Why We Need to Know More About Basement Moisture

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ABSTRACT

This paper focuses on moisture from and in below-grade spaces in existing structures, exploring the problems created by moisture, reviewing the condition of basements in colder climates, and suggesting that new methods for assessing the condition of existing basements are needed. A literature review of research on the connection between moisture and respiratory illness verifies the need for changes in the way basements are being finished and remodeled. A report of a pilot study pre-testing basements with moisture problems before finishing is included. Reasonable and practical information on how best to finish below-grade spaces to limit potential moisture problems in existing basements concludes the paper. This paper does not include original research on below-grade moisture intrusion nor does it include field-tested solutions to these problems.

INTRODUCTION

The purpose of this paper is to examine the literature on basement moisture research to determine what is known about the role that foundation moisture plays in the performance of residential buildings. Using this research review and the experience of the authors and others in the building industry, and from information gained from a pilot study described in this paper, six methods of constructing basements designed to reduce the risk of moisture problems are presented. This paper does not include original research on below-grade moisture intrusion nor does it include field-tested solutions to these problems.

The research clearly indicates that basements play a significant role in the moisture performance of residential buildings. Moisture that enters through the foundation of a house can ultimately affect the durability of the building structure and, more importantly, can have a profound impact on the health of individuals who live in the house. Since Americans spend 90% of our time indoors (ALA et al. 1994), much of that time in our homes, the potential risk is substantial.

Research also indicates that insulating on the interior of a basement wall in cold climates has a high potential for moisture problems. It appears the reason builders place insulation on the inside of a foundation wall is to avoid the extra care and cost that exterior insulation requires. Since most basements do not have capillary breaks and have damp-proofing instead of water-proofing, the potential risk of moisture problems outweighs these savings. We believe the literature clearly suggests that further research is needed to determine the actual risk factors associated with basement construction methods if the risk from moisture problems is to be minimized.

BACKGROUND

Water enters basements in several ways. It can enter by advection through cracks and holes in the foundation or slab as a result of hydrostatic pressure differences or capillarity. It also moves through the wall or slab into the basement space by diffusion as a function of the vapor pressure gradient. Mostly, this is positive (i.e., diffusion flow into the basement), but the gradient reverses during winter in a cold climate over the above-grade portion of the wall. As it enters or leaves the basement, it can wet the structural building materials including the foundation walls, slab, and anything in contact with them. If these wet materials dry to the inside, the relative humidity in

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the basement as well as the rest of the house will rise, increasing the moisture content of the house. The moisture content can then migrate throughout the structure, increasing surface moisture contents and condensing on cooler surfaces. Moisture in a house may also be generated from above-grade leaks, internal leaks, or occupant activity.

Structural Problems from Moisture—A Literature Review

Moisture negatively impacts the structural integrity of houses. Research documenting this damage dates back many years but became more prevalent with the progressive tightening of residential houses that began in earnest during the energy crisis of the 1970s (Sherwood and TenWolde 1982). The existence of moisture problems in any home depends upon several factors, including the quantity and duration of condensation, the building materials in place, indoor and outdoor temperatures, and the ability of the home to expel excess moisture (NAHB 1987).

Moisture damage includes wood decay, paint failure on finished surfaces, buckling of sheathing or siding, and the reduced effectiveness of insulation (Sherwood and TenWolde 1982). A Canadian field survey of 201 moisture-damaged houses (VanPoorten 1983) reported buckling and warping of siding, high moisture readings in sheathing, mold and mildew within the house, high moisture readings in wall cavities, severe window condensation, window frame damage, and mold and mildew as well as high moisture readings in attic spaces.

The Canada Mortgage and Housing Corporation *Builders' Series* (CMHC 1988) noted the following problems with regard to moisture in wall cavities: rotting of structural members, deterioration or staining of exterior sheathing, deterioration or staining of exterior siding, warping of wood siding, efflorescence or spalling of brick or stone, peeling of paint on exterior siding, corrosion of metal fasteners, mold and mildew on structural wall members and on exterior sheathing, and water staining on interior finishes. The report goes on to identify other problems relating to moisture such as condensation on walls, ceilings, windows, and other surfaces.

In the mid-eighties, a study was conducted in Champaign, Illinois (Rose 1986). In part, the study attempted to look for any connections between observed moisture and its sources. Results showed a relationship between moisture damage and moisture sources and also that construction practices, not lifestyle, were mostly responsible for the moisture problems. In a separate study, Angell (1988) concluded that the indoor relative humidity levels of 46% - 61% found in a group of panelized homes in Minnesota resulted in problems that included condensation on most storm windows, mold growth on indoor window sashes, condensation staining on walls and ceilings, wet basement rim joists, and general siding moisture stains. Anderson and Sherwood warned homeowners about condensation problems in a bulletin prepared for the Department of Agriculture as early as 1974.

Health Problems Related to Moisture—A Literature Review

While an expanding body of research indicates that moisture accumulation in the home is the cause of a variety of problems, the health problems attributed to excess moisture in the home must be recognized as the most pressing and disturbing. Although difficult to verify, studies completed over the last several years point to the accumulation of moisture and the mold and mildew associated with moisture as a leading cause of a growing number of health problems. A Canadian study (Ruest et al. 1996) specifically looked at basements and found that harmful molds were present in 16 out of 18 basements.

