Field Performance of Different Interior Basement Insulation Systems

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ABSTRACT

With the support of the Department of Energy's Building America Program, the Consortium for Advanced Residential Buildings (CARB) conducted a field evaluation of different interior basement insulation strategies in response to many documented cases of moisture accumulation in these types of systems. Equipment was installed to monitor temperature and relative humidity throughout eight assemblies installed side-by-side in the basement of a Chicago area home to assess their moisture performance. This effort was undertaken to gain a greater understanding of the moisture transport mechanisms present in interior insulation systems to aid in the design and implementation of durable, safe, and effective alternatives. Findings indicate that often overlooked construction details can be critical to moisture performance. Exterior insulations systems, though preferable from a moisture standpoint, were not investigated since the extra cost and complications associated with such systems make them relatively unpopular among home builders.

INTRODUCTION

As the thermal resistance and airtightness of the above-ground portion of building envelopes have increased over the years, heat loss through uninsulated foundation walls has become a larger fraction of total heat load than ever before (Huelman and Cheple 2001). In northern climates, foundation wall insulation is often the most significant specification difference between Energy Star and non-Energy Star homes. When insulation is placed on the outside of foundation walls, it is often damaged during the construction process, it can only be installed in a relatively short time window before backfilling, and it must be protected with a finish where it extends above grade. To avoid these complications, cost conscious builders who insulate their basements overwhelmingly choose to insulate on the interior. While interior insulation systems are generally less problematic during construction, with time they have a greater potential to contribute to moisture accumulation since they tend to retard the ability of foundation walls to dry. After one CARB home building partner experienced several instances of moisture pooling at the bottom of their basement insulation during the first summer after construction, the authors were prompted to investigate other interior insulation alternatives. This effort developed into a field-based research study that involved the side-by-side installation of eight different insulation systems in the basement of a newly constructed home outside of Chicago. Each system was equipped with temperature and relative humidity sensors to assess moisture performance. It was the objective of this study to gain a greater understanding of the mechanisms governing moisture movement in commonly used insulation systems subject to field boundary conditions and installation methods. This understanding could in turn be used to aid in the design of systems with the least risk of moisture problems. It is important to note that the findings presented in this paper are for common interior insulation systems subject to the conditions in a particular basement.

Other workers have made significant contributions to identifying the important principles governing moisture transport in basement wall assemblies. Swinton and Karagiozis (1995) conducted a two-dimensional transient numerical

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study of the hygrothermal performance of newly insulated basement walls in response to moisture accumulation at the bottom of interior insulation systems during the first summer after construction. Airflow was not modeled in this study. A main conclusion of Swinton and Karagiozis (1995) was that that summertime vapor diffusion toward the inside and bottom of the basement insulation in response to temperature gradients is one likely contributing factor to the observed moisture problem.

Based on experimental findings from the University of Minnesota's Foundation Test Facility, Goldberg and Aloi (2001) have developed a basic conceptual model for moisture diffusion through poured concrete foundation walls in a cold Minnesota climate. During the winter this model predicts that moisture diffuses from the moist soil to the basement interior along most of the height of the foundation wall. However, since indoor vapor pressure is usually greater than outdoor vapor pressure during the winter, moisture diffuses from inside to outside in the portion of the foundation wall that is above grade or just below grade. Thus, at a certain height in the foundation wall, a neutral plane may exist that divides the wall into two sections with opposite directions of vapor diffusion. A decrease in outdoor ambient humidity shifts this neutral plane down. A decrease in basement air humidity shifts this neutral plane up. During the summer, the model predicts that moisture will continue to be driven from moist soil toward the basement interior below grade. In the above grade portion of the wall, with outdoor vapor pressure usually higher than indoor vapor pressure, moisture will also tend to be driven toward the inside of the basement.

The water vapor diffusion-based explanations for the transport of moisture developed in these works were useful for interpreting the results of this field study. However, diffusion alone was not able to adequately explain the performance of many of the systems investigated. Findings presented in this paper indicate that air movement is a significant moisture transport mechanism in many of the systems. Other workers, such as Fugler (2002), in a study of basement insulation in existing houses, also found air movement to be important, noting that "wall cavities communicated easily with basement air" and "there was no attempt to air seal or enclose the insulation at the top of each wall."

FIELD TESTING DESCRIPTION

House

The test house for this project is located outside of Chicago, Illinois. Construction of the house was finished in September of 2002, and the basement insulation and monitoring equipment was installed in October of 2002. Since the house is being used as a model home for a large production builder, it was unoccupied for the entire testing period. The house rainwater drainage system is standard practice for the builder and the region. The site grading around the basement is either flat or slightly sloping away from the house. Gutter downspouts discharge to 24 in. splash pans that direct rainwater away from the house. Approximately 1 ft of the 8 in. poured concrete foundation wall is exposed to ambient conditions above grade on the sides and rear of the house. In the south-facing front of the house, the top of the foundation wall is shielded from solar radiation by a two-car garage and a covered porch set on a 5 ft wide poured concrete slab. Due to these conditions, the above grade portion of the front foundation wall does not receive any direct solar gains despite its southern orientation. The east and west sides of the house do not receive significant solar gains either since they are shaded by adjacent homes. Inside, a furnace and cooling coil attached to uninsulated sheet metal ductwork are located in the basement. The basement is directly conditioned via two supply air registers. It is also indirectly conditioned by conduction energy losses and air leakage from the supply ducts.

