Hygrothermal Performance of Basement Foundation Systems

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Abstract

This paper provides a brief review of below grade energy and moisture impacts on basement foundations, as well as the rest of the building. It discusses key issues that contribute to hygrothermal performance problems and concludes with critical research needs related to below grade moisture and thermal performance.

Keywords: basement insulation, foundation moisture, below-grade walls, moisture management, thermal performance

Introduction

This purpose of this paper is to examine the literature to determine what is known about the role that foundation moisture and heat transfer play in the overall performance of residential buildings. Using this research review and the experience of the authors and others in the building industry, a research agenda for basement foundation systems is presented. It is clear that both building professionals and homeowners need better information on below-grade moisture and thermal performance across a wide set of variables with field-tested solutions so that they can properly address some critical energy, durability and indoor air quality issues with basement foundation systems.

The Nature of the Problem

Basement construction and the use of basement space have changed dramatically over time. While we do not attempt to document these changes in this paper, we recognize that these changes in construction practice and building materials complicate the research in a practical sense.

Beginning in the early 1980's researchers began to focus attention on moisture entry into residential buildings through basement floors and walls (Canadian Mortgage and Housing Corporation 1988; Van Poorten 1983). Field research documented the presence of moisture, while those doing laboratory work looked carefully at how the moisture moved through the building components (Burch, Thomas and Fanney, 1993; Richards, Burch and Thomas, 1992). Computer modeling has also been important to understanding how moisture moves through building materials (Burch, 1991; Burch & Ten Wolde, 1992). In addition, researchers looked at in-situ wall assemblies and built demonstration buildings in an attempt to understand how moisture gets into buildings (Duff, 1968; Rose, 1993; Sherwood, 1987; Sherwood & Ten Wolde, 1982). It must be emphasized that the moisture that enters basements can move through the

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building with air movement, as well as vapor diffusion, putting the entire building envelope at risk.

This close attention to moisture movement was in response to two phenomenon; structural damage and health-related problems reported by people living in buildings where moisture or water is present. While structural and health problems have been the basis for this research for many years, health related problems, particularly with regard to mold, have in recent years become a major issue.

Structural damage from moisture is well-documented (Angell, 1988; Rose, 1986; Van Poorten, 1983). Likewise, health experts have shown beyond doubt the connection between moisture in homes and health problems (Dales, Burnett & Zwanenburg, 1991; Korsgaard, 1983, Spengler et al, 1994; Strachan & Sanders, 1989). In spite of the research completed to date, residential buildings continue to have moisture problems. In some areas of the country and in buildings with certain types of building components, these problems appear to be exacerbating. We submit part of the reason is that, although we know much about moisture movement through specific materials, understanding how moisture moves through the assemblies of various wall and floor systems is complicated. This is, in part, due to the required and desired expectations for basement walls and floors today. In addition, the performance of the building has a dramatic affect on how much moisture may enter (or exit) the building, causing problems at contact surfaces.

In the United States, we began to insulate basements in the 1960s. This was in part because homeowners wanted to be comfortable in these spaces as they began to use them as living space, and later in part as a response to the energy crisis of the late 1970s. The energy crisis resulted in more stringent energy and building codes leading to higher levels of insulation requirements in basement walls. Without water vapor ingression control or interior mitigation measures, 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.

Below grade and foundation moisture and heat transfer have three distinct impacts. The first, and probably most obvious, is the hygrothermal behavior of the foundation system itself. This would include energy efficiency, moisture accumulation, product durability, mold growth, and indoor air quality aspects of the foundation wall components. The second, moisture and air quality impacts throughout the rest of the structure, is likewise fairly familiar to most building scientist and practitioners. The third and more subtle impact is the somewhat discreet connections between the first two. For instance, the foundation insulation or other materials might redirect moisture to the band or rim joist, or condensation within the foundation system might run out the bottom soaking the slab or carpet, or three-dimensional heat flow at the corners or foundation floor connection may be quite different than modeled with common one-dimensional models.

What We Know and What We Don't (Adapted from Cheple and Huelman 2001)

n spite of a plethora of information on how to build basements to reduce the risk of thermal and moisture problems (Anderson 1970; CHBA 1994; CMHC 1987; Labs et al. 1988; Lstiburek, 1998; 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 of 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 recreational and living, and in part as a response to the energy crisis of the late 1970s and the related energy and building codes. 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 (CMHC 1992; 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 protection 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).

A fuller understanding of moisture transport mechanisms, important for appreciating the serious dilemma homeowners face when deciding how to finish an existing below-grade space, is

critical. This is important to better quantify the wetting and drying potential in these spaces and configurations (Lstiburek & Carmody 1994; Timusk, Pressnail and Chisholm 1995).
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, Olson and Carlson 1999).

