Insulating Basements: Part 1
Fundamentals

Builder Brief: BB0510

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INTRODUCTION

The perception of a basement has changed significantly over time from basic utility space to a space that is habitable or can easily be converted to a habitable space. This shift in expectation has presented numerous challenges to builders as basement walls are fundamentally different from traditional above-grade walls.

With residential construction, it is not only important to understand the building process but also the science behind it. A solid understanding of the physics of heat and moisture will allow builders and designers to produce more efficient structures. It will also allow for building components to be evaluated as parts of a whole system.

Insulating Basements consists of three PHRC Builder Briefs addressing fundamental building physics, basement wall materials, and basement wall systems. This first brief describes the fundamental building physics concepts that play a role in the performance of a basement wall system.

Building Envelope

Basement construction involves the below-grade portion of the building envelope. The primary purpose of the building envelope is to separate the interior environment from the exterior environment. There are three main components that make up the building envelope, including the interior environment, the enclosure system, and the exterior environment. As a result, basement walls must be designed to address the heat, air, and moisture flows between interior and exterior environments.

HEAT FLOW

Heat flows from warm to cold. Heat flow can take place through any of the following mechanisms and typically includes a combination of all three:

1. **Conduction**: Heat flow through a substance or material by direct contact.
2. **Convection**: Transfer of heat through air when considering building enclosures.
3. **Radiation**: Transfer of heat through electromagnetic waves travelling in a gas or vacuum.

Although heat transfer through conduction tends to govern in basement walls, convection caused by air leakage into or out of a structure (caused by negative or positive pressurization) can result in significant amounts of heat loss or gain.

Special Considerations

Although many design methods are based on the assumption that heat flow is at steady state (meaning temperatures don’t change over time), in reality heat flow varies over time. This is partially due to the fact that various components of a basement wall can store and release heat. The thermal mass of the soil adjacent to a foundation wall allows for heat to reach the enclosure system at different times as compared to above-grade walls. The fluctuations in temperature experienced by basement walls are typically smaller than what takes place above-grade, partially due to the relatively constant temperature of soil at increasing depths.

Heat flow is also assumed to be in one direction (typically perpendicular to the basement wall). This is not always the case, though, especially when considering thermal bridging and also fluctuations of surface temperature along the wall. Systems such as stud walls with cavity insulation do not allow for continuous heat flow across each plane in the wall system. Since the thermal resistance of studs (wood or metal) is lower than the insulation, heat flows more easily through the studs from one side of the wall to the other. This decreases the effectiveness of cavity insulation systems.

Ungrouted masonry walls are also prone to heat flowing vertically within the foundation wall. Voids within the wall allow air to carry heat (as well as moisture) throughout the foundation wall.

Heat Flow Management

In order to address the flow of heat within basement wall systems, thermal insulation is included as a component of that system. Thermal insulation can be located on the interior, exterior, or within the wall system. Other systems are available, often times making use of proprietary products such as insulated concrete forms made up of varying materials. PHRC Builder Brief 0199 (*New and Improved Basement Wall Systems*) describes some of these systems.

Exterior Insulation

Figure 1 shows a typical detail of a basement wall system with insulation on the exterior surface. The thermal implications of this configuration include the concept of a warm wall. With the insulation located toward the exterior side of the wall, most of the thermal resistance (R-value) of the layered system is located toward that side. Consequently, the largest thermal gradient exists near the exterior surface of the wall. This allows the rest of the wall to remain at a temperature that is typically warmer than the soil on the exterior side of the wall. Figure 2 illustrates this concept.

