by Dr. Nathan Yost, M.D.

The Case for Conditioned, Unvented Crawl Spaces

Prior to the Second World War, crawl space construction in the U.S. was predominately a Southern phenomenon in which houses were elevated several feet above ground, supported by block or stone piers. Damp soil conditions and problems with termites are thought to be the primary reasons for using this foundation method. In the Northern region of the country, crawl spaces were usually limited to portions of the foundation that were located below porches or additions, and often opened into a basement.

During and after WWII, efforts to decrease the cost of foundations and houses led to an increase in the construction of crawl spaces in many parts of the U.S. The majority of these crawl spaces were excavated below the exterior grade and contained air distribution ducts and air handlers. This increase in crawl space construction was quickly followed by reports of moisture problems in the floors above crawl spaces and in the attics of houses with crawl spaces. Moisture problems related to crawl space construction continue to occur in new homes using this type of foundation.

History of Building Code Requirements

Over the past 50 years, building code requirements for crawl space construction have evolved largely in the absence of research or a basis in moisture physics. According to Rose (1994) the first requirement for crawl space ventilation appeared in a 1942 publication by the Federal Housing Administration entitled *Property Standards and Minimum Construction Requirements for Dwellings*. The requirement was for "a total ventilating area equivalent to ½ percent of the enclosed area plus ½ square foot for each 25 lineal feet of wall enclosing that area."

While working for the Housing and Home Finance Agency, Ralph Britton investigated moisture problems in housing with crawl spaces. He recognized two strategies for controlling crawl space moisture: condensation control by ventilation, and condensation control by ground cover. However, neither Britton nor anyone else at the time determined the relative contributions made by ventilation versus ground cover. The majority of ground covers available during the 1940s and early 1950s were not very durable, so ventilation of crawl spaces was probably recommended even in the presence of a ground cover as a permanent back-up system. By the mid-1950s, the durability of polyethylene sheeting had been proven and many building codes began requiring a ground cover in crawl spaces in addition to venting to the exterior.

Problems with Current Crawl Space Construction

There are three characteristics typical of homes built over crawl spaces and which have moisture problems: excavated crawl space floor without effective drainage, absent or poorly installed ground cover, and exterior venting. Moisture problems and poor indoor air quality continue to affect new buildings constructed over crawl spaces. Some of these problems are the result of poor workmanship and maintenance, but others are the result of poor design and a lack of understanding of moisture dynamics. Ground covers are frequently installed incorrectly in that they are not continuous or sealed to the perimeter walls and piers. The floors of crawl spaces are often irregular and littered with sharp rocks and construction debris so that proper installation of the ground cover is virtually impossible. Subsequent work occurring in the crawl space often results in tears in the ground cover, allowing ground moisture into the crawl space air. Because this under-floor space is not considered "habitable" or "usable," most crawl spaces are not provided with effective drainage.

Few designers, contractors and homeowners understand the connection between a crawl space and the living space above. Even when insulation is carefully installed to the underside of the floor above a crawl space, effective air-sealing is rarely accomplished. Penetrations for plumbing, wiring and air ducts provide multiple pathways for crawl space air to enter the living space. During heating periods, the "stack effect" can easily draw crawl space air up into the structure above. Leakage from supply ducts in the attic can cause the air pressure inside the house to become lower than that in the crawl space. Because of this pressure differential, air containing moisture and other contaminants from the crawl space can then enter the house. (see Figure 1).

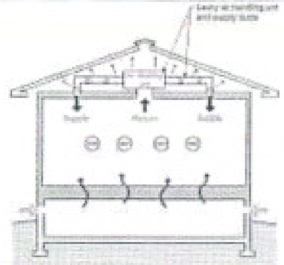

Figure 1: Leaky Ductwork and Air Handler in Vented Attic

- Supply ductwork and air handler leakage is typically 20% or more of the flow through the system

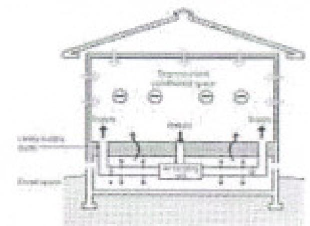

Figure 2: Leaky Supply Ductwork and Air Handler in Vented Crawl Space

- Air pressurization pattern with mechanical system ducts and air handler in the crawl space

Air distribution ducts and air handlers placed in a crawl space can contribute to moisture problems in several ways. Air ducts, whether metal or flexible, and air-handler cabinets always leak to some degree. They leak a lot when installed in the typical manner, and still leak a little even when conscientiously installed with mastic sealing connections. When supply air ducts leak, the air pressure within a house's living space becomes lower than the pressure in either the attic or the crawl space. Air moves from the crawl space into the living space due to this pressure differential. (See Figure 2)

