply air to and/or return air from registers in the house duct distribution system.

Provided the criteria in Exception 3, 4, or 5 are addressed as applicable, in our opinion, all strategies (with the exception of Strategy iii) appear to meet the intent of the code. Note that a "circulating fan" alone would serve no purpose if there were no way to evacuate moisture from the under floor (crawl) space.

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35
Q5? Your fifth question is predicated on a determination of what constitutes conditioned space?

A conditioned space is any space that does not communicate directly to the outside and that meets one of the following criteria:

- The space has a heating and/or cooling supply register; or
- The space has heating and/or cooling equipment designed to heat and/or cool the space; or
- The space contains uninsulated ducts or uninsulated hydronic heating surfaces; or
- The space is inside the building envelope.

See also the IRC definition for CONDITIONED SPACE (see Section 202).

Q6? Your sixth and final question asks whether Exception 3 to Section 324.4 permits foam plastic insulation to be installed in contact with the under floor (craw) space ground surface?

No. Exception 3 to Section 324.4 is specific to basement walls. Through reasonable interpretation of the code, it would appear that the combined effect of Sections 324.4 and 1102.1.7 on crawl space wall insulation requirements in areas of "very heavy" termite infestation probability favor the insulation of the floor over the crawl in lieu of insulating the walls of the under floor (crawl) space. Section 324 contains the provisions specific to protection against termites in the IRC.

Your remaining questions seem to touch on the idea of suggesting code changes to the IRC. As a reminder, any interested person, persons or group may submit a code change proposal which will be duly considered when in conformance with the Code Development Process Rules of Procedure for the International Codes. The Rules of Procedure may be obtained directly from the ICC web site at www.iccsafe.org.

We recognize that there is a considerable amount of dispute among the building science, academic and design communities regarding the role of exterior venting in keeping crawl spaces dry. In some climates such vents may add moisture to crawl spaces by allowing entry of warm and moist exterior air into the crawl space and increasing moisture through condensation. Most building codes do call for natural ventilation by way of screened crawl space vents meeting minimum opening requirements or alternatively, mechanical ventilation of these underfloor (crawl) spaces.

We hope this letter answers your question(s) in full. If you need further assistance, please feel free to call me directly at (708) 799-2300 Ext. 307.

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December 7, 2001
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The above opinion is based solely on the information which you have provided. We have made no independent effort to verify the accuracy of your submitted information nor have we conducted a review beyond the scope of your question. As this interpretation is only advisory, please consult with the authority having jurisdiction, the code official.

Very truly yours,

Darren B. Meyers, EIT
BOCA Technical Staff

Endorsements:  BCRC Report, July, 1979
CABO CC 79-33
THE BOARD FOR THE COORDINATION
OF THE MODEL CODES

OPEN HEARING REPORT
July 19, 1979
9:00 A.M.
Knoxville Hyatt Regency Hotel
Knoxville, Tennessee

AGENDA

1.0 Standby Power and Emergency Systems for High-Rise Buildings
2.0 Loads
3.0 Ventilation
4.0 Safety Glazing
5.0 Covered Mall Buildings
6.0 Roof Coverings
7.0 Automatic Sprinkler Systems
8.0 Pile Foundation Systems

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INTRODUCTION

The Board for the Coordination of the Model Codes (BCMC) in an effort to comply with their charge from the Council of American Building Officials (CABO) Board of Directors to eliminate conflicts in the model codes has compiled this hearing agenda. The items on the agenda are based on the determinations of BCMC since the last open hearing (July 21, 1978). These items may be modified after public hearing; the results of the hearing will be presented to the CABO Executive Committee with the recommendation that they be sent through the individual code change processes of the three model code groups.

The open hearing on items in this agenda will be held on July 19, 1979 at 9:00 a.m. and continue until completion. The location will be the Knoxville Hyatt Regency Hotel, 500 Hill Avenue, Knoxville, Tennessee 37901 (615/637-1234).

Oral and written comments are invited from all interested parties. Written comments received in the BOCA office prior to July 13, 1979 and those received at the public hearing will be read into the record. BCMC will make a final recommendation to the Board of Directors of CABO after consideration of the information received at the public hearing. All comments should be addressed to the BOCA office at 17926 South Halsted Street, Homewood, Illinois 60430.

The subjects included in this agenda were considered by BCMC Meetings in Los Angeles, California, August 22-23, 1978; Houston, Texas, October 12-13, 1978; Rosemont, Illinois, January 31-February 1, 1979; and Kansas City, Missouri, April 18-19, 1979.

Please notice that many of the subjects contained herein are not complete revisions and/or text on the subject but are intended to portray those provisions with which conflicts have been identified in the model codes and coordination needed. Your comments are appreciated.
2.7 Combination of loads

2.7.1 General: Loads listed herein shall be considered to act in the following combinations, whichever produce the most unfavorable effects in the building, foundation, or structural member concerned, reduced when appropriate, according to Section 2.3. The most unfavorable effect may occur when one (1) or more of the contributing loads are not acting:

1. dead load
2. dead load plus live load
3. dead load plus (wind load or earthquake load),
4. dead load plus thermal load,
5. dead load plus live load plus (wind load or earthquake load),
6. dead load plus live load plus thermal load,
7. dead load plus (wind load or earthquake load) plus thermal load, and
8. dead load plus live load plus (wind load or earthquake load) plus thermal load.

Thermal load is the loads, forces, and effects due to contraction or expansion resulting from temperature changes, shrinkage, moisture changes, creep in component materials, movement due to differential settlement or combinations thereof.

2.7.2 Probability factor: The total of the combined load effects may be multiplied by the following load combination factors. An increase in the allowable stresses will not be allowed in conjunction with the decrease due to the above load combinations.

1. 1.00 for combinations 1 through 4 listed in Section 2.7.1 above.
2. 0.75 for combinations 5 through 7 listed in Section 2.7.1 above.
3. 0.66 for combination 8 listed in Section 2.7.1 above.

2.7.3 Stress Increases: All allowable stresses and soil-bearing values specified in this Code for working stress design may be increased one-third when considering wind or earthquake forces either acting alone or when combined with vertical loads. No increase will be allowed for vertical loads acting alone.

Reason: ECBC reviewed sections 7.17 of the BCC, 1205 of the SBC and 7303 of the UBC and determined that these provisions are appropriate.