Insulation Systems

The insulation systems selected for this work may be grouped into three construction categories. The first of these categories is made up of systems with rigid insulation installed directly in contact with the foundation wall. In each of the two systems investigated, the rigid insulation is held against the foundation wall with 1 × 4 horizontal furring strips (Figure 1). These furring strips are attached to the concrete with nails driven through the rigid insulation. The insulating material in one of the systems was 1.5 in. thick polyisocyanurate with foil facing on each side. The other system contained 2 in. thick expanded polystyrene (EPS). Due to its foil facing, the polyisocyanurate is a Class I vapor retarder, while the thickness of EPS used, with a permeability of approximately 2 perms, is Class III vapor retarder (ASHRAE 2001). The EPS system was installed along the full height of the foundation wall and finished with gypsum board to comply with local fire codes. The foil-faced polyisocyanurate system has an appropriate flame spread rating and therefore was not finished with gypsum board. However, since the polyisocyanurate system contains a Class I vapor retarder, the bottom 6 in. of the foundation wall was left exposed in this system to allow for some drying to the inside. The polyisocyanurate has a thermal resistance of 10 $ft^2 \cdot h \cdot °F/Btu$, while the EPS has a thermal resistance of 8 $ft^2 \cdot h \cdot °F/Btu$.

The second category of systems tested consist of 2 × 4 wood-framed walls offset roughly 1 in. from the foundation wall as is standard practice to allow for irregularities in the concrete surface (Figure 2). The stud cavities in two of these systems are insulated with encapsulated fiberglass batt products from two different manufacturers. Both of these systems are left otherwise unfinished, with no gypsum board. The cavities in a third and fourth stud wall system are insulated with unfaced fiberglass batts and kraft-paper-faced fiberglass batts, respectively. Since fiberglass and kraft paper cannot be left exposed, these systems were finished with gypsum board. All of the fiberglass batts used have a thermal resistance of 11 $ft^2 \cdot h \cdot °F/Btu$.

Table 1. Vapor Retarder Classes

	Class I Vapor Retarder	Class II Vapor Retarder	Class III Vapor Retarder
Permeance range	0.01-0.1 perms	0.1-1.0 perms	1.0-10.0 perms

The final construction category is composed of poly-faced fiberglass blankets with a thermal resistance of 11 $ft^2 \cdot h \cdot °F/Btu$ (Figure 3). In one system, the poly facing is unperforated and may be classified as a Class I vapor retarder. In another system, the poly facing is perforated and may be classified as a Class III vapor retarder. Flaps on either side of the blanket facing were stapled to 2 × 2 pressure-treated furring strips nailed into the foundation wall. The furring strips were spaced at 48 in. on center to accommodate the width of the blankets. In order to mimic the standard practice of the builder, the bottoms of the blankets were suspended 6 in. above the basement slab floor. The builder had developed this installation strategy to address the previously mentioned problem of moisture accumulation at the bottom of insulation.

Monitoring Equipment

All of the insulation systems monitored are at least 8 ft wide. At the center of this width in each wall system, Type-T thermocouples and relative humidity sensors were installed at three vertical locations: 1 ft above the slab floor, 1 ft below the top of the concrete wall, and in the center of the 100 in. high foundation wall. Most wall systems contain two such vertical profiles: one set of sensors against the concrete wall and one set on the room side of the insulation but still enclosed in the wall system (i.e., between fiberglass insulation and a facing material). The polyisocyanurate system has only one profile, between the rigid insulation and the foundation wall. It is important to note that the temperature and relative humidity of the concrete foundation wall itself were not measured. The sensors against the foundation wall measured the temperature and relative humidity of a pocket of air at the interface between the concrete and the insulation.

Care was taken to seal the transitions between separate insulation systems to eliminate air movement between insulation system test panels. Since there is significant shading on the south, east, and west, and only 1 ft of the foundation wall is exposed above grade, it is unlikely that direct solar radiation significantly affects the hygrothermal performance of any of the insulation systems. Finally, all of the insulation system sensors are separated by at least 10 ft from any of the outdoor splash pans.