Biological air pollutants are everywhere. They are found indoors as well as outdoors in ambient air. Humans and animals shed viruses, allergens, and bacteria continually. While a number of factors are important for the growth and release of these contaminants, high air moisture content is especially important. High air moisture content encourages house dust mite population and allows fungal growth on damp surfaces (Korsgaard 1983; Miller 1992). Bacterial populations, however, thrive at both low and high moisture content levels (LaQuartra and Chi 1988). Biological agents in indoor air are known to cause three types of human disease: infections, hypersensitivity diseases, and toxicoses. Exposure to biological contamination has also been shown to relate to nonspecific upper and lower respiratory symptoms (ALA et a1. 1994).

The American Lung Association reports a 59% increase in the number of American asthma sufferers between 1982 and 1996. Even more alarming, a 123% increase was found for that period for people between the ages of 18 and 44 (ALA 2001). Sweden has also seen a sharp rise in the number of asthma patients. A 1990-91 study in Sweden (Ekstrand-Tobin 1993) confirmed several common hypotheses linking the indoor environment and asthma. There were a greater number of people with asthma in homes with known moisture damage. In addition, homes with natural ventilation (relying on natural infiltration for exchange of indoor and outdoor air) had considerably higher bacteria counts in dust as well as greater quantities of particles in the air.

A study of 4,625 children, aged 8 to 12 years old, was conducted in six American cities in 1988 (Brunekdreef et al. 1989). Over 50% of the homes reported signs of dampness in all but one of the cities surveyed. The researchers found a strong and consistent association between measures of home dampness and respiratory symptoms of occupants in these homes.

Parents or guardians of 15,523 children living in 24 North American communities selected to represent a range in ambient outdoor air pollution levels completed questionnaires over a three-year period from 1988 to 1991. Health and housing characteristics were surveyed. The presence of molds and mildew inside the home was quite common (36% overall), with five communities reporting more than 50%. Logistic regression analysis showed home dampness, individual mold, and water variables were all significantly associated with increased respiratory health symptoms (Spengler et al. 1994).

The results from these studies are consistent with other studies that have indicated an association between respiratory symptoms in children and housing conditions related to moisture and molds. Melia et al. (1982) found a significant positive association between the prevalence of respiratory illness and the relative humidity found in homes in a study of 183 English homes. A more recent study, conducted in 185 homes in the Netherlands (Waegemaekers et al. 1989), compared the occurrence of dampness in the sample homes with the concentration of viable mold spores in the indoor air of the homes. Homes where researchers found two or more dampness characteristics also had higher average spore counts and a higher incidence of respiratory symptoms. Strachan and Sanders (1989) found that wheezing and chest colds reported during a one-year period were strongly associated with patches of dampness and molds during that same time period in 1000 children aged 7 years who were randomly sampled in England. While most studies reviewed looked at respiratory symptoms of children, a Canadian study (Dales et al. 1991) focused on the parents of school-aged children. Symptoms of 14,799 adults aged 21 and over were surveyed. The prevalence of lower respiratory symptoms, such as coughing, phlegm production, and wheezing, was found to increase among respondents who reported dampness or mold when compared to those not reporting these conditions.

In response to health complaints by workers or homeowners, six residential and office environments were measured for fungi (Reynolds et al. 1990). As researchers investigated these buildings, they also wrote protocol for collecting samples and suggested health guidelines for threshold limit values. In one case study presented, a residence was visually inspected for evidence of water damage, mold, and mildew. Bulk and swab samples were also taken and examined. These samples verified a variety of indoor fungal organisms taken from lumber in the basement, water-damaged carpet, ceiling tile, wallpaper, beams, walls, ductwork, and water damage near a fireplace. In this case study, as well as others conducted for this research, water damage was found to be one of the primary causes of the fungal growth and the contamination of the indoor air.

Pearce et al. (1995) note that the cause of many indoor air symptoms and complaints is mold. Spore levels vary dramatically in response to temperature and moisture. Pearce also points out that mold colonies are extremely difficult to eradicate once they are established. Because of the size of mold spores, they can be inhaled into the deepest recesses of the lung where they can trigger reactions that irritate the immune system. Some molds produce toxic substances that can be acute or chronic. Pearce notes that, "While mold related health problems are poorly characterized, it is generally agreed that people should not live in moldy buildings."

As recently as 1997, Huang and Kimbrough (1997) reported that children living in homes with mold exhibit more persistent cold-like symptoms. These authors conclude that management of the homes these children live in should include decreasing humidity.

In 1997, Verhoeff and Burge examined nine studies, including some of the studies cited in this review. Acknowledging that nearly one-third of the population is at risk for developing allergenic disease, the authors were in hope of establishing a level of exposure that might lead to guidelines for fungi in homes. Unfortunately, the large number of variables discovered during the statistical review prevented these guidelines from being developed at that time. If we are unable to provide a ceiling for a safe level of fungi, we must be extremely cautious in allowing moisture in our homes and workplaces.

BASEMENTS FOR LIVING SPACE

Today's homebuyers appear to simply take for granted that the basements built for them will someday become living space. In existing homes, we know that below-grade spaces have been used for living space for many years. Basement areas are often used for play areas for children. A growing number of people are sleeping in basement bedrooms (Fuoss 1994).

There are several reasons to be concerned about living in spaces below-grade. The construction techniques we have been using for many years do not always take into account moisture, soil gases, radon, backdrafting, and proper ventilation. In order to make good choices when building and finishing below-grade spaces, both the builder and the consumer need more and better information about moisture in these spaces. Based on existing usage and rising costs, these below-grade spaces are likely to be used for living space even more in the future. However, we continue to build basements that do not protect against moisture intrusion for a variety of reasons, such as

- lack of wide dissemination of significant bodies of research data,
- unwillingness of the building industry to embrace research recommendations for improved basement building practices,
- absence of funding to advance research into already identified problem areas (particularly since the mid-1990s).