3.0 Ventilation
3.1 Roof spaces: Where determined by the Building Official due to atmospheric or climatic conditions, enclosed attics and enclosed rafter spaces formed where ceilings are applied direct to the underside of roof rafters, shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain and snow. The net free ventilating area shall be not less than 1/150 of the area of the space ventilated, except that the area may be 1/300 provided at least 50 percent of the required ventilating area is provided by ventilators located in the upper portion of the space to be ventilated at least 3 feet above eave or cornice vents with the balance of the required ventilation provided by eave or cornice vents.

3.2 Foundation spaces. Underfloor areas shall be ventilated by an approved mechanical means or by openings in exterior foundation walls. Such openings shall have a net area of not less than 1/4 square feet for each 25 linear foot of exterior wall. Openings shall be located as close to corners as practicable and shall provide cross ventilation on at least two approximately opposite sides. They shall be covered with corrosion resistant mesh not less than 1/8 inch nor more than 1/2 inch in any direction.

1. Openings shall have a net area of not less than one (1) sq. ft. for each one hundred fifty (150) sq. ft. of crawl space.

2. Where an approved vapor barrier is installed over the ground surface, the required net area of openings may be reduced by fifty (5) percent.

Reason: ECMA reviewed sections 507 of the BBC, 3202c of the UBC and 1302.5e of the BBC and determined that the above text represents the state-of-the-art.

4.0 Safety Glazing

4.1 Louvered windows or jalousies: Regular plate, sheet or patterned glass in jalousies and louvered windows shall be no thinner than nominal 7/32 inch and no longer than 48 inches. When other glass types are used, design shall be submitted to the Building Official for approval. Exposed glass edges shall be smooth.

Wired-glass with wire exposed on longitudinal edges shall not be used in jalousies or louvered windows.

4.2 Labeling: Each light shall bear the manufacturer's label designating the type and thickness of glass. When approved by the Building Official labels may be omitted from other than safety glazing materials provided an affidavit is furnished by the glazing contractor certifying that each light is glazed in accordance with approved plans and specifications.

To qualify as glass with special performance characteristics, each unit of laminated, heat strengthened, fully tempered, and insulating glass shall be permanently identified by the manufacturer. The identification shall be etched or ceramic fired on the glass and be visible when the unit is glazed. Heat strengthened and tempered spandrel glasses are exempted from permanent labeling. This type of glass shall be labeled with a removable paper label by the manufacturer.
Revise the first paragraph of Section R-509 as follows:

**Underfloor Crawlspace:**

Section R-509. The space between the bottom of the floor joists and the earth under and building (except such space as is occupied by a basement or cellar) shall be provided with a sufficient number of ventilating openings through foundation walls or exterior wall to insure ample ventilation, and such openings shall be covered with a corrosion-resistant metal wire mesh not greater than 1/2 inch nor less than 1/4 inch in any dimension. The minimum net area of ventilating openings shall be 1 square foot per 100 square feet of building. Each 100 linear feet of exterior wall shall have 1/4 square feet for each 100 square feet of crawlspace area. Such ventilating openings shall be within three feet of each corner of said building.

**Reason:** To clarify intent of code and to be consistent with recent recommendations.
Chapter 3: Assessment of current crawl space technology

3.1 Overview

Crawl spaces are widely used in building construction throughout North America. They are cheap to build, functional in terms of providing a level foundation for flooring on sloping sites, and popular as spaces in which to locate plumbing, ductwork, and heating systems. Crawl spaces are also the source of a host of moisture, mold, indoor air quality, and thermal problems.

For the better part of a century, conventional knowledge has held that crawl spaces need to be ventilated to allow moisture that percolates up from the ground and evaporates into the crawl space air a means of escape. Subsequently, virtually all crawl spaces are built with wall vents. These vents are typically 8x16” openings covered with a wire mesh or grate to keep animals and insects out. Very few site-built homes have sealed crawl spaces, that is, crawl spaces with insulated walls and no wall vents.

However, research has shown that despite their intended design, wall-ventilated crawl spaces frequently incur moisture problems and degrade the thermal integrity of the building. As currently constructed and used over time, wall-ventilated crawl spaces can compromise the occupants’ health and cost them money in terms of unnecessarily high energy bills and building repairs. In short, crawl space design needs to be improved.

3.2 Typical crawl space components

Components that make up a crawl space system include the foundation elements (footings, walls, and beam piers), the floor (bare earth or concrete slab), moisture control elements (ground moisture barrier, wall vents, drainage, and moisture proofing), the house floor system (joist beams, sills, joists and subflooring), insulation, and an access panel or door.

The footing supports the exterior walls and internal beam piers. Builders favor using inexpensive trench footings for crawl spaces, as opposed to the formed footings used in basement construction. Trench footings are dug with a backhoe and the footing will be exactly as wide as the blade scoop. Concrete is poured in to fill the trench and cover over reinforcing rods. Trench footings leave no room for drainage pipe and gravel to be installed at the level of footing. Usually no polyethylene moisture barrier is installed under footing. Sloped sites require a stepped foundation.

Crawl space walls and beam piers are laid on top of the footing. Crawl space walls are typically made of masonry block, masonry block and brick, or block piers with a brick curtain wall. Some crawl spaces employ a partial wood stud wall installed in stepped foundations. The first part of the wall is masonry and then switches to wood frame. These wood-framed pony or knee walls allow the bottom edge of siding to be brought down closer to the ground. Frame walls get exterior sheathing and siding but no interior finish.
Crawl space floors are usually bare earth. Earth floors are cheap, although they generate a considerable amount of moisture. They require minimal work in terms of excavation and leveling and finish. Many crawl spaces are built without any work done on the earth floor. High crawl spaces will often have a small concrete floor slab at the entrance. The slab provides a raised durable surface to store items on such as lawnmowers.

The ground moisture barrier in a crawl space is usually made up of large sheets of 4 or 6 mil polyethylene. “Poly” serves as a vapor diffusion retarder and water barrier that minimizes ground moisture evaporation into the crawl space air.

Wall vents are the main strategy used to control moisture in crawl spaces. Vents are typically 8 inches high by 16 inches long. They are installed evenly around the perimeter based on 1/150 code sizing requirement (1 square foot of net free ventilation for every 150 square feet of floor area.) Many wall vents have dampers, which are intended to be closed in winter to keep the floor warmer and to prevent crawl space pipes from freezing.