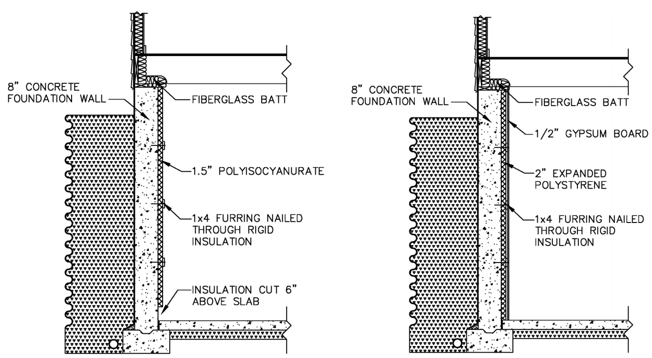

Figure 1 *Rigid insulation systems.*

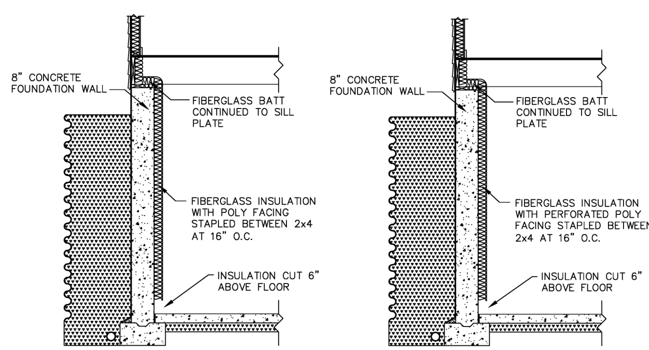

Figure 3 *Fiberglass blanket insulation systems.*

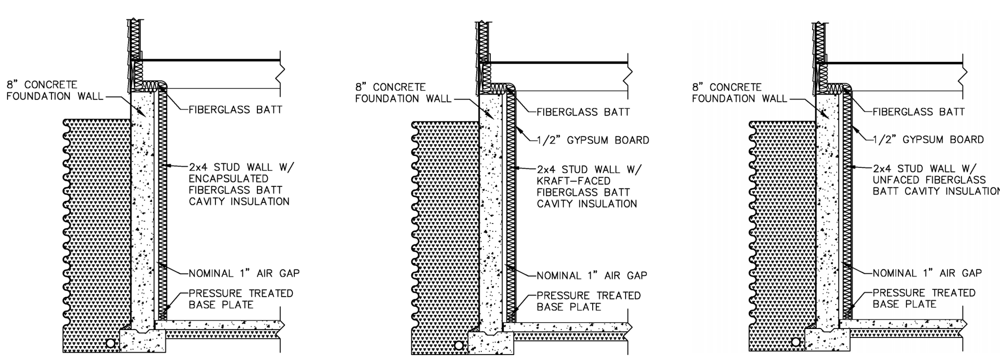

Figure 2 *Two-by-four stud wall systems with fiberglass batt cavity insulation.*

RESULTS

Due to the direct and indirect conditioning of the basement and the lack of occupants in the house (no internal moisture generation), basement conditions tended to be warm and dry during both the winter of 2002-2003 and the winter of 2003-2004. During the summer of 2003, the house thermostat setpoint was relatively low, resulting in long air-conditioning system run times and significant dehumidification of the basement air. During the summer of 2004, the house thermostat setpoint was relatively high, resulting in minimal dehumidification of basement air. These different summer operating conditions were ideal for a field study since the performance of the systems subject to a mild internal boundary condition during the first summer may be compared to the performance of the systems subject to a severe internal boundary condition during the second summer. Moisture movement through the three primary insulation system types in response to these conditions appears to be dominated by distinct physical processes. The authors found water vapor pressure to be the most useful parameter for understanding these dominant moisture transport mechanisms. In addition to indicating the potential for moisture diffusion, vapor pressure is useful for data interpretation because it quantifies the absolute moisture content of air at a particular measurement location. Thus, the vapor pressure of the basement air represents a type of "signature." In certain systems, the vapor pressure throughout the insulation closely tracked the basement air vapor pressure throughout the duration of the monitoring period. The authors interpreted these results to indicate that there was excellent communication between basement air and the air throughout the insulation system.

Rigid Insulation Systems

In the first summer of the monitoring period, there was a large difference between the basement air and outdoor ambient vapor pressure as a result of the aforementioned dehumidification provided by the HVAC system. Thus, in the case of the polyisocyanurate system during the first summer, the above grade portion of the foundation wall is in contact with a moisture source, and the bottom 6 in. of the foundation wall (below where the polyisocyanurate has been cut) is in contact with a moisture sink. In response to these boundary conditions, a vertical gradient in the concrete surface vapor pressure, evident in Figure 4, developed from July to September of 2003 in this system since significant drying due to diffusion through the polyisocyanurate was not possible. The lowest measurement location against the concrete is in moisture equilibrium with the basement air since it is 12 in. above the slab floor and only 6 in. above the bottom of the polyisocyanurate.

During the winter, there was no dehumidification due to the HVAC system, and the vapor pressure of the basement air and outdoor ambient air was similar. In response to these boundary conditions, the vapor pressure against the concrete was in equilibrium at all heights and closely tracks that of the basement air. Thus the potential for moisture to diffuse from the basement air and toward the concrete near the top of the foundation wall was not observed. If the house had been occupied, internal moisture generation may have increased the basement air vapor pressure sufficiently to create a favorable gradient to drive moisture toward the concrete near the top of the foundation wall.

Due to the minimal dehumidification provided by the HVAC system, the basement air vapor pressure was much higher in the second summer than in the first summer. The indoor-outdoor vapor pressure difference was also correspondingly smaller during the second summer. The vapor pressure against the concrete near the top of the foundation wall was only slightly higher during the second summer than the first summer. At the same time, the vapor pressure against the concrete near the bottom of the foundation wall was much higher during the second summer, resulting in a minimal vertical vapor pressure gradient.