The Condition of Today's Basements

In spite of a plethora of information on how to build basements to reduce the risk of moisture problems (Anderson 1970; CHBA 1994; CMHC 1988; Labs et al. 1988; Lstiburek and Carmody 1991), the building industry in the United States has not changed much in many years. Foundations, by and large, continue to be built from durable materials such as concrete block, poured concrete, and wood that, depending on their specific implementation, can be quite porous in service.

A practice that has exacerbated moisture problems in basements is the installation of interior insulation. Homes built before the 1950s rarely had insulation on below-grade walls (Goldberg, Czernik et al. 1996; Goldberg and Aloi 2001; Goldberg and Huelman 2000). Basements began to be insulated in part because homeowners wanted to be comfortable in these spaces as they began to use them for recreation and living and in part as a response to the energy crisis of the late 1970s and the related energy and building codes. Without water vapor ingression control or interior mitigation measures, this bare wall practice can yield very high interior humidity levels. This is a particular problem during the winter in cold climates where it can cause damage to above-grade masonry during spring freeze/thaw cycles. Adding insulation without proper consideration of wall and slab water vapor fluxes can create wall and/or interior moisture problems.

A capillary break is important in preventing water entry into a basement (CHBA 1994; Lstiburek and Carmody 1991; Timusk 1983). This water can add to the interior vapor source strength. While there is some evidence that capillary breaks are being installed, many foundations are being built without these breaks. Even fewer have moisture and vapor retarders under slabs. Little actual research has been conducted on the number of houses being built with these protective mechanisms.

Although many guides and papers, dating as far back as 1961 (Crocker), warned that basements must be kept dry to be successful living spaces, this warning is often unheeded. In the article cited above, Crocker states that waterproofing is critical to this success. Since that time, others (Anderson 1970; Day 1995; Dellinger and Herman 1988; Labs et al. 1988; Timusk 1983) have recommended waterproofing as a first line defense against water entry into a basement space. The research, however, is sketchy at best. Researchers often acknowledged that preventing moisture movement into buildings is nearly impossible (Lstiburek and Carmody 1991; Timusk 1983). However, it is clear the envelope vapor retarder configuration can affect the vapor transport and the resultant mechanical dehumidification load. If there is no vapor retarder present, the dehumidification load can reach significant levels (Goldberg 1999).

In the last fifteen years, almost every imaginable combination of moisture and energy control has been suggested. Unfortunately, there is a lack of published field research supporting these methods. In short, we don't have a substantial published body of hard experimental evidence indicating which methods work. Part of this challenge is, of course, the myriad of conditions under which foundations must perform, the unwillingness of commercial entities to release proprietary information, and the cost of translating large existing databases into qualitative results (Goldberg, Langenfeld et al. 1994).

MOISTURE TRANSPORT AND ACCUMULATION IN BELOW-GRADE SPACES

A brief review of moisture transport mechanisms, important for understanding the serious dilemma homeowners face when deciding how to finish an existing below-grade space, is included below. This review is important to better understand the wetting and drying potential in these spaces (Lstiburek and Carmody 1994; Timusk et al. 1995).

Liquid Transport Bulk Gravity Flow. Liquid water movement and entry into below-grade spaces is more complicated than above-grade building components. First, the soil adjacent to the foundation and slab can severely restrict the flow or gravity drainage and enhances the opportunity for water to find a hole or weakness in the foundation system. Second, the soil acts as an extremely large reservoir of moisture to enhance the wetting period and potential. Third, a rising water table can greatly enhance the hydrostatic pressure exerted on the slab and foundation wall.

Capillary Action. The wicking of water from the soil reservoir can carry water up and into the foundation wall materials. Capillary action can be especially problematic for covered floor slabs.

Water Vapor Transport. Below-grade water vapor movement is more complex as well. As in above-grade components, the water vapor flow can be divided into advection and diffusion components. However, predicting wetting or drying is far more challenging below grade.

Diffusion. Diffusion can be complex to characterize experimentally, particularly below grade where positive and negative diffusion fluxes can occur in three dimensions simultaneously. Vapor pressure may vary over the height of the wall. Some of the building materials have a high moisture absorptivity. In general, the top portion of the wall diffusion will be outward in the winter and inward in the summer. The portion of the wall below the neutral vapor pressure plane and above the floor slab will experience an inward diffusion flux throughout the year (Goldberg and Huelman 2000).

Air Movement. Air has the potential to carry far more water vapor for wetting or drying. It, however, is driven by air pressure differentials that can be highly varied and dynamic.

Because in-situ measurements of water vapor migration are extremely challenging, the research has been somewhat limited to specific soil conditions and construction types that could be accurately monitored in the lab or controlled field conditions (Goldberg 1999). In other words, in an existing building it can be difficult to determine the water vapor flow through the below-grade elements. Therefore, most assessment techniques are based on visual evidence and professional judgment and, therefore, can be susceptible to significant error or misinterpretation by novices (CMHC 1992; Ginthner et al. 1999).