Exterior drainage is used to drain ground water away from the exterior wall and footing on the uphill and side-hill sides of the house. The system usually consists of perforated drain pipe embedded in gravel covered with filter cloth and exterior wall dampproofing. Interior drainage systems are not commonly used in crawl spaces. They are sometimes installed on sloped sites to gather water at the low end of the crawl space and transport it outside. The system usually consists of nothing more than a vertical pipe installed in the ground or a horizontal pipe or hole cut through the bottom of the crawl space wall.

Joist beams provide internal central support for the home’s floor joists. Most homes have one or two beams, typically made of three 2 x 12” boards nailed together. Southern yellow pine is common, although pressure treated wood is occasionally used. Steel I-beams are rarely seen as a substitute. The joist beam is usually the lowest wood to the ground in the crawl space. As such, it is more likely to have elevated wood moisture content if there are moisture problems in the crawl space.

The sill forms the transition from the masonry wall to the house wood frame construction. Sills are usually made of 2 x 6” or 2 x 8” pressure treated lumber. The wood sill is typically bolted directly on top of the masonry wall without a capillary break, that is, a material that prevents the movement of water. On rare occasions, crawl spaces have metal termite shields between sill and masonry. These form an excellent capillary break.

Floor joists are typically made of 2 x 10” Southern yellow pine (untreated). They are installed on 16” centers. Some crawl spaces are built with wood I beams and open web floor trusses for joists. These are available in long lengths and allow longer clear spans without joist beams.

Sub-flooring usually consists of 4 x 8’ plywood or OSB sheets nailed or sometimes glued on top of joists. The sub-flooring functions as the primary air barrier in wall vented crawl spaces. Neither the floor covering (carpet, tile, etc.) nor the floor insulation are effective
in stopping air flow. Any cracks or holes left unsealed will reduce the effectiveness of the subfloor as an air barrier.

Crawl space insulation usually consists of R-19 fiberglass batts installed in the floor joist cavities with tension wires. If faced vapor barrier batts are used, the batt is usually installed with vapor barrier facing up against the floor.

Access to the crawl space is usually provided through a panel or door frame opening in the crawl space wall. The access is often located at the downhill (highest) side in sloped crawl spaces. The panel/door is usually made of metal or wood that is not insulated or weather-stripped.

3.3 Crawl space designs

3.3.1 Wall vented crawl spaces

Wall vented crawl spaces rely heavily on passive (non-mechanical), uncontrolled ventilation to remove excess moisture from the crawl space. The intended driving force with this design is wind. In breezy weather, outside air blows into vents on the windward side of the house and is sucked out vents on the leeward side.

In practice, two other driving forces cause unintended crawl space airflow. One of these is known as stack effect. During winter, heated air rises up inside the house and escapes through openings (cracks, lighting fixtures, chimneys, attic staircases) in the walls and ceiling. This air is replaced in part by cold air sucked into crawl space wall vents and through cracks and holes in the floor.

The use of fans inside the house creates another unintended airflow. Exhaust fans, such as those used in bathrooms, the range hood, and clothes dryer, create negative pressure in house. This pulls air in through crawl space wall vents and through cracks and holes in the floor. Depending upon whether they are located inside the home or in the crawl space, ductwork with leaks and air handling unit fans can also create positive and negative pressure differences in home, which in turn force air in or out through crawl space vents.

While air movement in the crawl space is good for drying purposes, builders should seek to prevent the movement of crawl space air into the home because of the potential for drawing in mold spores, radon, moisture, and other pollutants commonly found in crawl spaces.

Ventilation air for drying the crawl space is provided by airflow between the outdoors and the crawl space. The drying potential is determined by the moisture content of the outdoor air and the amount of air flowing through the wall vents. The crawl space will dry when the moisture content of outdoor air is lower than that of crawl space air. In most climates, this occurs primarily in the winter when the outdoor air has minimal moisture content.
Little or no drying takes place when the moisture content of outside air approaches that of the crawl space. The crawl space actually gets wetter when the moisture content of outside air is the same as or higher than the crawl space air.

It is important to remember that wall vents are not the only moisture control strategy available for crawl spaces. Other important features include polyethylene ground moisture barriers, floor drains on sloped crawl spaces, and, occasionally, moisture protection for exterior crawl space walls.

3.3.2 Fan assisted wall vented crawl space

Mechanical ventilation, usually in the form of an exhaust fan, is sometimes added to a wall vented crawl spaces. Using an exhaust fan, makeup air comes mostly from the outdoors via other vents; however, some may come from air drawn from inside the house.

Fan use can greatly enhance drying performance, but it can also hurt it. A fan increases drying when the outside air is dryer than the air in the crawl space. Conversely, a fan will increase moisture in the crawl space if the air it pulls in is wetter than what is in the crawl space.

Preferred fan systems have moisture sensing controls that operate the fans when outside air can dry the crawl space and turn the fans off when that air would dampen the crawl space. In Southeastern climates, protracted periods of wet weather in summer limit the usefulness of these fan systems.

3.3.3 Closed crawl space designs

Though they are uncommon in most homes built today, crawl spaces can be intentionally designed to seal out outdoor air. Closed crawl spaces do not have wall vents. Instead, they rely on other strategies to keep moisture out of the crawl space.

Strategies for moisture control include the use of gutters and site grading to direct rainwater away from crawl space walls. Below grade walls are protected with exterior damp proofing and perimeter drainage systems. A full ground moisture barrier with sealed seams and edges is installed on the ground to keep moisture from rising up into crawl space. Internal drainage systems collect and remove any water that falls on top of the ground moisture barrier. Deletion of wall vents and air sealing wall penetrations keeps outdoor air moisture from entering the crawl space. Vapor retarding materials are applied to the inside of the crawl space walls.

Closed crawl spaces offer the potential for reducing energy consumption in the home by providing superior thermal characteristics to vented crawl spaces. In addition to the air barrier at the floor sheathing, sealing work creates a second air barrier at the walls and ground. Since a closed crawl space has two air barriers, insulation can be installed either under the floor of the house or on the crawl space walls. Wall insulation is preferred as it
can be installed continuously around the crawl space wall as opposed to the fragmented system of installing batts between floor joists.

If insulation is installed on the walls, the crawl space will be indirectly conditioned by the home’s heating and cooling system and temperatures may approach those of the home’s interior. When the home is heated, a certain amount of heat will be conducted through the un-insulated floor. Heating systems or air handling units located in the crawl space will add an additional source of heat. In summer, the crawl space will be kept cool by ground temperatures which generally remain below 70 degrees F.

Some guidelines call for intentionally conditioning crawl spaces. This can be done by providing supply and/or return air to the crawl space or by installing air transfer registers in the floor between the crawl space and home. In these cases, the crawl space temperature can be very close to that inside the house.