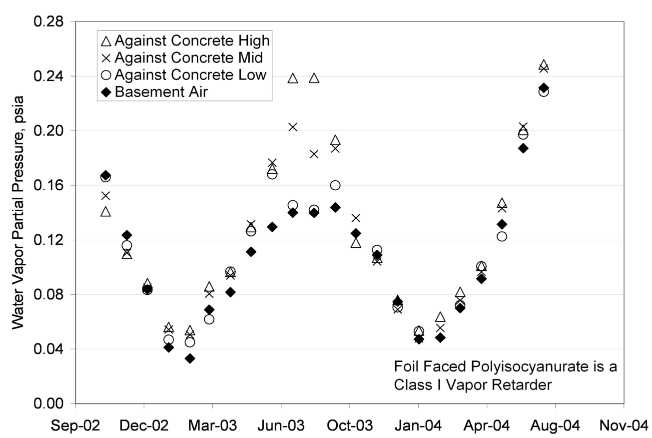

Figure 4 *Average monthly vapor pressure—polyisocyanurate.*

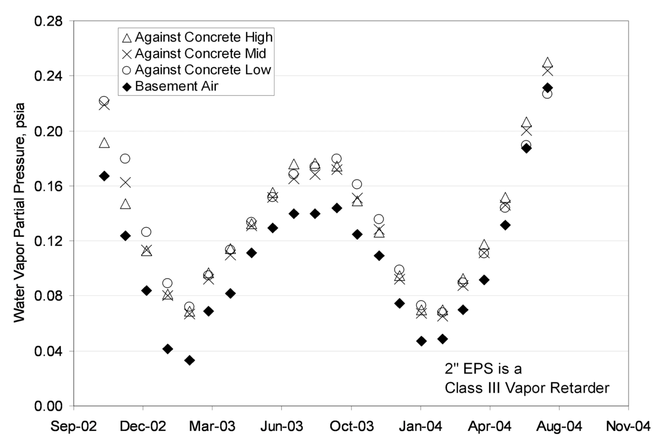

Figure 5 *Average monthly vapor pressure—EPS finished with gypsum board.*

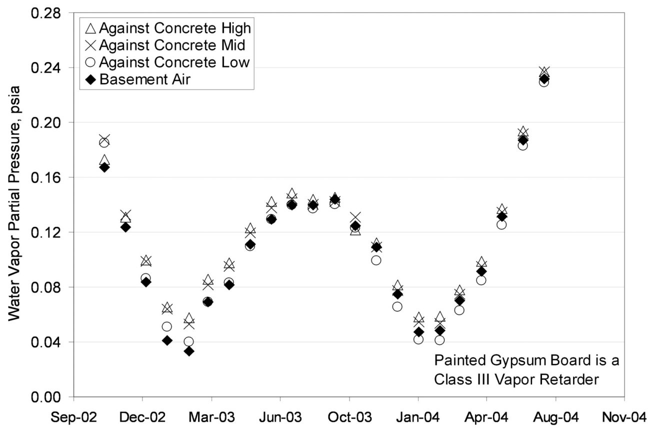

Figure 6 *Average monthly vapor pressure—2 × 4 stud wall with unfaced batt and gypsum board.*

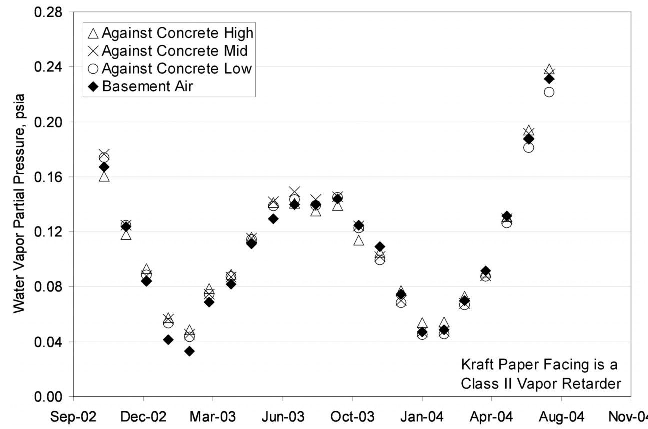

Figure 7 *Average monthly vapor pressure—2 × 4 stud wall with kraft-faced batt and gypsum board.*

Compared to the polyisocyanurate system, the EPS system responded very differently to the significant summertime indoor-outdoor vapor pressure difference during the first summer. Behind the EPS, the concrete surface vapor pressure was nearly in equilibrium at the three measurement heights since this system allows uniform drying due to diffusion through the EPS to the dehumidified basement air. As a result of the higher basement air humidity during the second summer, much less drying to the inside due to diffusion through the EPS was possible, and the performance of the EPS and polyisocyanurate systems were nearly identical. During both winters, the vapor pressure at all measurement locations between the EPS and concrete was higher than the basement air vapor pressure. Thus, as was also the case with the polyisocyanurate system, the potential for moisture to diffuse from the basement air through the insulation and toward the concrete near the top of the foundation wall was not observed.

In short, moisture transport through the two rigid insulation systems investigated is dominated by vertical diffusion though the foundation wall behind the polyisocyanurate and horizontal diffusion through the EPS. It is noteworthy that while the primary paths for moisture diffusion are different for these two systems, the vapor pressures against the concrete at all measurement heights were similar for both systems when there was a relatively small difference between indoor and outdoor ambient vapor pressure during both winters and the second summer. It is also important to note that regardless of the magnitude or direction of the vapor pressure gradient between the basement air and the foundation wall, neither of the rigid insulation systems investigated was ever at risk for condensation due to moisture diffusion since they both have vapor barriers on each side of the insulation. The foil facing on each side of the polyisocyanurate is a Class I vapor retarder. The first 0.5 in. of EPS on each side of this system is a Class III vapor retarder. At the same time, neither rigid system resulted in moisture accumulation over a full annual cycle.

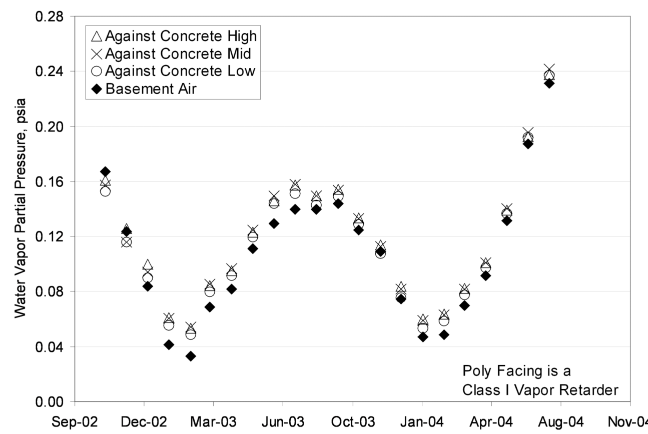

Figure 8 *Average monthly vapor pressure—2 × 4 stud wall with encapsulated batt #1.*

Stud Wall Insulation Systems

The moisture performance of all of the assemblies involving a 2 × 4 wall insulated with fiberglass batts was found to be similar. In Figures 6, 7, and 8 it is evident that the average monthly vapor pressure at all locations against the concrete closely tracks basement air vapor pressure for the stud wall systems with unfaced, kraft-faced, and poly-faced fiberglass batts. This identical behavior is remarkable since polyethylene encapsulating material is a Class I vapor retarder, kraft paper is a Class II vapor retarder, and the painted gypsum board used to finish the unfaced batt system is a Class III vapor retarder. Thus, at least near the inside surface of the concrete, the primary moisture transport mechanism seems to be due to air circulation between the basement and the stud wall systems and not water vapor diffusion.