ASSESSING BASEMENTS FOR USABILITY

It is necessary to assess existing basements to ascertain the risk factors associated with finishing below-grade spaces. There have been several consumer-oriented publications for assessment of basement conditions and suggested remedial measures (AES 1981; Carmody and Anderson 1997; CMHC 1992). However, due to the risk involved in finishing below-grade spaces, it would seem prudent to develop a systematic evaluation of the foundation, including soil type and exterior and interior conditions. Items important to include in such an assessment tool are included below.

Site Conditions

Site conditions must be considered. Warning signs include the proximity to a body of water or to a hazardous waste site, a high water table, poor site drainage, poor roof drainage, and high soil radon concentrations. Soil types may be easier to determine. Clay soils would indicate a high risk. The site assessment should take into consideration the placement of trees, shrubs, driveways, sidewalks, the placement of any irrigation systems, and natural land configurations.

Foundation Details

Foundation and footing conditions and drainage details often can be determined by minimally invasive diagnostic procedures. However, in some circumstances, excavation may be the only way to determine these conditions. This may not be possible or, in some cases, prudent.

The foundation wall material and the condition of the foundation wall are also important factors in assessing risk. A concrete block foundation may be at higher risk than a poured concrete wall. If the house has a wood foundation, there may be other considerations.

A drainage system placed on the exterior of the foundation wall would typically lower the risk potential for interior moisture. Unfortunately, few older houses have these drainage systems in place. The type of backfill material can also impact draining potential. Pea gravel or a drainage mat would represent a low risk; compacted clay, a high risk.

The presence of a capillary break between the footing and the foundation wall would lower risk of water intrusion. Likewise, properly placed drain tile would lower moisture risk. If the house has a step footing, the drain tile should be located at lowest location.

The slope of the land away from the building can greatly influence the potential for moisture intrusion. The ground should slope no less than 6 inches for each 10 feet. Gutters, downspouts, and downspout extensions will also lower risk (Ginthner et al. 1999).

The basement floor should be at least 4 feet from the water table level. HUD requires a four-foot distance; the USDA Rural Development requires 3 feet or more (Ginthner et al. 1999).

Interior Conditions

Interior drainage may be the best alternative for existing houses. While newer homes may have this feature, many older ones do not. To maintain the lowest risk for moisture problems, indoor relative humidity must be controlled. In a like manner, the temperature of the walls and slab will greatly influence potential for problems. A warm, dry wall and warm, dry slab lower the risk for moisture problems. (CMHC 1987; Ginthner et al. 1999).

Assessment Tools

Basement assessment must be completed at several different times to get an accurate picture of what is happening below grade. The measurements from the assessment tools listed below are typically one-time readings that must be repeated. In some cases, the equipment can be set up to run continuously. Since this ties up equipment for extended periods, it can be cost-prohibitive. Seasonal return visits for testing are more common. Care should be taken in making recommendations based on one-time measurements.

Blower Door. The blower door is used to measure overall house tightness, but it can be used to determine pressure differences between the basement and the upper levels of the house if the basement is sufficiently separate. This will show the migration patterns of moisture from the basement to the rest of the house. This can play a role in determining how one might remedy moisture problems in the basement and whether pollutants are reaching other areas. In a limited way, it may be able to identify stack effect impact. Blower door readings can give insight into the role of the mechanical systems and vapor migration with relationship to the rest of the house. A leaky basement duct system can pick up moisture from the basement and move it to the rest of the house.

Moisture Meter. Probe type moisture meters will indicate the level of moisture in wood members in the basement. These devices can also be set to measure moisture in drywall. Surface moisture meters can be set to measure moisture in block or concrete. These meters are particularly helpful as indication for further investigation.

Infrared Camera. Infrared cameras may be used to determine below-grade leaks in drainage systems or any water systems that may be under the slab if these leaks are thermally differentiable. Under similar favorable thermal conditions, they also may be used to find leaks in finished walls, although the moisture meters may be easier and faster for this purpose.

Vapor Movement Testing. One of the most difficult assessments to make is the contribution of vapor to the interior from slabs and below-grade walls. A measurement kit used in a university Moisture in Basements study and described later in this paper proved to be an effective vapor measurement tool (Vaprecison 2001). It consists of a plastic tray measuring approximately 12 inches square that is placed on floor or wall. A desiccant-filled container is weighed, recorded, and placed under the tray before it is sealed. The test remains in place approximately 72 hours. The container is re-weighed and a calculation is completed to determine the vapor transmission through the wall or slab.

Pressure Diagnostics. Measuring pressure with the use of a pressure gauge can help determine moisture movement from sump pumps, crawl spaces, and from the basement to other parts of the house. Knowing the air pressure differentials from one location to another under a variety of house operating conditions will give an indication of air flow characteristics within the building, which in turn can transport water vapor.

Radon. Indoor radon levels can be an indicator of movement of other soil gases, including water vapor (Goldberg, Quast et al. 1995). Radon enters houses below grade as a gas through foundation walls and slabs by diffusion. It also enters the basement by advection through gaps and crevices. It then moves to other parts of the house through diffusion and stack effect. Or, it can be picked up in the basement and distributed to other parts of the house through the duct system. Testing for radon should be done on every level of the house. The Environmental Protection Agency provides guidelines for testing radon (EPA 2001).

Fiber Optic Cameras. A more sophisticated tool for discovery of leaks in drain tile and drainage systems is the fiber optic camera. This method also can be used to examine block cores.

Hygrometer. A survey of basement conditions should include a measurement of relative humidity (RH). Basement RH should be compared with the RH on all other levels of the house and in crawl spaces as a function of temperature.