Closed crawl spaces can also be independently or separately conditioned. The most common application of this type is to permanently install a dehumidifier in the crawl space. The crawl space dehumidifier, which is piped to a drain or outside, provides year-round moisture removal capability.

In closed crawl spaces, as with vented crawl spaces, builders should be concerned about the possible air transport of pollutants, including mold spores, radon, termiticides, particulates, and bugs from the crawl space into the living space. This can be avoided by minimizing air movement between these spaces. One strategy is to install a small exhaust fan in the crawl space directing air to the outside. This creates a continuous negative pressure in the crawl space relative to the house. Another strategy for preventing infiltration from the crawl space is to pressurize the house through the continual operation of a small fan system. Positive pressure inside the house will ensure that the movement of air is outward.

In closed crawl spaces, there will be a gradual buildup of dust and insects, since these are not periodically removed from the crawl space as they are from the house through cleaning.

3.4 Crawl space shortcomings and solutions

While they may function well in theory, crawl spaces as currently designed, built, and used in this country face a number of shortcomings. Moisture problems are rampant and energy losses are unnecessarily high. Over time, these problems can compromise the structural integrity of the home and the health and economic well-being of the occupants. Listed below are the key technology issues related to crawl space construction, along with recommendations for how to avoid these problems. In some cases, specific building code changes have also been recommended.

3.4.1 Insufficient ground moisture barriers
Research indicates that installing a moisture barrier on the ground is one of the most important components for controlling moisture buildup in crawl spaces. Simply put, the barrier prevents ground moisture from evaporating into crawl space air and condensing on building surfaces.

However, research has also revealed that most homes, including newly-constructed homes, either have no moisture barriers in the crawl space or have only partial barriers. Standard practice in the building industry is to cover between 75-90% of the floor area with a moisture barrier. Total coverage is uncommon due both to practical limitations in laying rolled material around piers, water heaters, and other components in the crawl space, and by builders’ fear of making crawl spaces “too dry.”

Standard practice is to use 4 or 6 mil polyethylene as a ground moisture barrier. This is typically purchased in roll form and laid out on the ground with no fasteners. While this thickness is adequate to prevent moisture from passing through, experience indicates that 4-6 mil poly is not durable enough to stand up to human traffic over time. Typically, builders will lay the polyethylene down as soon as the building is framed in. Plumbing, electrical and HVAC contractors will come in behind the builder, crawling over the polyethylene and dragging all manner of equipment. This frequently results in dislocation or tears. Over the years, additional damage is caused as repair workers and the homeowners go in and out of the crawl space.

Thus, while 4-6 mil polyethylene may be adequate as a moisture barrier in theory, it is rarely so in practice.

Preliminary recommendation:

To ensure that ground moisture barriers perform as intended over the life of the building, builders should install 10-12 mil polyethylene or reinforced polyethylene. These products are not available at most building supply stores and must be special ordered or searched for via the Internet.

Crawl space vapor barriers should be staked in place using 6” turf staples or spikes with washers. Vapor barriers should be laid out on an 8’ grid and seams should be overlapped by 6 inches and be sealed with mastic or poly tape.

Potential code provision:

Require a minimum 6-mil polyethylene ground moisture barrier in all crawl spaces.

Require that the moisture barrier cover a minimum of 95% of the exposed ground in the crawl space.

3.4.2 Lack of internal drainage

Properly applied moisture barriers are effective for preventing water vapor from passing from the ground into the air. Conversely, they will also collect any water that drains onto them from above, and if that water is allowed to puddle, it will defeat the purpose of
keeping the crawl space dry. Water can collect on top of vapor barriers from a number of sources, including plumbing leaks, duct condensation, spills inside the house, and flooding. Over time, this problem will occur in virtually all homes.

Puddling is most associated with flat crawl spaces. Sloped crawl spaces will drain naturally and often have a drain pipe at the lowest point, although puddling can still occur where there are depressions.

**Preliminary recommendation:**
To prevent water from puddling on top of crawl space vapor barriers, the ground under the house should be graded and/or filled so that any water will drain to specific collection points where it can be removed from the crawl space. Builders should focus on getting drainage beneath bathrooms, laundries, and kitchen sinks—the most likely sources of leaks. Water heater overflow pipes and air conditioning condensate drain lines should be run to a drain pipe or outside the crawl space.

A cheap drainage system can be provided by cutting 1” holes in the polyethylene at low points in the crawl space. A sump pump will provide high grade drainage.

**Potential code provision:**
Require a crawl space drainage plan.

3.4.3 Crawl spaces built too low

In order to save money on building materials and to reduce the number of steps going into the house, builders frequently construct crawl spaces as low as possible. The emphasis on universal access and the associated use of ramps has increased the trend toward lower crawl spaces.

The downside of lower crawl spaces is that access within the crawl space is greatly reduced. In low crawl spaces, there may not be enough headroom to install, inspect, and maintain insulation, plumbing, and ductwork. Low hanging joist support beams, ductwork, and waste pipe drain lines exacerbate access problems. Ductwork, particularly big flex returns, may actually touch the ground in low crawl spaces, causing a reduction in thermal performance and increasing condensation formation.

The closer the floor framing is to the ground the higher the moisture content will be in the wood, and the more likely it will be to have visible mold.

Low crawl spaces limit what can be done to provide drainage grading away from foundation walls. Sound construction practices call for a 5% grade extending for 6 feet away from the foundation. This grade may be impossible to achieve with low crawl spaces on flat sites.
Finally, low crawl spaces decrease the likelihood that homeowners will find or address moisture and other problems inside the crawl space. “Out of sight, out of mind” becomes the rule for problems in these areas.

*Preliminary recommendation:*
Increase crawl space wall height by at least one course of block above current practice. Each course of block adds 8” in crawl space height.

Trench under low clearance beams and ducts.

*Potential code revision:*
Require minimum ground clearance of 18” for beam, joists, and ductwork.

### 3.4.4 Crawl space duct leakage

The crawl space is the most popular location in which to install the duct system. Ducts can be installed in the attic, but HVAC contractors avoid this whenever possible due to the uncomfortable working conditions in summer. Two-story homes will typically have one HVAC system in the crawl space and one in the attic.