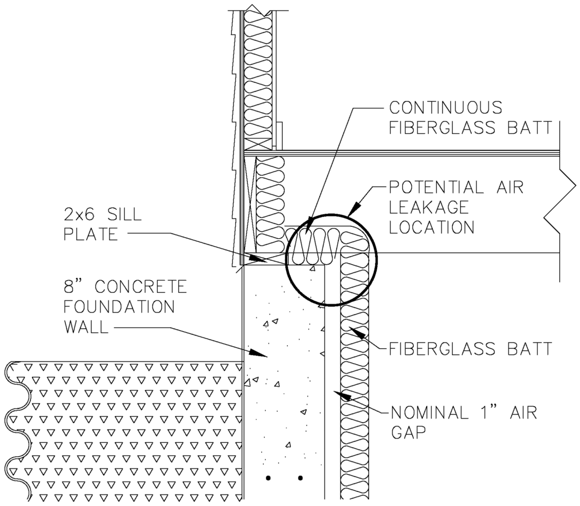

Figure 9 *Potential air leakage location in stud wall insulation systems.*

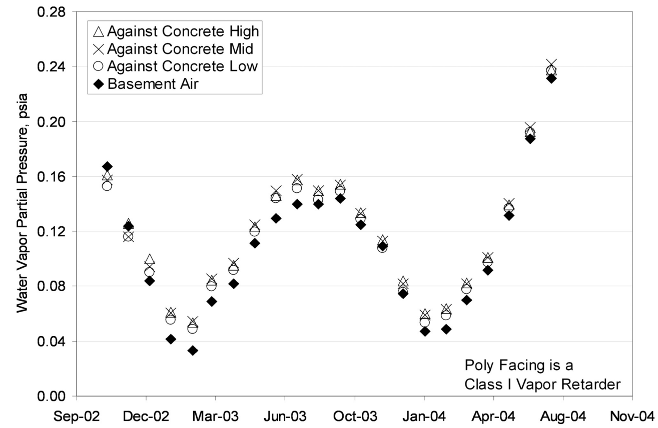

Figure 10 *Average monthly vapor pressure—2 × 4 stud wall with encapsulated batt #2.*

During the first summer, the stud wall systems had the lowest measured vapor pressure against the concrete of any of the systems studied. Thus, in these cases, dehumidified basement air that moved through the stud wall systems acted as an effective drying agent. During the second summer, when basement air was not significantly dehumidified, measured vapor pressures in the stud wall systems were correspondingly higher.

With measured data indicating that air movement is the primary mechanism for moisture transport in the stud wall systems, a plausible explanation for exactly where air enters and leaves these constructions is necessary. All of these systems contain a nominal 1 in. gap between the 2 × 4 wall and the foundation wall. The sides of this cavity were sealed with expanding foam at each end of a particular insulation system test panel. The concrete foundation wall and slab effectively air seal the rear and bottom of this cavity. However, the top is only separated from room air by small pieces of fiberglass encapsulated batt placed across the top of the foundation wall. In the case of the two encapsulated batt assemblies, the room-side Class I vapor retarder stapled (but not taped) to the face of the studs is not an effective air barrier. The kraft-faced and unfaced assemblies are finished with drywall on the room side. While this construction may provide more resistance to airflow though the front of these systems than the face-stapled poly, no extraordinary measures were taken to ensure an airtight drywall application.

Thus, the stud wall systems may be characterized as relatively airtight on the rear, sides, and bottom, somewhat resistant to air movement in the front, and not at all resistant to air movement at the top. The main driving force for air movement through these assemblies is likely due to the temperature difference between the cold foundation wall and room conditions. A reasonable scenario would then be for cavity air adjacent to the foundation wall to be cooled and sink. This process would start a convective loop with sinking air forced toward the warm side of the assembly after it reached the bottom of the cavity, where it would be heated and start to rise again, exiting the assembly either at the top or through the front. To replace this exiting air, new room air would then be drawn into the cavity at the top. The well-mixed air movement that would result from this scenario explains the nearly uniform vapor pressure measurements at all heights and locations observed in the stud wall assemblies throughout the year.

In order to test this air movement theory, on October 30, 2003, the top of the gap between the stud wall of encapsulated batt system #2 and the foundation wall was sealed with expanding foam. As an additional barrier to air movement, the polyethylene encapsulating material was taped to the faces of the studs in this system where it had formerly only been stapled. Encapsulated batt system #1 served as a control for this experiment since it was not air sealed and is adjacent to encapsulated batt system #2.