Thermometer. Temperatures should be recorded for the basement as well as other levels of the house. It is important to reference the time of year and conditions when using temperature as a diagnostic indicator.

Subslab Pressure Mapping. This tool is used most often by radon mitigation contractors, but it also can give an indication of moisture movement under the slab. The ground under the slab is depressurized and then tested in several areas to determine if there is a good pressure connection below the slab cavity throughout the basement space.

Core Drilling. Core drilling should be used as a tool only after less intrusive tools have indicated a need to do so. Surface moisture readings and perhaps infrared testing are recommended first.

Mold Testing. In some instances, mold testing may be recommended. For the most part, visual confirmation of mold growth should be adequate to recommend cleanup and moisture mitigation.

Disassembly of Wall Members. If assessment testing indicates moisture, disassembly of walls may be necessary to verify the presence of mold. In these instances, the disassembly is likely necessary to clean up the mold and dry the wall members before determining the lowest risk method of putting the wall back together.

MAKING BASEMENTS LIVABLE

The Moisture in Basements Project

Early in 1999 a pilot study for field investigations of below-grade spaces was designed and conducted. Subject houses were limited to those where owners were planning to finish or remodel below-grade spaces for living areas. Only houses where some type of below-grade moisture problem had been identified were eligible.

Homeowners were offered a free investigation, a report about the investigation, and written advice for their projects if they chose to participate in the study. In return, they agreed to open their homes to investigators for at least one, and perhaps two, investigations. They also agreed to review the recommendations and consider following as many as possible and to document whatever procedure and materials were used in their projects, even if they did not follow the recommendations.

The original plan design called for an investigation following completion of the finishing or remodeling. Unfortunately, it became clear that the time period of the study was insufficient to allow a final inspection. Secondly, it became clear that, although homeowners agreed to report the methods and materials used to complete the project, only invasive investigation could verify the results.

Five homeowners agreed to take part in this study. The five investigations took place between July 20, 1999, and November 18, 1999. Each investigation took 2.5 to 3.5 hours to complete. Although recommendations for moisture control were limited by the study design to below-grade spaces, the entire house was investigated. As stated earlier, research has shown that basement moisture can cause problems elsewhere in the house.

Testing Parameters. Measurements of temperature and relative humidity were recorded. Tests were completed for vapor emissions, house tightness, carbon monoxide, and moisture content of wood members. Visual inspection included an interior survey for signs of moisture, rim joist condition, exposed stud walls, windows, doors, cracks in walls and floors, and an exterior survey for general conditions related to moisture intrusion. Exterior considerations included slope of ground from the structure, condition of siding, windows, porches, decks, stoops, presence and placement of gutters and downspouts, driveway condition, and roof configuration.

Following the investigation, each homeowner received a written report that included recommendations for finishing or remodeling intended to reduce the risk of moisture problems. Areas of concern were noted for both the interior and exterior of the house. While each house was unique, some areas of concern as well as recommendations were similar. Exterior observations included:

- Exterior foundation grading was a problem in some areas of all five houses. Water was not diverted away from the houses.
- Gutters were not installed in many instances.
- In some areas, bushes and shrubs were planted close to the house, encouraging water to be drawn to the foundation.
- Sidewalks and porches had pulled away from the house in at least two houses, allowing water to enter next to the foundation.

- Exterior penetrations were not properly sealed in many cases.
- Windows and doors did not have the proper flashing detail to control water entry in many instances.

Interior observations included:

- All houses had some windows that showed signs of moisture damage, although in one house, damage was negligible.
- All houses had some basement heating ducts with leaks, some significant.
- A vapor emissions test was conducted in at least three places in each house. Results suggested that no home in the study should have carpet as a floor covering in the basement according to recommendations provided by the flooring covering manufacturers.
- Blower door test results indicate that all of the houses in the study were somewhat leaky.

Study Conclusions. Although limited, researchers concluded this study to be important. Parameters of a field investigation as it relates to basement moisture were identified. It is clear that a whole-house diagnostics must be completed to determine the contribution of moisture in the basement from the many different sources. It is also clear that any remedial studies must be conducted over at least a one-year and preferably a two-year period. It is not possible to determine if remedial work is adequate to control moisture in a short time period.

PRACTICAL SOLUTIONS FOR BELOW-GRADE SPACES

While the focus of this paper is existing basements, it seems worth noting that if basements were constructed differently in new houses being built today, the below-grade challenges faced by homeowners in the future could be greatly reduced. Within the context of existing research on below-grade moisture and its contribution to structural and indoor air quality issues, it is prudent to recommend exterior waterproofing and insulation systems for new construction. This approach, which has been demonstrated at a university's Foundation Test Facility over 11 years of experimentation, provides protection from bulk water, allows the wall to dry inwardly without risk of condensation, and keeps the concrete wall temperature close enough to indoor temperatures to avoid condensation in both winter and summer (Goldberg 1999). While a capillary break between the footing and foundation wall would still be recommended to control the overall moisture load, it would not likely create a severe moisture accumulation problem due to the ability of the wall to dry inwardly. The floor slab should have adequate horizontal drainage, a capillary break from soil moisture, a vapor diffusion retarder, and an air barrier system. For heavy or insulative floor finishes, rigid insulation is recommended under the slab to isolate it from ground temperatures to improve condensation control and drying potential. Even with such measures in place, it would still be prudent to ensure proper indoor moisture or humidity control through a combination of ventilation in the heating mode and dehumidification in the cooling mode.