The problem with installing ducts in the crawl space is that if leaks occur in the ductwork, unhealthy air will be drawn from the crawl space into the living space of the home. Leaks in the return duct will directly suck in contaminants, including mold spores, particulates, and radon. Air filters installed in the house at the head of the return duct will not catch contaminants drawn in further down the line, nor are common filters able to catch such small particles. Leaks in the supply lines will depressurize the house, sucking air into the house through any holes in the floor.

Even if sealed ducts are installed, flex duct and ductboard are prone to damage. Repairmen may damage the ducts while working in the crawl space. Rodents have a tendency for burrowing into flex ducts and ductboard, and cats may damage them while prowling in the crawl space.

Designs that use wooden floor joists and metal sheeting to form a plenum almost always leak. Without attention to detail, it is virtually impossible to form a tight seal between wood and metal.

*Preliminary recommendation:*
Avoid placing ducts in the crawl space. Instead, locate them within the conditioned space of the home.

Do not use wooden joists for floor plenum returns.

Install high-efficiency filters at the air handler unit, not at the head of the return duct.
Possible code revision:
Seal all ducts in the crawl space.

3.4.5 Floor insulation problems

The current practice for insulating floors over crawl spaces is to install R-19 fiberglass batts in between the floor joists. These batts are typically supported by metal wires (tiger claws) which are pushed upward between the joists and held in place by friction. This method of insulation works well in theory, but not in practice.

First, the metal wires compress the batt insulation to approximately half of its original thickness, reducing its insulation value by a corresponding amount. Second, floor insulation is not continuous in the joist cavities. Gaps and voids are left around floor bracing, framing details, and electrical, plumbing and duct penetrations. These gaps reduce the overall insulation value of the floor. Third, if crawl spaces are damp or wet, the insulation will absorb moisture from the air. Over time, batts will get heavier and may fall out. Even if it doesn’t fall out, wet insulation loses R-value.

If there are any holes in the floor system, crawl space air will be drawn through them due to the unequal pressures inside and outside the conditioned space. These air leaks will bypass the floor insulation.

Two new floor framing systems are very difficult to insulate: I beam joists, by virtue of their design, do not offer a surface on which metal insulation wires can easily be installed. Open web trusses are virtually impossible to insulate using the traditional method.

The result for most homes built with crawl spaces is that the actual R-value of the floor insulation is significantly less than R-19.

Preliminary recommendation:
Use friction-fit batts, instead of batts held in place with insulation wires.

Use batts that completely fill joist cavities and hold them in place with mesh netting stapled to the bottom edge of the joist.

Potential code revisions:
None.

3.4.6 Air leakage through the floor

The typical practice in home construction is to drill overlarge holes through the floor for electrical, plumbing, duct, phone, and cable lines. These holes are prime avenues for air leakage. Leakage can also occur through edge cracks between the 4’ x 8’ sub-flooring.
Air leakage degrades floor insulation performance and increases the load on the heating system. It also allows unhealthy air to be drawn into the house from the crawl space.

**Preliminary recommendations:**
Use tongue and groove sub-flooring and/or caulk or construction adhesive around the edges of sub-flooring.

Seal all floor penetrations with expanding foam. Use fire stop caulk where required.

**Possible code revision:**
Seal all floor penetrations.

3.4.7 Moisture condensation on ductwork, air handling units, and cold water pipes

Cold metal surfaces condense water droplets out of moist crawl space air. This regularly occurs on ducts during operation of the air conditioning unit(s) when supply air temperatures are between 55 and 65 degrees F. These water droplets fall on top of the ground moisture barrier, where they may form puddles.

Visible mold growth is more likely around ducts and pipes on which water condenses. Mold spores may be drawn into the house through leaks in the ducts and flooring system.

**Preliminary recommendation:**
Insulate cold water pipes in the crawl space.

**Possible code revision:**
Require air handling unit cabinets to have minimum R values.

3.4.8 Mold on wood framing

As a result of excess moisture, many crawl spaces have visible mold on wood framing. The presence of mold is unpredictable from one house to another, even within the same neighborhood. However, the likelihood of mold increases as the climate gets hotter and more humid. In those houses that do have mold, the amount ranges from a few spots to thick coatings over large areas of exposed wood.

**Preliminary recommendation:**
None.

**Possible code revision:**
None.

3.4.9 Lack of moisture control between masonry wall and wood floor frame
Water present in the soil, splashing onto the foundation from rain, or being driven into the foundation by wind will wick upward through porous masonry block into wooden sills and floor framing. The increased moisture content encourages mold growth on the wood. Over time, high moisture loading in the wood can lead to structural rot and encourage termite infestation.

Preliminary recommendation:
Use sill seal or metal termite shields between the foundation wall and wooden sill.

Possible code revision:
Require a capillary break between the foundation wall and the sill.

3.4.10 Homes built without gutters and downspouts

Gutters and downspouts are the primary mechanism to get roof rainwater away from foundations. To be effective, especially on flat sites, gutters and downspouts should be used in conjunction with grading of the soil or underground drainage systems designed to carry the water away from the building.

A popular cost-saving measure in the building community is to omit gutters altogether. Since gutters can easily be added after home is finished, builders may offer gutters as an added cost option. Unfortunately, many homeowners do not choose this option.

In homes built without gutters, rainwater runs off the roof and lands with considerable force on the ground under the roof edge drip line. Over time, the soil along this drip line will erode, even when the ground is graded away from the house. Erosion allows water to puddle and saturate the soil next to the crawl space wall.

The excess water can enter the crawl space in two ways, both involving capillary flow. First, water is drawn from the saturated soil through the masonry block in the crawl space wall and footing. Second, capillary flow will also draw in rainwater splashing off the ground and onto the crawl space wall. Both will result in wet interior walls.

Preliminary recommendation:
Install gutters and downspouts for all roof eaves as part of the base home package, not as an option to be added at the homeowner’s request. Otherwise, provide for drip line protection through soil grading, waterproofing of below-grade walls, and a drainage system to carry water away from the crawl space.

Install horizontal drain lines running off site on those sides of the house having uphill or level grades.

Possible code revision:
Require gutters and downspouts for all sides of the house having uphill or level grades.
3.4.11 Lack of below grade moisture control on exterior of crawl space walls

Where crawl spaces have been excavated out, a common feature on sloping sites, part of the crawl space wall will be below grade. Below-grade walls present particular challenges when it comes to moisture control.

Ground water that comes in direct contact with a masonry wall will wick through the wall into the crawl space. Common signs of this problem are darkened, moisture-stained surfaces and efflorescence (white salt deposits) on the interior block wall. Efflorescence is the result of moisture leeching salts out of the block and then evaporating and leaving the salts.