It is important to note that air sealing the top of a stud wall system will not prevent a convective loop from occurring within the cavity behind the insulation but it will prevent basement air from being drawn into this cavity. Thus, even in the air-sealed system, convection still results in a well mixed moisture distribution and equilibrium in the vapor pressure against the concrete surface, as is evident in Figure 10. It is also clear from Figure 10 that in the summer after air sealing, the vapor pressure against the concrete surface behind encapsulated batt system #2 is actually less than the basement air vapor pressure at the low- and mid-height measurement locations. In the summer before air sealing, the vapor pressure against the concrete in encapsulated batt system #2 was never less than the basement air vapor pressure. In both summers of the monitoring period, the vapor pressure against the concrete behind the

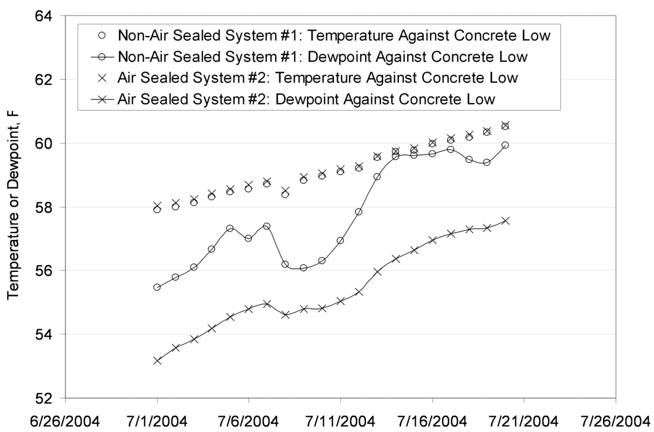

Figure 11 *Temperature and dew point of non-air-sealed and air-sealed stud wall systems.*

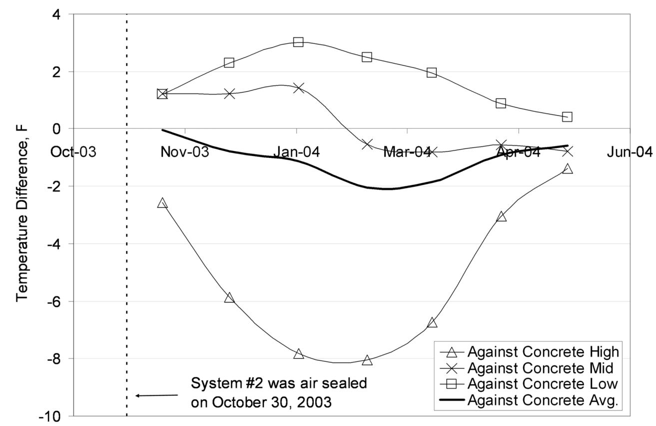

Figure 12 *Average monthly foundation wall surface temperature of non-air-sealed system #1—air-sealed system #2.*

non-air-sealed encapsulated batt system #1 was never less than the basement air vapor pressure. These results suggest that humid air that moved through non-air-sealed system #1 during the second summer acted as a moisture source when it came in contact with the bottom and middle of the concrete foundation wall. This speculation of basement air acting as a moisture source during certain conditions is confirmed by the July 2004 temperature and dew-point measurements presented in Figure 11. From this figure, it is evident that while the temperature against the concrete at the low measurement height is nearly identical for both systems, the corresponding dew point at this location is approximately 2°F higher in the non-air-sealed system compared to the air-sealed system. It is also clear from Figure 11 that condensation of humid basement air on the cold surface near the bottom of the foundation wall occurred in non-air-sealed system #1, while air-sealed system #2 prevented such condensation from occurring.

In addition to affecting the moisture performance and condensation risk, air-sealing system #2 was also found to impact thermal performance. In Figure 12, the difference in average monthly foundation wall surface temperature between non-air-sealed system #1 and air-sealed system #2 is presented.

Though the average foundation wall surface temperature was lower behind the air-sealed system, air sealing actually resulted in warmer temperatures near the top of the wall for the entire winter and warmer temperatures around the middle of the wall for part of the winter. These results suggest that in addition to contributing to greater heat transfer between the foundation wall and the basement air, air movement through a non-air-sealed stud wall also results in greater temperature equilibrium at the surface of the concrete. Thus, air-sealed system #2 tends to be warmer at the top and cooler at the bottom than non-air-sealed system #1. Since air sealing was not performed until October 30, 2003, a significant difference in the average monthly foundation wall surface temperatures between system #1 and #2 was not evident until December, 2003. The performance difference between the two systems peaked in midwinter when the foundation wall was coldest and, therefore, the driving force for natural convection was greatest. By late spring, the foundation wall surface temperature in both systems closely approaches basement air temperature, resulting in less of a driving force for natural convection and more identical thermal performance between the two systems.

Therefore, whereas air movement was found to dominate the moisture performance of a non-air-sealed stud wall system even in the summer, air movement seems to only significantly affect the thermal performance of a non-air-sealed system when the driving force for natural convection is greatest during the winter. The 2°F higher foundation wall surface temperature measured after air sealing during February and March of 2004 is significant because during February and March of 2003, when both encapsulated system #1 and #2 were not air sealed, the average foundation wall surface temperature difference between the two adjacent systems was 0.1°F. Thus, the foundation wall behind non-air-sealed system #1 is warmed both by conduction through the wood studs and cavity insulation and by convection due to basement air that moves freely into the cavity behind the stud wall. At the same time, the foundation wall behind air-sealed system #2 is warmed only by conduction through the wood studs and cavity insulation. The average foundation wall surface temperature behind the non-air-sealed system was 14.0°F colder than the average basement air temperature during February and March of 2004. The average foundation wall surface temperature behind the air-sealed system was 15.9°F colder than the average basement air temperature during February and March of 2004. These results indicate that the net effect of air movement through the non-air-sealed encapsulated batt system on winter foundation wall heat loss is small but not insignificant.