While the thermal performance of building envelopes is well documented, it is still somewhat limited for foundation systems. Two-dimensional below grade thermal modeling is well established and three dimensional modeling has been successfully used in a number of specific configurations. There has been a significant amount of empirical testing. However, it has been generally limited to conventional materials and designs and, of course, is only significant for the specific location and soil conditions at the test site.

Below grade moisture performance assessment is still in its infancy compared to the thermal characterization. The in-situ work is very material, location, and soil dependent and the modeling is only beginning to reach a level capable of answering some of the most rudimentary questions for simple configurations.

Research Needed

While the literature review recognizes 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 basement walls and floors. While this list focuses explicitly on basement issues, it is important to note that the research should be extended to explore similar questions for other foundation types.

For simplicity the research topics have been placed under several large headings. However, it is important to recognize that many of these are interconnected and interdependent.

A. Importance of Foundation Moisture on Whole Building Performance
  - ✍✍ Better understanding of below-grade moisture contribution based on surface drainage, soils, water table, construction materials, and design
  - ✍✍ Impact of radiant floor heating on moisture transport, especially at the walls
  - ✍✍ Role and impact of basement ventilation and dehumidification on below-grade wall and slab performance

B. Risk Assessment and Strategy Selection for New or Current Basement Foundations
  - ✍✍ Role of grade location and slope, as well as exterior features such as patios, driveway, sidewalk and plants
  - ✍✍ Identifying and testing robust systems for high risk foundations
  - ✍✍ Improved tools and methods for assessing below grade moisture in existing houses
    - ✍✍ Better understanding of soil variability and contributions to below-grade wall and slab performance

C. Foundation Component Performance

  - Comparing roles and rates of diffusion and air flow in interior foundation insulation performance
  - More comprehensive analysis of various vapor retarders under the slab
  - Impact of step down footings and walkout stem wall on wall moisture
  - Further research on moisture transport and redistribution within concrete masonry units
  - Potential role of subslab depressurization or ventilation in below-grade moisture control
  - Impact of dampproofing versus waterproofing based on soil types and construction materials

D. Optimizing Designs and Materials for Thermal Performance and
  - More research on hybrid or mixed insulation systems
  - Reducing complexity of foundation insulation approaches
  - Increase field research on alternative materials and designs for below-grade walls
  - Matching appropriate finishes for existing basements configurations and conditions

With these research issues in mind, it might be useful to think of the basement foundation wall as three distinct, yet vertically connected zones. The upper zone is approximately 6” below grade to the above-grade framing. This can be as little as 6 or 8” in height to as much as 4 feet or more in some house designs. The middle zone is from 6” below grade to approximately the normal frost depth. This will vary with frost conditions by location and by season. It would typically be 2 to 4 feet of vertical height. The bottom zone is the remaining wall that is below the normal frost depth, yet above the floor slab. For some house designs this zone may be negligible, while on other designs it could be as much as 3 to 4 feet.

From a hygrothermal perspective, the bottom zone experiences fairly stable and constant conditions. Temperatures will range from freezing to typical deep ground temperature of 55 degrees or so. Moisture conditions will vary some depending on both long-term and short-term rain cycles. However, in most locales this ground will be generally saturated conditions. Also, the heat transfer is always outward and the moisture load is generally inward. The upper zone will experience almost all of the same temperature and moisture conditions and cycles as the above grade walls. This means large changes in magnitude, as well as direction, of heat and moisture flow depending on both varying indoor conditions and climatic effects. The middle zone will clearly fall between these two extremes. While somewhat dampened in magnitude the wall will frequently experience reversals in flow of both heat and moisture.

In addition to recognizing the different zone conditions, it is critical to fully appreciate and understand the vertical connection between these zones. It is important to better define and characterize this connection based on conditions, materials, and designs as it impacts the performance of the entire foundation system.

The authors believe that this view of basement foundation systems might lead to new design and material strategies that effectively manage the varied demands of these three zones. It also could prompt a review of existing systems against these three conditions, as well as suggest an opportunity for less homogeneous approaches to foundation construction, especially in regards to the insulation systems.

Conclusions

The current literature suggests a variety of concerns in finishing below-grade spaces. 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. It also appears clear that more research is necessary to validate these theories. Both in-situ and laboratory research are needed.

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.

And lastly, we need a serious initiative for more extensive and comprehensive research on the hygrothermal performance of basement foundation systems across a wide range of climate conditions and material choices. We need research and research facilities that can simultaneously address the large number of below-grade parameters in soil type and moisture conditions and well as the multiple foundation types, designs, and materials that impact thermal and moisture performance of foundations and whole buildings.

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