Builders frequently fail to provide any exterior moisture control on below-grade walls of crawl spaces, instead relying on wall vents to remove moisture. Builders are much more likely to provide moisture control on basement walls. However, exterior moisture control is vital for both types of construction.

Exterior moisture control consists of several elements that work together as a system. Failure to use any one element can defeat the functioning of the others. The first involves damp-proofing the exterior wall below grade. Damp-proofing can be accomplished through the application of cementitious coatings (parging), asphalt coatings, or acrylic or other approved polymer sealers to the foundation wall exterior.

The second element involves the installation of perforated drain pipe at the footer level. Perforated drain pipe will collect any ground water or water that seeps down from above and carry it off the site.

Gravel fill around the drain pipe is another crucial element. Water travels through the gravel fill in the trench. Excess water flows more rapidly through the pipe.

Finally, filter fabric should be installed over the gravel to keep interstitial spaces in the gravel from filling and clogging.

In most residential construction, footings for crawl spaces are formed by digging a trench with a backhoe scoop and pouring in concrete. This method provides no extra space in which to put in drain pipe and gravel, so these are generally put on top of the footing. This may be inadequate to keep moisture away from the foundation. Some builders will use a form for the footing. Here, the trench is dug wider and concrete is poured in the form. The trench is wide enough that drainage can be installed at the footing level.

Many residential building codes, including the International Residential Code (IRC), call for installation of an “approved drainage system” (i.e. exterior moisture control) when the interior crawl space grade is below the outside finished grade. However, this provision is often overlooked on the assumption that wall venting will relieve any moisture problems in the crawl space.
**Preliminary recommendation:**
Use footing forms to allow for installation of drain system at footing level or dig out the trench once the concrete is formed.

Always moisture proof below-grade walls during construction. Moisture proofing is much more difficult to do later.

**Possible code revision:**
Rewrite existing provision for clarity concerning requirements for a drainage system.

3.4.12 Insufficient clearance off ground for crawl space vents

It is not uncommon to see crawl space vents installed low to the ground, at ground level, or even below ground level. Vents may have adequate clearance during construction, but after finish grading or the addition of dirt or mulch for landscaping, clearance may be insufficient. Low vents create pathways for puddling rainwater, flood water, and roof splash to enter the crawl space.

The problem of insufficient vent clearance occurs most often with low crawl spaces on flat sites and with vents facing uphill on sloped sites. Water streaks visible inside crawl space walls and under vents are indicators of this problem.

Builders typically seek to solve the problem of insufficient clearance by installing a metal well around the vent to keep water from getting in. If wells are used, they should be filled with gravel and covered by a filter cloth. The gravel should connect down to an exterior drain pipe at the footing.

**Preliminary recommendation:**
Raise crawl spaces to provide adequate clearance for all wall vents.

**Possible code revision:**
Require 8 inch minimal clearance from the bottom of all crawl space wall vents to finished grade.

3.4.13 Lack of site drainage

For proper house construction, the finished grade needs to slope away from all crawl space walls. Achieving this grade can be a problem on flat sites and uphill walls of sloped sites.

Drainage problems are also created when homeowners plant shrubs and bushes as landscaping around crawl space walls. Homeowners may pile on mulch, compost, and gardening soil, which builds up over time and impedes drainage away from the home.
The absence of gutters may lead to erosion at the drip line which defeats drainage. Even with gutters, heavy rains and/or blockage by leaves will lead to overflows.

Preliminary recommendation:
Develop an exterior drainage plan accounting for landscaping and potential erosion around the home.

Avoid low crawl spaces.

Fill in grade around foundations with non-porous clay-type soils to create a 5% grade on flat sites and uphill walls.

Possible code requirement:
Require finished grade to be sloped 5% for at least 5 feet away from house.

3.4.14 Crawl space built on wet ground building sites

Low-lying areas, areas with high water tables and/or predictable flooding can make for wet building sites. This is a common problem in coastal plains, flood plains, swampy areas, and flat areas with high rainfall. The water problems found on these sites can overwhelm conventional crawl space moisture strategies. Crawl spaces may frequently flood below and/or above the ground moisture barrier. High humidity associated with these locations will exacerbate moisture problems.

Preliminary recommendations:
On frequently wet sites, build homes on piers instead of crawl spaces, or build on control filled sites.

If a crawl space must be built, use a package of advanced features, including elevated crawl space walls, concrete floors, interior drainage to a sump pump, flood relief venting, and a vapor barrier under the floor framing.

Possible code revision:
Add more restrictive moisture control provisions for wet building sites.

3.4.15 Protecting crawl spaces from moisture intrusion during construction

Builders commonly wait until a house is almost finished before installing a moisture barrier around the crawl space. However, crawl spaces require moisture control as soon as the sub-flooring is nailed on. During construction, rainwater can enter the crawl space through vents and by capillary action through the block. Water percolates up through the ground. The sub-flooring prevents the sun from drying out the crawl space ground and cuts off drying winds. Under these conditions, the moisture content in wood flooring will rise and the wood will become vulnerable to mold growth.
**Preliminary recommendation:**

After the floor joists are installed and the sub-flooring is nailed on, remove all rubble and construction scraps from crawl space, then install a ground moisture barrier over crawl space floor. Assuming the site has been properly graded, any water that gets into the crawl space and on top of ground moisture barrier will be drained out. If no drainage has been installed, the ground moisture barrier will trap water that penetrates the crawl space.

Until the house is weathered in, that is, roof, wall, windows and exterior doors are installed, protect the crawl space from rain penetration through the subfloor. Cover and seal off all holes and penetrations that could drain rainwater into the crawl space. Use tongue and groove sub-flooring and/or glue around edges of the sub-flooring. Regularly check the crawl space ground for puddles during and after rains and drain as needed.

If weathering in the house is going to take a long time, wrap the entire floor deck in large sheets of 6 mil polyethylene. Fold over seams to create water tight edges. Install battens and fasteners to prevent the poly from lifting in the wind.

**Possible code revision:**

Develop construction moisture control regulations.

3.4.16 Termite control issues with wall insulation

Insulating the crawl space is important for limiting heat loss through the floor. In wall vented crawl spaces, insulation is typically installed between the floor joists. For sealed crawl spaces, insulation (typically rigid foam board) is installed on the inside of the crawl space wall. This provides continuous insulation, as opposed to the numerous gaps involved in insulating between floor joists.