Blanket Insulation Systems

Like the polyisocyanurate system, the fiberglass blanket system faced with an unperforated polyethylene material contains a Class I vapor retarder that does not allow significant horizontal diffusion through the system along the entire height of the foundation wall except for the bottom 6 in. where the blankets are cut above the slab floor. Unlike the polyisocyanurate system, while the unperforated blanket is faced with a Class I vapor retarder on the room side, it is not encapsulated with such a vapor retarder. Thus, at the top and bottom of the blanket, fiberglass is exposed to basement air. Since the permeability of fiberglass to water vapor diffusion is much greater than that of concrete, vertical diffusion through the blanket system is likely a more significant moisture transport mechanism than vertical diffusion through the foundation wall. In response to humid outdoor air in contact with the top of the foundation wall and dry indoor air in contact with the bottom of the foundation wall during the first summer, a vertical gradient in the vapor pressure against the concrete developed in the fiberglass blanket system. This gradient in vapor pressure at the concrete surface is similar, though not as pronounced, as that which was observed behind the polyisocyanurate. Like the polyisocyanurate system, the vapor pressure near the bottom of the foundation wall behind the unperforated blanket is nearly identical to that of the room air. The vapor pressure against the concrete at foundation wall mid-height in this system is also similar to that of the polyisocyanurate system. However, the vapor pressure against the concrete at the top of the foundation wall is significantly less than that of the polyisocyanurate system. This discrepancy in performance between these two systems during the first summer is likely due to the ability of the foundation wall to dry to the dehumidified basement air through the fiberglass at the top of the blanket system. During the second summer, when there was less of a difference between indoor and outdoor ambient vapor pressure and the potential for the foundation wall to dry to humid basement air was not as great, the measured vapor pressures against the concrete were similar for the unperforated blanket and polyisocyanurate systems.

By allowing some drying of the foundation wall to the basement air through perforations in its facing material, the perforated blanket system performed similarly to the EPS system, resulting in a greater degree of equilibrium between vapor pressure at the concrete surface and basement air vapor pressure—especially near the top of the system in the summer. Near the bottom of the foundation wall against the concrete, the vapor pressure measurements behind both blanket systems tended to be relatively similar. This result is an indication that at the bottom of the perforated blanket system, downward diffusion through the fiberglass is a much more significant moisture transport mechanism than horizontal diffusion through the perforated facing material.

Because some contractors install fiberglass blankets between horizontal furring strips attached to the top and bottom of a foundation wall, modifications were made to both blanket systems on October 30, 2003, in order to assess the impact of this alternative installation method on moisture performance. During this retrofit, the existing fiberglass blankets and vertical furring strips were left in place and the bottom and top of the blanket facing material was stapled to the newly added horizontal furring strips. After this retrofit, it is evident from Figures 13 and 14 that stapling the top and bottom of both blanket systems slightly retarded drying to the basement air, especially at the high and low height measurement locations. While the basement air and outdoor ambient air vapor pressure were rapidly decreasing between October and November of 2003, the vapor pressure at the high and low positions against the concrete either did not decrease or slightly increased during this time. This effect was less pronounced in the perforated blanket system since some drying was still possible in this system through the facing material.

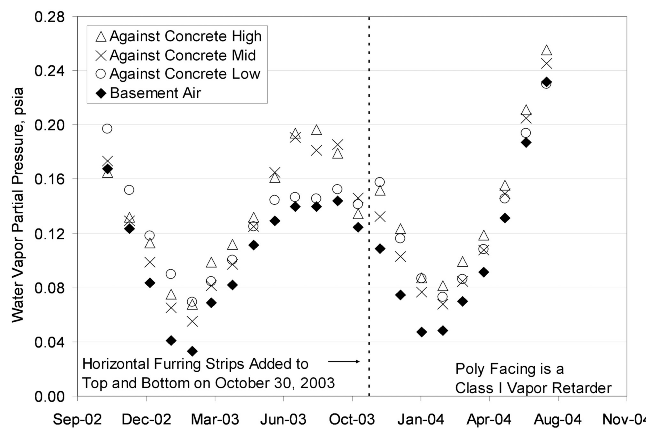

Figure 13 *Average monthly vapor pressure—fiberglass blanket with unperforated poly facing.*

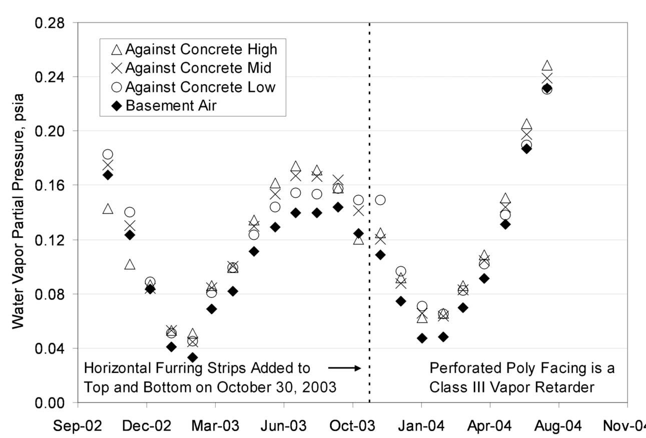

Figure 14 *Average monthly vapor pressure—fiberglass blanket with perforated poly facing.*

Thus, allowing the bottom of the fiberglass blankets to be in contact with basement air and using a perforated facing material can clearly result in greater foundation wall drying to the inside and, therefore, improved moisture performance during certain conditions. At the same time it is important to note that when the basement air was very humid, significant drying of the foundation wall to the inside was not possible, and these details are relatively inconsequential. Thus, during the second summer of the monitoring period, there was only a slight difference in the vapor pressure against the concrete at the high measurement location and no difference in the vapor pressure against the concrete at the low measurement location behind the perforated blanket compared to the unperforated blanket. This finding indicates that a perforated facing material is not likely to significantly decrease the risk for summer condensation due to the downward diffusion of vapor through a fiberglass blanket system cut slightly above the slab floor. By warming the cold, lower portion of the foundation wall, cutting the blankets above the slab floor may have decreased the risk for such condensation in both blanket systems. Since this study did not include a side-by-side comparison with blankets fully extended to the floor, it was not possible to directly quantify any moisture performance benefits of cutting the bottom 6 in. of a blanket system.