That crawl space air may contain high levels of moisture, soil gases or mold, depending on soil conditions and the adequacy of the ground cover. Leaky air ducts in a vented crawl space can increase cooling costs by 20–30 percent due to the large volume of unconditioned air that is drawn into the air conditioning system. In addition, the moisture in this air frequently results in high indoor relative humidity, decreasing occupant comfort. Lowering the air conditioner's cooling set point in an attempt to improve comfort not only increases energy consumption but draws even more humid air into the system.

Today, the cooling systems of nearly all houses in the U.S. built over crawl spaces deliver cooled air through ducts located in the crawl spaces. The temperature of these ducts and the subflooring around floor registers is frequently below the dew point of exterior air. Venting these crawl spaces results in condensation on the duct work and on the subflooring around the floor registers. Meticulous sealing of ducts and duct-to-boot or -register connections may still not prevent all condensation. Water plus organic material is a recipe for mold growth, and leakage in the ducts or the floor provides pathways for mold to enter the living space.

Traditionally, the floor above a crawl space was not insulated and the crawl space—especially its ground or floor—was warmed by heat from the house. Insulation installed in the floor over a crawl space decreases the flow of heat from the house, but condensation becomes more of a problem because warm, moist air entering the crawl space contacts colder surfaces. That is to say that insulating the floor above a crawl space separates it from the house thermally, but lack of air sealing still leaves the crawl space coupled with the living space.

Building Science Basics

All residential structures built in the U.S. today should be durable and energy-efficient while providing comfort and good indoor air quality for occupants. Contrary to the opinions of some in the building community, these objectives are not mutually exclusive but in fact go hand-in-hand. Meeting these goals requires controlling the flow of heat, air and moisture—in both its liquid and vapor forms.

Controlling moisture from liquid sources requires effective control of ground water and rainwater. Rainwater must be diverted away from the building through proper drainage; similarly, ground water must also be properly drained and kept out of crawl spaces.

Although attempting to control the diffusion of water vapor through the use of vapor barriers is a common approach, controlling air flow across the building envelope is much more important. Under normal temperatures and conditions, the diffusion of moisture is a slow process. Airflow, however, can quickly deposit large amounts of moisture within a building assembly. Along with moisture, controlling airflow also helps manage the flow of heat and airborne contaminants, making it an essential factor with respect to occupant comfort, indoor air quality and building durability.

There is one major downside to minimizing the flow of

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heat and air: a reduction in the rate at which building assemblies dry when they get wet. Although every effort should be made to prevent wetting of buildings, it is inevitable that some will occur. As such, building assemblies should be designed not just to minimize wetting, but also to maximize drying of the interior, exterior or both.

Recommended Crawl Space Construction

Local climate conditions should always influence decisions about design, materials and construction methods. From a building science perspective, the two fundamental ways to build a house over a crawl space are unconditioned and vented, with the thermal boundary and the pressure (air) boundary at the bottom of the floor of the living space; or conditioned and unvented, with the thermal and pressure boundaries at the perimeter of the crawl space. There are two major factors to consider when determining which design approach is appropriate. Is duct work or an air handler located in the crawl space, and can the floor of the crawl space be effectively air-sealed at the appropriate time? If under-floor duct work or an air handler is located in the crawl space then a conditioned, unvented crawl space is the preferred method. If no mechanical system is located in the crawl space, then either option will work.

The emphasis is on conditioning the crawl space because when conditioned, there is no need to vent them. Alternatively, when crawl spaces are vented there must be effective air-sealing between the crawl space and the conditioned space above.

Details for a Conditioned, Unvented Crawl Space

The easiest way to understand a conditioned, unvented crawl space is to think of it as a short basement. A crawl space that communicates with the living space should be inhabitable: dry, comfortable and with good air quality. The essential design characteristics, as illustrated in Figure 3, are:

- effective drainage of ground water,
- ground cover that is continuous and sealed to the perimeter walls and piers,
- the installation of insulation to the perimeter walls,
- minimal air leakage to the exterior (effective air-sealing of perimeter walls),
- sealed air-distribution ducts,
- conditioning of the air within the crawl space, and
- the installation of sealed combustion appliances only.