One disadvantage to crawl space wall insulation is that it may provide a pathway for termites to infiltrate the house. In fact, most termite control companies resist or will not issue warranties on foundation wall insulation, particularly foam plastics. To guard against termite infestation, insulation manufacturers recommend, and some state codes require, providing “view strips” around the crawl space wall. View strips are horizontal bands approximately 2 inches wide where there is no insulation.

Another alternative is to terminate the wall insulation before it touches the ground. ICC code requires 6” ground clearance for plastic foam when used on exterior of walls. Unfortunately, view strips and gaps for ground clearance significantly degrade the weighted average performance of wall insulation.

**Preliminary recommendation:**

Use continuous wall insulation.
Possible code requirement:
Require metal termite shields between masonry and wood floor frame as termite barrier and view strip.

3.4.17 Fire safety issues with foam plastic wall insulation

Rigid board insulation is well-suited to crawl space wall insulation because it is durable and can provide a continuous insulation barrier. Apart from the issue of termite infestation, another downside is that rigid board insulation is flammable and emits toxic fumes when burned.

ICC code requires thermal protection over rigid board insulation to provide an acceptable fire rating. The requirement mostly affects the application of expanded polystyrene (white bead-board) and extruded polystyrene (blue-, pink-, and green-colored board) insulation.

However, the use of thermal barriers presents several problems. Covering rigid board insulation with a thermal barrier adds to the cost, and certain types may deteriorate if exposed to moisture. The least expensive approved thermal barriers are ¼ inch plywood, particle board or hardboard, and 3/8 inch gypsum board. All of these are cellulose based (gypsum board has paper faces) and, thus, can degrade if they become wet. Because moisture can wick up and through masonry block on crawl space walls, cellulose-based thermal barriers have a strong potential for getting wet and for developing mold.

Preliminary recommendation:
Use a fire-rated foil-covered, polyisocyanurate board, such as Thermax, and Tuff-R, for a thermal barrier. Foil facing provides the required thermal barrier and also serves as a vapor barrier.

Seal floor holes and ducts. Don’t provide any air pathway for burning foam fumes to enter the house.

For brick and block crawl walls, sandwich foam in between the brick and block. This provides an excellent thermal barrier, protects the insulation, and provides an integral moisture and vapor barrier.

Possible code revision:
None

3.5 Assessment of advanced technologies for crawl space construction

This section examines advanced technologies for crawl space construction that offer improved moisture, indoor air quality and/or thermal control. Many technologies offer multiple benefits in these three areas. Some of these technologies have received limited application in the field. Others are untested.
Information was gathered from the technical committee, construction professionals, and researchers, and from an internet search. While it covers the major topics, the list should not be considered all-inclusive.

3.5.1 Capillary break mortar and block additives

Various block and mortar additives are available that minimize the moisture wicking capability of concrete blocks and mortar. Typically used on concrete slabs, commercial building walls, and basement walls, these additives provide long-lasting, integral capillary moisture control.

In crawl spaces, additives could be used for above and below grade walls in both wall-ventilated and sealed crawl spaces. They would be particularly applicable to sealed crawl spaces, because of the additional need for moisture control. Unless they are incorporated into the conditioned space (i.e. heated and cooled), sealed crawl spaces need to be protected from all sources of potential moisture gain, including wall moisture flow from below and above grade walls.

_Crawl space applications:_

A minimal cost application would involve using a mortar admixture on the ground level brick and block courses. This would transform the mortar in these courses to continuous capillary break strips that minimize ground moisture wicking up through the masonry walls from the footings and below-grade wall surfaces.

Additives could be used in the concrete footing, again to reduce wicking from the ground through the footing and up into the walls.

A more expensive application is to use block that includes a moisture-blocking additive. This would likely be a special order item that might double block cost. It would be most effective in reducing moisture flow in above grade walls.

These additives are largely untested in crawl spaces. They are recommended for further study and application in project work.

3.5.2 Spray-on moisture barrier

Spray-on moisture barriers are a commercial product designed for use on the exterior of basement walls. They could have applications in crawl spaces if sprayed on interior surfaces and the tops of crawl space walls and beam columns. They might also be sprayed on exterior surfaces of below grade crawl space walls. They would best be sprayed on before the floor framing is installed.

As of yet, this method is untested in crawl spaces.
Advantages: A spray-on moisture barrier provides both a capillary break and a vapor barrier. The product adheres to the interior wall surface and is durable. It provides continuous coverage of surfaces, around corners, joints, and cracks.

Disadvantages: Spray-on moisture barriers are expensive and their availability is limited. They are recommended for further study in closed crawl spaces.

3.5.3 Automatic mechanical ventilation

Few, if any, wall-vented crawl spaces are built with ventilation fans. Fans are usually added later as a response to moisture problems in crawl space. Usually, these are exhaust fans that utilize existing wall vents and are manually controlled. In humid climates, continuous mechanical ventilation during humid weather will often increase the crawl space moisture load.

To be most effective at moisture removal in humid climates, mechanical ventilation needs to use an automatic control strategy that operates the ventilation fan when the outdoor air is drier than the crawl space air, and conversely turns the fan off when outside air is wetter than the crawl space air.

Several products are available that mechanically ventilate the crawl space based on comparing moisture differences between the outdoor air and crawl space air. Systems that can execute this control should promise a significant improvement over passive wall venting.

These systems incorporate various combinations of supply/exhaust fans, make up air vents, outdoor and crawl space relative humidity sensors and controllers.

Products include:

- Smartvent (http://www.smartvent.net/index.html)
- Atmox (http://www.atmox.com/learn.htm)

Further study of these technologies is needed to obtain annual field performance data.

3.5.4 Treat wood for mold control

Surface mold is common on wood joists and beams in crawl spaces. Mold requires moisture to grow, thus, the appearance of it in the crawl space is a sure sign of a moisture problem. Visible mold can appear within several days of high moisture conditions. Mold can grow during construction when there is wet weather or ground conditions. Wall vented crawl spaces will experience high relative humidity for long periods of time during humid weather. Both sealed and wall vented crawl spaces will be humid where water leaks or other intrusions puddle or flood on top of the ground moisture barrier.
Wood treated with fungicides resists surface mold growths. Pre-treated wood is best because it ensures uniform coverage. Fungicides could also be sprayed or painted on during construction.

However, homeowners need to be aware of the potential for fungicide residues to be transported from the crawl space to the inside of the home. This could present a health hazard to the home’s occupants. Builders should take precautions to seal all floor penetrations and make sure duct systems in the crawl space are air tight.