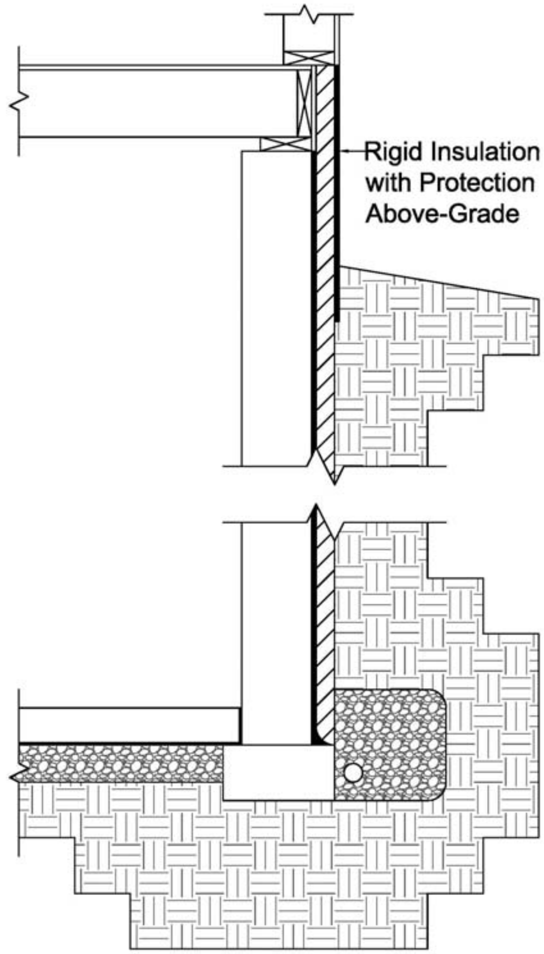

Figure 1: Exterior Insulation

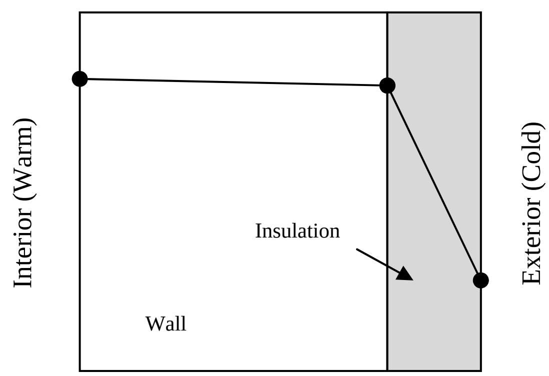

Figure 2: Temperature Variation across Wall

Interior Insulation

Figure 3 shows a typical detail of a basement wall with the insulation on the interior surface of the wall.

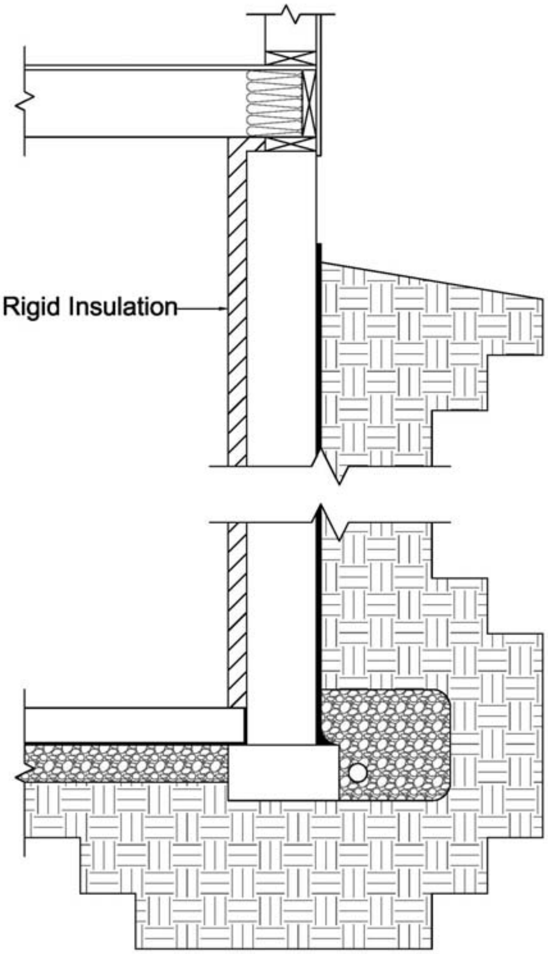

Figure 3: Interior Insulation

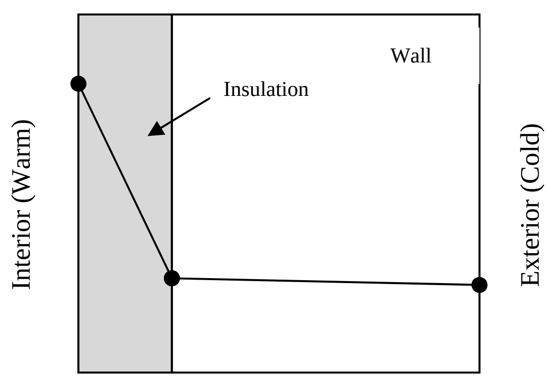

Figure 4: Temperature Variation across Wall

This configuration places most of the thermal resistance of the layered wall system near the interior surface. Consequently, the remainder of the wall yields a temperature near the conditions that are maintained outside of the building envelope. Typically this leads to the wall maintaining temperatures that are lower than those within the conditioned space, especially below-grade. Figure 4 illustrates this concept.