DISCUSSION

The two-year field monitoring period resulted in the possibility to study the performance of the different interior basement insulation systems over a wide range of internal boundary conditions: relatively dry basement air during the first summer, relatively humid basement air during the second summer, and relatively dry basement air during both winters. However, the performance of the different systems subjected to relatively humid basement air during winter was not measured.

The moisture performance of the stud wall systems as they are typically installed was found to be completely dependent on basement air humidity and independent of the classification of vapor retarder used. If the basement air is dry, movement of basement air through these systems can act as a moisture sink. If the basement air is humid, it is possible for air moving through these systems to act as a moisture source and condense on cold concrete surfaces near the bottom of the foundation wall. Air movement through these systems was also found to slightly affect thermal performance. However, a small degradation in the insulating value of an assembly is much less worrisome than the potential for condensation associated with this air movement. Ideally however, it would be desirable for a basement insulation system to be able to tolerate realistically high levels of basement air humidity. To this end, it may be possible to eliminate air movement and the associated condensation risk behind stud wall systems by building a stud wall flush to a foundation wall. In the experience of the authors, most stud wall basement insulation systems are offset from the foundation wall due to potential irregularities in the concrete resulting from form ties or form work. Also, if a wood stud wall is in direct contact with concrete, it should be pressure treated, which increases the cost of such a system. For stud walls that are offset from a foundation wall, detailed air sealing or the use of blown-in insulation that completely fills the gap behind stud walls may also eliminate air movement. However, the extra quality control and cost required by these strategies are not likely to be acceptable to a production home builder. The one positive aspect of a non-air-sealed stud wall system is that air movement may act as an effective drying agent in the case of moisture accumulation due to bulk water movement through cracks in the foundation wall.

Diffusion alone was found to be the dominant moisture transport mechanism in the rigid insulation systems. The measured vapor pressures behind the Class II vapor retarder EPS system and the Class I vapor retarder polyisocyanurate system were different during certain boundary conditions. However, when the basement air was not significantly dehumidified during the second summer of the monitoring period, there was very little difference in the measured vapor pressures behind both of these systems. The fiberglass blanket systems installed differed from the EPS and polyisocyanurate assemblies in that significant vertical diffusion through the fiberglass blanket insulation itself is possible. Thus, in both unperforated and perforated blanket systems, the diffusion of vapor toward the inside and bottom of the insulation during the summer predicted by Swinton and Karagiozis (1995) was observed. Since the vapor pressure against the concrete near the bottom of the wall behind these systems was found to closely track basement air vapor pressure, it is unlikely that perforations in the facing material significantly reduce the risk for condensation near the bottom of these systems. Cutting the bottom of the blankets above the slab floor may decrease this condensation risk and should be further investigated. Swinton and Karagiozis (1995) reported that condensation has still been documented with such part-height insulation strategies. However, even in the case of condensation, cutting the bottom of fiberglass blankets may allow accumulated moisture to evaporate more rapidly.

CONCLUSIONS

Moisture movement through each of the interior basement insulation system types was found to be dominated by distinct physical processes. The results presented in this paper are of course for a specific basement and particular operating conditions.

Moisture transport through the stud wall systems as they are typically installed was found to be dominated by the communication of basement air with air in the gap formed by offsetting the 2×4 stud walls from the foundation wall. In these systems, diffusion was insignificant and systems with a Class I and Class III vapor retarder performed identically. Air movement through a basement insulation system is not desirable because it requires basement air humidity control to ensure that no condensation occurs. It was possible to effectively air seal the cavity behind the stud wall systems from the basement air; however, this level of quality control is unrealistic to expect from a production home builder.

Moisture transport through the rigid insulation systems studied was found to be dominated by vertical diffusion through the foundation wall behind a Class I vapor retarder system and horizontal diffusion through a Class II vapor retarder system. It is noteworthy that while the primary paths for moisture diffusion are different for these two systems, the vapor pressures against the concrete at all measurement heights were similar for both systems when there was a relatively small difference between indoor and outdoor ambient vapor pressure—a condition that occurs when basement air dehumidification is minimal. It is also important to note that regardless of the magnitude or direction of the vapor pressure gradient between the basement air and the foundation wall, neither of the rigid insulation systems investigated was ever at risk for condensation due to moisture diffusion since they both have vapor barriers on each side of the insulation. At the same time, neither the full height class III vapor retarder system or class I vapor retarder system cut 6 in. above the slab resulted in moisture accumulation over a full annual cycle.

Finally, moisture transport through the blanket systems was found to be dominated by vertical diffusion through the fiberglass blanket itself and by horizontal diffusion in the case of a perforated facing material. As was the case with the rigid insulation systems during the summer, when the basement air was not dehumidified, drying to inside could not occur and the permeability of the assemblies was relatively unimportant to moisture performance.

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