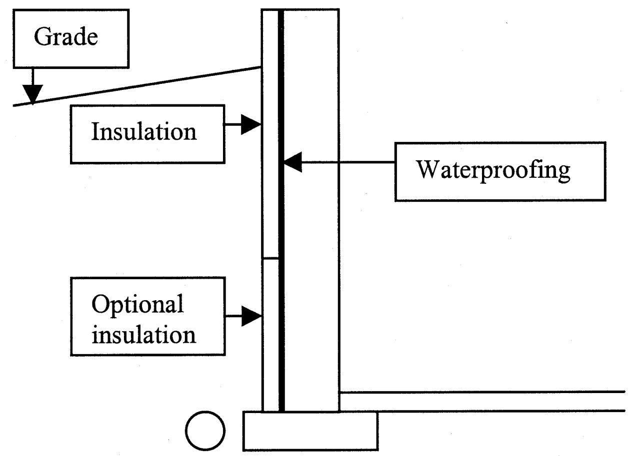

Figure 1 *Exterior insulation and waterproofing.*

It also seems noteworthy that except for a very recent paper on an interior rigid fiberglass system (Goldberg and Aloi 2001), the authors were unable to find any research-based literature supporting the current practice of interior fibrous insulation without proper waterproofing and/or moisture protection between the wall and insulation system. Even in the 1970 *Wood-Frame House Construction* handbook (Anderson), a waterproof coating is shown between the foundation wall and interior insulation.

Existing Construction

Assuming that exterior insulation and other features mentioned above have not been installed in an existing house, the options for finishing interior below-grade spaces become much more limited. Based on the research reviewed, six suggested conceptual solutions are presented below. Each has its own level of risk and cost.

Concept One: Exterior Insulation and Waterproofing (see Figure 1). While exterior waterproofing and insulation systems remain the best solution in new construction and retrofit application, they will undoubtedly be difficult and costly. Exterior features, such as steps, porches, sidewalks, patios, and existing landscaping, impede the task of excavating around an existing foundation. This approach does, however, provide the opportunity to fix both moisture and thermal problems without disruption to the interior of the home. However, it does not provide a remedy for any deficiencies with the floor slab other than to reduce the wall moisture and vertical drainage contribution.

This approach should have a very low risk of future interior basement moisture problems if it is properly installed. Bulk water flow and condensation should be virtually eliminated. Limited water movement by capillary action or diffu-

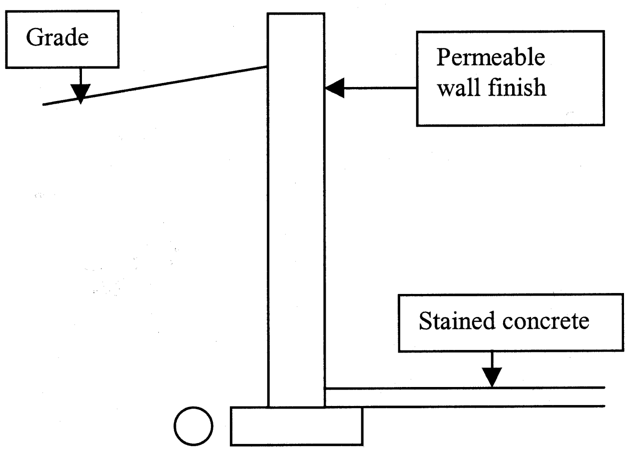

Figure 2 *Interior finishes without insulation or carpeting.*

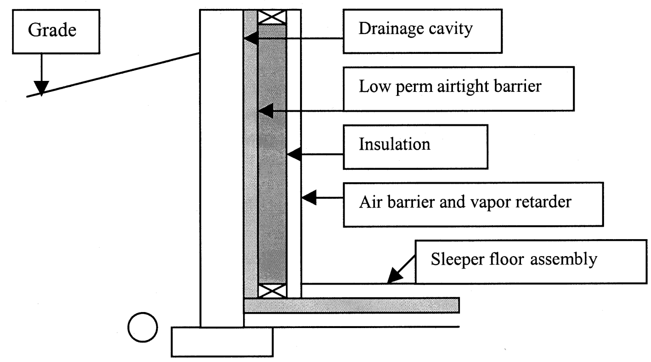

Figure 3 *Interior finishes in front/top of a barrier and insulation system.*

sion can dry inward. This suggests that winter and summer humidity control would be important to provide, as well.

The cost for this remedy is, however, likely to be prohibitive in most cases. Excavation around the foundation wall to a depth below the floor slab would be required. Where hollow masonry walls exist, it might be necessary to excavate to the footing level for all step footings or walkout stem walls.

It is the belief of the authors that exterior insulation and waterproofing best fits the recommendations of the research and literature reviewed and provides the lowest risk and best overall long-term solution. Unfortunately, the difficulty and expense of an exterior solution leaves interior approaches a more likely scenario for most existing houses. These interior systems add a great deal of risk due to the uncertainties of the exterior soil and moisture conditions, the type of dampproofing or waterproofing coatings, the existence of a capillary break, and the quality of the subsurface drainage system.

Concept Two: Interior Finishes without Insulation or Carpeting (see Figure 2). For most homes, this option presents the lowest risk and lowest cost. However, to ensure success, the homeowner must employ aggressive interior humidity control. In the heating mode, mechanical ventilation should be used to keep indoor humidity at reasonable levels. In the cooling mode, whole basement (or whole house) dehumidification will be necessary to manage basement humidity conditions.