The use of fungicides is recommended for further study.

3.5.5 Combustible gas detection

Builders who install gas furnaces, water heaters, or gas piping in sealed crawl spaces without mechanical ventilation need to be concerned with the possibility of gas leaking into the space and causing the potential for an explosion.

One precaution would be to install an alarm system that would sound if there was a gas leak. A more advanced system would automatically ventilate crawl space with outdoor air if a leak is detected. Another version shuts off the gas supply if a gas leak is detected. A final alternative would be to not install gas lines or equipment in sealed crawl spaces.

None of these alternatives were tested for this project, however, they are recommended for sealed crawl spaces with gas equipment and/or piping.

3.5.6 Capillary break pebble beds

Prior to the development of polyethylene ground moisture barriers, gravel beds were commonly used as a moisture control strategy in crawl spaces. The concept behind this strategy is that voids between the pebbles minimize the capillary flow of ground moisture. Pebble beds can also provide a drainage pathway for water leaks into the ground. However, the release of moisture into crawl space air will still occur in pebble beds if the ground is wet.

Given the availability of polyethylene ground moisture barriers, the use of a pebble bed is not a recommended practice, except for very dry building sites.

3.5.7 Thermal block alternatives to standard brick and block wall components

Several products are available for sealed crawl space construction that integrate insulation into the block system. One of these is insulated concrete forms (ICFs). ICFs consist of dry stacked, hollow core blocks made of expanded polystyrene. After the wall is assembled, the cores are reinforced and poured full of concrete.

Advantages: ICFs provide two continuous layers of insulation for excellent thermal insulation and good moisture control. Many products are available.
Disadvantages: Both the interior and exterior surfaces of ICFs need finishing with a durable material. Termite control companies also resist the use of this system.

Another product that integrates insulation is autoclaved, aerated concrete block. The numerous air pockets in these porous blocks add significant thermal resistance. They are best suited for use in above-grade crawl space walls.

Advantages: These lightweight blocks give continuous insulation without termite control issues. No interior thermal barrier is needed for fire safety with this system.

Disadvantages: The porous block must be thoroughly moisture-proofed. Availability of this product is limited.

3.6 Good practice guidelines for crawl space construction

Construction of sound crawl spaces is possible by following a set of guidelines that employ the latest knowledge about moisture control, air movement, and thermal integrity. This following list incorporates packages of design features for improved crawl space construction. Recommendations will be refined as ongoing project research dictates.

The purpose of the list is to promote a discussion of what are most needed and cost effective improvements. Discussion will refine, add, and subtract items from the list.

As these lists become finalized, they should be developed into simplified guideline documents with graphics for distribution to builders, homeowners and code officials.

3.6.1 All Crawl spaces

Cover 100% of crawl space ground with a polyethylene moisture barrier of no less than 6 mil thickness.

Stake ground moisture barrier in place to keep it from being dislodged. Overlap seams by 12 inches.

Provide a capillary break between ground and footings. Install 4 inches of gravel and line trenches with 6 mil poly before pouring concrete.

Provide a capillary break between wood sill and masonry.

Provide access to all areas of the crawl space. Maintain minimum clearance of 24 inches between bottom edge of joists and ground. Maintain minimal clearance under ducts and joist beams of 12 inches.

Provide a drainage system and waterproofing for all below grade exterior wall surfaces where the interior surface is lower than the exterior finished grade.
During initial site grading, slope the crawl space ground to provide drainage pathways to direct and drain from the crawl space any water that may accumulate on top of the ground moisture barrier.

Run all overflow and drain pipes outside of the crawl space. Do not discharge water flow into the crawl space.

Terminate dryer vent discharge outside of the crawl space. Do not vent dryer exhaust into the crawl space.

Slope grade away from all crawl space walls by at least 5% for 5 feet.

Install gutters and downspouts or provide a drip line protection plan.

Seal all cracks and seams in the sub-floor during installation and seal all subsequent plumbing, electrical, ductwork, telephone, and cable penetrations.

Locate crawl space access panels/doors to minimize potential for crawl space flooding through the opening.

Provide at least 12 inches of clearance between edge of landscaping and crawl space wall.

3.6.2 Wall vented crawl spaces

Treat wood beams, sills, and joists with a fungicide to prevent mold growth on wood surfaces.

Avoid installing any ductwork in the crawl space. If ductwork is installed, seal all ductwork and air handling unit cabinets.

To avoid condensation, insulate ductwork and air handling unit to R-6 minimum. Insulate cold water pipe with ½ inch closed cell foam.

Install wall vents with operable dampers that can be closed in summer and/or winter.

Reduce amount of wall vent opening from 1/150 ratio to approved ground moisture barrier ratio of 1/1,500.

Install wall vents with a minimum of 8 inch clearance between the bottom of the vent and the finished ground surface.

Install friction fit batts to totally fill floor joist cavities. Hold batts in place with mesh netting.
3.6.3 Closed crawl spaces

Water proof exterior surfaces of above grade masonry walls.

Use mortar admixture to provide a capillary break in brick and block courses at ground level.

Upgrade ground moisture barrier to an air barrier by sealing the seams between sheets and the edges to walls and beam piers.

Upgrade ground moisture barrier using minimum 10-mil polyethylene or a thin concrete floor over 6 mil polyethylene.

Air seal framing cracks: Masonry to sill, sill to band joist, band joist to subfloor.

Air and moisture seal all crawl space wall penetrations, including cold water supply, waste pipes, and air conditioning refrigerant lines.

Do not return air used to control moisture in the crawl space to the house.

Install only direct-vent combustion furnaces and water heaters in the crawl space. Direct vent appliances have all combustion air piped to the appliance directly from outside and all exhaust gases piped from the appliance directly to outside.

Insulate and weather-strip the crawl space access panel or door.

Install a remote relative humidity sensor that will allow the homeowner to monitor crawl space relative humidity from inside the house.
3.7 Technology Assessment References

**Building Codes, Books, Reports, and Conference Papers**


Chapter 4: Web References


“To Vent or Not to Vent”: Article describing the controversy over crawlspace venting, http://www.goodcents.com/web/to_vent_or_not_to_vent.asp


“Wood destroying fungi in residential construction”: Overview article about wood mold and related decay, http://www.umass.edu/bmatwt/fungi.html

“Pressure testing”: Background information on house and duct air leakage testing, http://www.southface.org/home/sfpubs/techshts/blowdoor.pdf


Source List
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
1791 Tullie Circle, N.E.
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www.ashrae.org