The variations in temperature throughout a basement wall system below-grade not only have an effect from an energy standpoint, but they also have an impact on moisture flows and condensation formation throughout the wall.

MOISTURE FLOW

Moisture transport is driven by differences in concentration as well as thermal gradients. Moisture flows from areas of high concentration to areas of low concentration as well as from warm to cold. The influence of temperature on moisture flow has to do with the higher capacity of warm air to contain water vapor as compared to cold air. Moisture flow can take place in any of the following processes:

1. **Diffusion**: Transfer of water vapor driven by differences in concentration.
2. **Convection**: Transport of water vapor through the movement of air.
3. **Capillarity**: Movement of liquid water through a porous material.

Moisture flow can be broken down into moisture transport through air and through porous materials. With regard to basement walls, moisture transport through air usually involves gaps in the wall, either through improper construction technique or design flaws. For example, gaps in penetrations through interior finish systems (such as light switches and other utilities) allow air from the interior space to move into the wall system, carrying with it moisture from within the basement.

Moisture transport through porous materials, on the other hand, involves both water vapor and liquid water movement through the enclosure system. Building materials differ greatly in their ability to resist the movement of moisture in the form of both liquid water and water vapor. Many common building materials, such as concrete, are considered to by hygroscopic and are prone to moisture infiltration. The pores within these materials allow for transport to take place through both diffusion and capillary suction. In order to combat this low resistance to moisture infiltration, coatings or membranes that are less prone to moisture transfer are often included in the basement wall. The main difference between these materials has to do with permeability. A material with a low permeability has a high resistance to the transfer of moisture, while a material that is highly permeable provides little resistance to the transport of moisture.

Moisture Sources

By understanding the various sources of moisture that a basement wall system is exposed to, is it significantly easier to address these sources throughout the design process. Figure 3 shows a diagram of the various moisture sources below-grade. These moisture sources include the following, as shown in Figure 5:

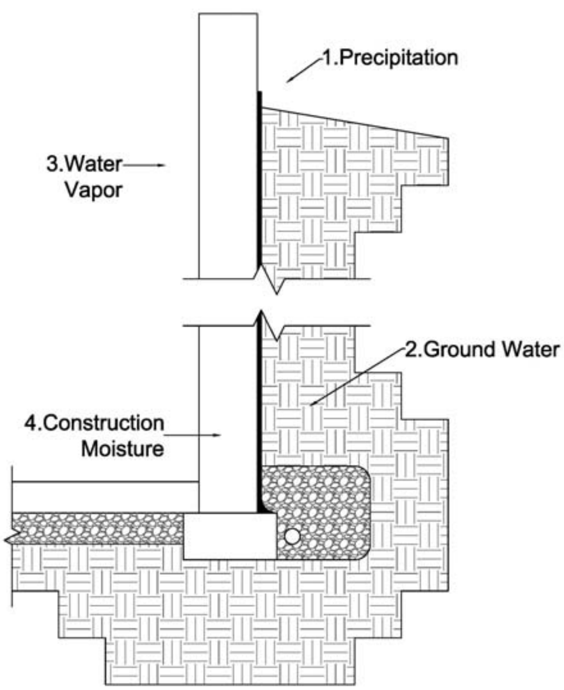

Figure 5: Moisture Sources for Below-Grade Walls

Precipitation and ground water serve as the primary sources of liquid water for the basement wall. Ground water consists of the stored water and ice within the soil adjacent to the basement. The amount of ground water present depends on a variety of factors including the type of soil as well as site grading. Precipitation provides a short term yet significant source of liquid water. It is important that this source of liquid water be addressed throughout the entire structure instead of at the face of a foundation wall. Ensuring that water drains away from a basement wall system is the most effective method of combating this moisture source. Including proper roof overhangs, free draining backfill, and site drainage away from the structure help to achieve this goal.

The soil adjacent to a basement wall can be assumed to be saturated. This assumption means that there is a significant and constant source of water vapor present on the exterior surface of the wall. The damp-proofing or water-proofing typically addresses this source. Also, water vapor from within the below-grade space from occupant activity can also act as a source for water vapor to enter the basement wall system.

One significant variable in the construction of basement walls involves moisture from construction. This includes moisture from the curing of cementitious products as well as moisture resulting from rain events during the construction process. It is important to be aware of the amount of moisture present within the wall system at the time of finishing on the interior of the wall.