Different materials and methods can be used to accomplish these objectives. For example, a thin concrete slab can be cast over a polyethylene sheet to create a sealed ground

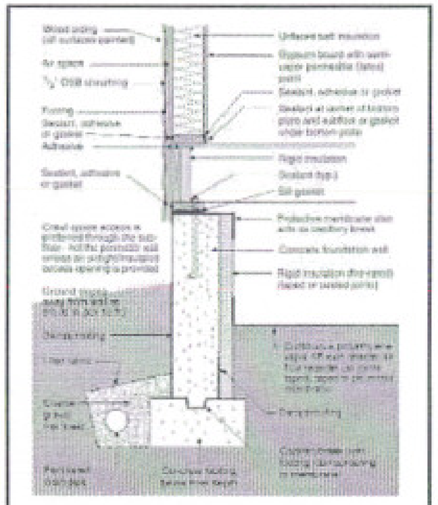

Figure 3: Conditioned, Unvented Crawl Space

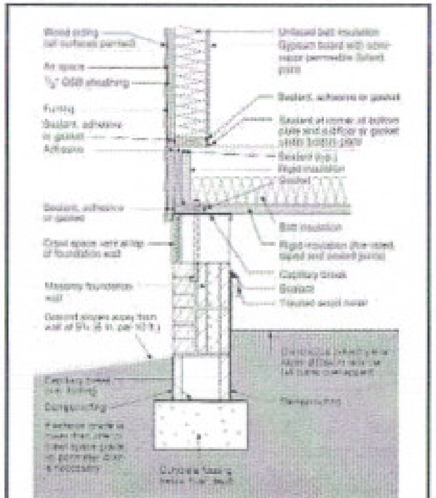

Figure 4: Vented, Unconditioned Crawl Space

cover. Water in construction materials can contribute to moisture problems in crawl spaces, so a low water-to-cement ratio (0.45 or less) is recommended. Concrete with higher water content may require supplemental dehumidification in the crawl space for 6 to 12 months to prevent fungal growth on wood framing.

A small amount of conditioned air can be supplied to the crawl space with passive return through floor registers. Alternatively, air can be continuously exhausted from the crawl space, thus ensuring that soil gases or contaminants in the crawl space do not reach the living space. In this situation, the crawl space will be conditioned by air that moves from the living space because of the pressure differential created by the crawl space exhaust fan.

Details for a Vented, Unconditioned Crawl Space

The easiest way to envision a vented, unconditioned crawl space is to think of it as a house built up on piers, with the building envelope located at the underside of the floor deck. Essential design characteristics, as illustrated in Figure 4, are:

- effective drainage of ground water,
- ground cover that is continuous and sealed to the perimeter walls and piers,
- the installation of insulation under the floor,
- plumbing run within the floor cavity or well insulated,
- all air distribution ducts installed within the floor cavity or in the interior of the structure, and
- a continuous air barrier installed on the underside of the floor framing.

Note that effectively sealing the underside of the floor is difficult to accomplish unless there is adequate clearance between the floor and the ground.

Conclusion

A crawl space foundation is an excellent design when an above-grade floor is desired or when an under-floor space is needed for mechanical systems. The two basic strategies for constructing crawl spaces are to make them unconditioned, vented and effectively separated from the living space; or conditioned, in which case they should be unvented. Control of ground moisture is essential to both strategies, and can be accomplished through foundation drainage and properly installed ground cover.

A conditioned, unvented crawl space is recommended when mechanical systems and air distribution ducts are to be located within the underfloor area. This design minimizes the unintentional introduction of unconditioned air into the air distribution system and reduces the probability of condensation on cold surfaces. Conditioning such crawl spaces serves to provide an energy-efficient, durable foundation system; helps to maintain occupant comfort; and reduces the likelihood of moisture-related problems. ◆

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Dr. Nathan Yost, M.D., recently joined Building Science Corporation (BSC), a building and construction consulting firm, after an eclectic career in medicine and construction. He worked in general construction for several years between college and medical school, and has been involved in multiple renovations and additions to his own houses over the past 25 years, as well as periodically working with his brother's construction company. After leaving clinical medicine, he spent 18 months learning about current construction practices and failures and worked as a consultant to the American Lung Association of Ohio's Health House® program.

Dr. Yost's work for BSC includes investigating buildings, writing, researching, consulting and educating builders. He has written several articles on mold concerning both how to deal with its presence and, more importantly, how to build houses to prevent moisture and mold problems. His investigations of moisture-related problems in both residential and commercial buildings frequently involve analyzing the interaction between the building envelope and the mechanical systems. As part of the Building America team, he works with production builders to produce energy-efficient, durable, comfortable homes with good indoor air quality.

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