However low the cost and risk of simply not finishing the walls and floors below grade, many homeowners may find this approach aesthetically unacceptable. One alternative suggestion is to use a stained concrete finish for the slab. This treatment is gaining popularity. It allows for the use of small area rugs that can be removed easily for frequent cleaning. A more expensive, but nearly equal low risk choice is the installation of ceramic or clay tile on the slab. Both allow for moisture diffusion through the material.

Wall finishes are a little more difficult under this option. Any interior paint or sealer could serve as a negative side moisture barrier and might eventually peel or spall. It would be best to select a very permeable surface finish to enable the foundation wall to dry readily to the inside. Homeowners would have to understand the importance of keeping the wall and any future wall treatments permeable.

While this is a very low risk approach as far as materials are concerned, moisture transport may not be as carefully controlled as one might want. Consequently, the moisture load in the interior space may be high. Interior humidity conditions must be carefully controlled to provide sufficient drying of the foundation system and prevent elevated humidity concerns in the basement or elsewhere in the home.

The authors believe this is the most prudent approach for many existing basements to lower both the structural and air quality risk at a modest cost. Unfortunately, as shown in the field study previously discussed, few homeowners are willing to forgo wall insulation and carpeting for what they perceive as thermal, acoustical, and tactile comfort. This approach suffers a large energy penalty since as much as 40% of the whole house envelope heat loss can occur through a heated basement (Labs et al. 1988).

Concept Three: Add Interior Finishes in Front/Top of a Barrier and Insulation System (see Figure 3). This option is the most aggressive and expensive of the interior solutions presented in this review. Suggested by Carmody and Anderson (1997), it employs a sealed barrier or liner to be installed on all walls and floors. This barrier is usually held off the wall and floor surfaces so that moisture can flow behind and under it to a concealed drainage system. In some instances, this cavity is also vented to manage humidity conditions behind the barrier. Once this barrier is in place and sealed at the top edge, the interior wall framing and sleeper floor can be installed. In cold climates, it is imperative that an air and vapor retarder be placed on the interior of the insulation to prevent condensation from interior sources (Goldberg and Huelman 2000).

In theory, this approach provides a low risk option for a finished basement space, provided the wall and floor barrier is adequately sealed to prevent any trapped moisture or biologicals from reaching the interior environment and the interior finish includes an air and vapor retarder.

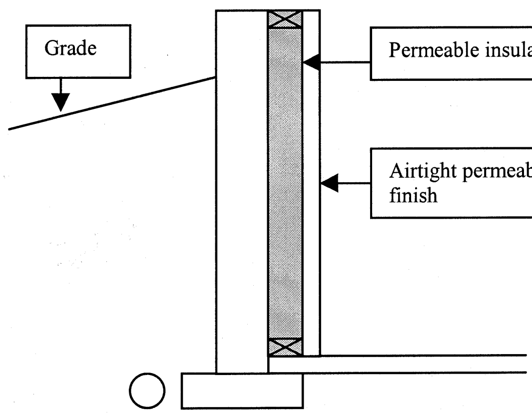

Figure 4 *Added interior finishes with highly permeable insulation.*

Concept Four: Add Interior Finishes with a Highly Permeable Insulation (see Figure 4). This approach attempts to provide ample drying opportunity rather than trying to eliminate or retard the moisture flow. The wall strategy incorporates a permeable insulation material, an interior air barrier, and a highly permeable interior finish (Forest and Ackerman 1999; Goldberg and Aloi 2001; Lstiburek 1998). The floor covering must be highly permeable as well. These in place, a dehumidification system must be used to ensure positive drying potential in the basement. Likewise, winter humidity levels must be properly maintained to prevent any condensation at the top of the foundation wall from the inside.

It is the opinion of the authors that this approach should only be used on very dry foundations and floor systems. There will still be a modest risk if there is strong capillary movement in the slab or lower foundation wall. This system would be susceptible to moisture accumulation without aggressively managed humidity control.

The four approaches listed above suggest the entire wall will be treated uniformly. Based on the very different thermal and moisture parameters, it would seem that the top and bottom portions of the basement foundation wall might be treated differently (Timusk et al. 1995). Review of older research actually shows a partial interior insulated foundation (Anderson 1970). However, this technique was later shown to have poor energy performance due to short-circuiting up and out behind the insulation system, especially with concrete masonry foundations (Goldberg 1999; Labs et al. 1988).

Concept Five: "Hybrid" Approach for Concrete Walls (see Figure 5). In a 1995 paper, Timusk, Pressnail and Chisholm suggested a novel approach for building foundation walls. The top and bottom portions are treated differently to reflect the very different hygrothermal conditions represented by those two locations. The bottom is insulated on the outside with semi-rigid fiberglass or dampproofing and the top portion is insulated on the inside with an interior air barrier and vapor retarder. This approach eliminates the challenge of finishing the exterior foundation insulation above grade. The interior insulation system can be tied into an interior finished wall system. However, as described, this wall would be difficult to retrofit to an existing basement. It is important to note that this approach has been optimized for moisture control but certainly could have a sizable thermal penalty.