Moisture Management

Typically the main line of defense against moisture infiltration in basements involves the incorporation of either a damp-proofing or water-proofing layer into the wall, usually on the exterior. Damp-proofing is fundamentally different from water-proofing in that its primary functions are to inhibit the transfer of water vapor and to prevent liquid water from entering the system through capillary suction. Damp-proofing coatings or membranes typically have a low water vapor permeability but do not provide adequate resistance to hydrostatic pressure, or the infiltration of liquid water. Water-proofing, on the other hand, consists of a material that resists the transport of liquid water as well as water vapor.

There are various cost and construction implications that affect the choice of either system.

While damp-proofing and water-proofing coatings and membranes provide a necessary capillary break on the face of the wall, it is also important for there to be a capillary break between the foundation wall and the footing in order to prevent moisture from entering through the base of the wall's footing. This must be installed during the construction of the foundation wall.

Regardless of the material used to combat moisture flow into a basement wall system, the assumption moving forward must be that no system is perfect. Over time, moisture will enter the wall. With this in mind, it is important to not only address moisture infiltration but to also consider how moisture can exit a wall once it has found its way in.

Drying

It is important to understand how a basement wall dries once it has become wet. Traditional wall systems are prone to drying toward the interior or exterior side of the wall, depending on the climate. However, since soil is located on the exterior of basement walls, the option to dry to the exterior is eliminated below-grade. This has significant implications with regard to the design and material selection process.

An uninsulated wall is free to dry toward the interior environment, provided interior dehumidification is employed when necessary. This had been the case for years in unfinished basements. Moisture was not an issue in unfinished basements if you were able to dehumidify the space and keep any vulnerable items in that space up off of the floor and away from the walls. Once layers are added to a foundation wall, including insulation, the wall's ability to dry decreases significantly.

In the past it was common for basements to include vapor barriers on the interior side of the wall. The thought behind this was to prevent moisture from entering the wall from both sides. However, time proved that every wall will be exposed to some level of moisture. In systems with interior vapor barriers, the moisture that entered the system was unable to exit. This has led to numerous issues including the formation of mold and the degradation of the wall system. It is important to design insulated basement wall systems with the drying potential of that system in mind. In other words, allow the wall to dry toward the interior and avoid using vapor barriers on the inside of the wall system.

One aspect of the drying of a wall that is important is the duration of the drying process. While moisture can enter a basement wall in a variety of ways from a variety of sources, moisture can usually only exit a layered wall system through diffusion of water vapor. This results in the drying process being a significantly slower process than wetting and puts components of the wall system at risk should too much moisture build up within the wall. This also puts emphasis on the moisture storage potential of basement wall components to be able to bridge the gap between wetting and drying.

Condensation

Another critical aspect of moisture management within basement wall systems involves the prevention of condensation throughout the layers of an insulated basement wall. Condensation occurs in basement walls for a variety of reasons, including materials being exposed to levels of moisture above what they can store as well as humid air coming in contact with surfaces at a temperature below the dew-point of that environment. We have all been exposed to the effects of dew-point temperatures and resulting condensation throughout our daily lives. Basement walls are at risk of similar physical mechanisms, especially those systems that have insulation near the interior surface of the wall. As mentioned previously, interior insulation results in a foundation wall that is cooler than the interior environment. Any humid interior air that comes in contact with the cool foundation wall may shed some of its stored moisture in the form of condensation on the surface of the wall. Condensation can have significant effects on the performance of a basement wall, including health effects due to mold growth as well as the degradation of wall components.

The drying potential of a layered wall system plays a key role in the prevention of interstitial condensation. Beyond keeping insulation near the exterior of a basement wall (thus keeping the wall warm), condensation can be prevented by keeping interior air from entering the wall system as well as allowing moisture built up in the wall system to dry toward the interior of the building envelope.

AIR FLOW

As mentioned throughout the discussions of heat and moisture flow, convection can serve as a fundamental mechanism for the transport of both heat and moisture in basement walls. While conduction and diffusion tend to be the primary motivating factors during the design and material selection process, the negative effects that convection can play on the performance of a basement wall system are significant and are often overlooked. Heat and moisture flow through materials (through conduction and diffusion) tend to be rather slow processes that are spread out over the face of the wall system. Air leakage can be much more significant and concentrated. As was mentioned previously, humid air that is allowed to reach the potentially cool surface of the foundation wall associated with interior insulation systems can result in condensation. This can bring about a host of problems for the homeowner. With this in mind, it is important for interior finish systems to serve as an adequate air barrier for the wall system in order to prevent convection from dominating the transport processes for both heat and moisture transfer.