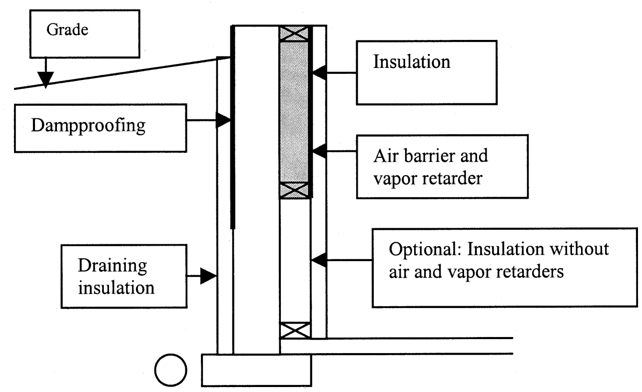

Figure 5 *"Hybrid" approach for concrete walls.*

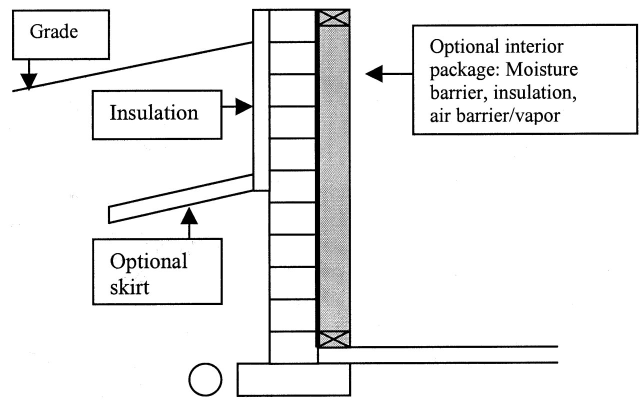

Figure 6 *Mixed approach for block walls.*

Concept Six: Mixed Approach for Block Walls (see Figure 6). Due in part to the convective transport within concrete masonry foundation walls, the thermal and moisture responses are quite different (Goldberg and Huelman 2000). One way to neutralize this looping is to insulate the top portion of the wall on the exterior. This will eliminate the potential for temperatures at the top of the wall to be colder than those at the bottom. This insulation could be placed vertically on the top portion of the wall only or could include a horizontal skirt, such as that used in shallow frost-protected foundations. The exterior insulation retards the convective looping, warms the top foundation wall in winter, and slows inward water vapor in summer. There would then be a lower risk if interior insulation is installed. However, bulk water leakage or capillary rise in the foundation wall still could cause serious moisture accumulation potential and greatly enhance the risk associated with this approach. Therefore, this approach is recommended only when bulk water is absent or can be very well controlled.

Based on the investigation of the moisture potential using the assessment tools described earlier in this paper, Table 1 shows the comparative risks of the six concepts presented above.

TABLE 1
Comparative Risk Levels for Conceptual Approaches*

	Existing Foundation Moisture Status			
	Very Dry	**Probably Dry**	**Likely Moisture**	**Known Moisture**
1. Exterior insulation	Low	Low	Low	Medium
2. Interior finish only	Low	Low	Medium	High
3. Interior drainage/barrier	Low	Low	Low	Medium
4. Permeable insulation	Low	Medium	High	High
5. Hybrid system (concrete)	Low	Low	Medium	High
6. Mixed approach (masonry)	Low	Medium	Medium	High

* Potential for durability or health concerns based on literature review, field study, and authors' experiences.

CONCLUSION

In reviewing the literature on problems and application of finishing below-grade spaces, several points are notable. Many of the common methods used to construct basements today are causing moisture and indoor air quality problems. Although there has been some well-documented research in this area, it is limited in types of conditions and applications.

There are some rational and theoretically supported solutions that are not being used in the market today for whatever reason. In appears clear that more research is necessary to validate these theories. In situ and laboratory research is needed. In order to do this effectively, an intensive program of assessment and identification of problems is warranted.

It appears that interior moisture management is critical for good indoor air quality regardless of the basement construction and finishing choices. Research on the use of ventilation and dehumidification is important to the overall success of maintaining healthy indoor air quality and durable structures. This must include a careful evaluation of the energy implications of these control measures due to the close relationship between energy and drying potential.

Finally, the authors submit the following recommendations for changes to basement and foundation construction. Overall, drainage must be improved. We should promote the use of foundation waterproofing instead of dampproofing. Research supports that exterior insulation is superior to interior insulation. Moisture protection under the slab is critical, especially if floor coverings are to be included in the finished space. Insulation under the slab would provide increased flexibility for future floor coverings.

RESEARCH NEEDS

While the literature review shows the wide range of foundation moisture research that has been done, there are still a number of important unanswered hygrothermal issues for below-grade spaces. Below is a list of research items that will be critical to our improved understanding of below-grade moisture and the development of more robust designs for below-grade walls and floors.

- Better understanding of below-grade moisture contribution based on construction materials and design
- Impact of dampproofing versus waterproofing based on construction materials and design
- Role of grade location and slope, as well as exterior features such as patios, driveway, sidewalk, and plants
- More comprehensive analysis of vapor barrier under slab
- Impact of radiant floor heating on moisture transport, especially at the walls
- Comparing roles of diffusion and air flow in interior foundation insulation
- Impact of step down footings and walkout stem wall on wall moisture
- Improved tools and methods for assessing below-grade moisture in existing houses
- More research on hybrid or mixed insulation systems
- Better understanding of soil variability and contributions to below-grade wall and slab performance
- Further research on moisture transport within concrete masonry units
- Increased field research on alternative materials and designs for below-grade walls
- Role and impact of basement ventilation and dehumidification on below-grade wall and slab performance
- Potential role of subslab depressurization or ventilation in below-grade moisture control

This list focuses on basement issues. However, it is important to note that the research should be extended to explore similar questions for other foundation types.

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