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Performance of Thermal Insulation on the Exterior of Basement Walls

by M.C. Swinton, M.T. Bomberg, M.K. Kumaran, N. Normandin and W. Maref

Basement problems are a frequent source of claims made under new home warranty programs. This Update presents the results of an IRC/industry research project on the performance of insulation systems applied to the exterior of basement walls.*

A survey of new home warranty programs across Canada showed that the combined action of water and soils on basements was responsible for most major basement failures in new homes in 1994 and 1995.[1] Frost action on basement walls was cited as a contributing factor in 40% of the failures; swelling clays (resulting from strong fluctuations of wetting and drying in clay soils) were responsible for another 36%; and frost action on the footings, a high water table and the presence of water-borne soluble salts contributed another 9% for a combined total of 85% of all failure cases surveyed.

In the case of major basement failures, repairs are generally expensive: not only does the foundation itself usually need to be repaired, but also the elements that protect it have to be put in place to prevent future problems. For instance, the provision of drainage elements, such as eaves troughs, proper grading, wall and footing drainage, accounts for a substantial share of the repair costs incurred by warranty programs for basement repairs.

The need to protect the foundation from the below-grade environment is not a new concept.[2,3,4,5,6] (The first consideration of insulation applied to the exterior of house basements goes back about 30 years.[3,4]) Over the years, new products and systems have been introduced to perform this function. How these products and systems actually perform and whether or not they can meet the performance requirements for basement applications are key issues being addressed by those responsible for developing regulations governing their use in Canada.

It was in this context that IRC initiated a research program in collaboration with industry partners to take a fresh look at how exterior basement insulation systems perform (see Text Box 1 "Design and Installation Parameters Investigated" for discussion of insulation system variables).

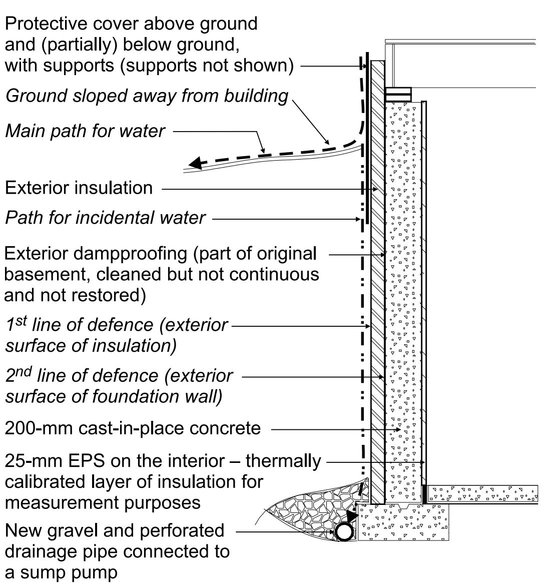

Figure 1. Principle flow path for above-ground water and two lines of defence below ground

* The industry consortium members were the Canadian Plastics Industry Association, the Expanded Polystyrene Association of Canada, the Canadian Urethane Foam Contractors Association, Owens Corning Inc. and Roxul Inc.

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Text Box 1
Design and Installation Parameters Investigated
(See Figures 2 and 3)

The following parameters were investigated:

- Five insulation products:
  1) moulded expanded polystyrene (EPS) Type 1
  2) moulded expanded polystyrene (EPS) Type 2
  3) medium density spray-polyurethane foam
  4) semi-rigid mineral fibre intended for exterior application to basement walls
  5) semi-rigid glass fibre intended for exterior application to basement walls
- Two installation approaches for the insulation products:
  1) in direct contact with the soil below grade
  2) wrapped (but not sealed) in two layers of polyethylene
- Various joining techniques for the insulation products:
  1) butt joints
  2) ship-lap joints
  3) continuous spray foam
- Two approaches to relieving water pressure on the inner side of the insulation boards:
  1) grooves
  2) no grooves
- Two approaches for mounting the above-ground protective cover (fibre-cement board):
  1) vertical Z-bars
  2) horizontal Z-bars
- Two grading schemes:
  1) sloped away from the wall (good landscaping practice)
  2) sloped towards the wall (poor landscaping practice)
- Two approaches with respect to the gravel underneath the backfill:
  1) Protected by filter cloth over the gravel
  2) Unprotected

Exterior basement insulation can play a number of roles within the basement envelope system (see Text Box 2). Since heat-loss control and ground-water management are the critical roles that any exterior insulation must play, both were assessed in the IRC study. Heat-loss control is dependent on many factors, including how well the basement wall system manages water (i.e., keeps moisture out of the wall system).

The water-management capability of the insulation is related to the overall water-management strategy for the basement envelope system (see Figure 1). The diversion of ground water away from the basement is the primary means of controlling the quantity of water that the below-grade wall has to deal with. Surface-water control is seldom perfect, however, hence the basement envelope system must be designed to keep out any rain and melt water that finds its way below grade.

The most effective strategy for managing water is to provide two lines of defence. When exterior basement insulation is used, the first line of defence is the exterior surface of the insulation, which supplies a continuous means of managing water from the ground surface down to the gravel and drainpipe at the footing. The second line of defence is the outer face of the foundation

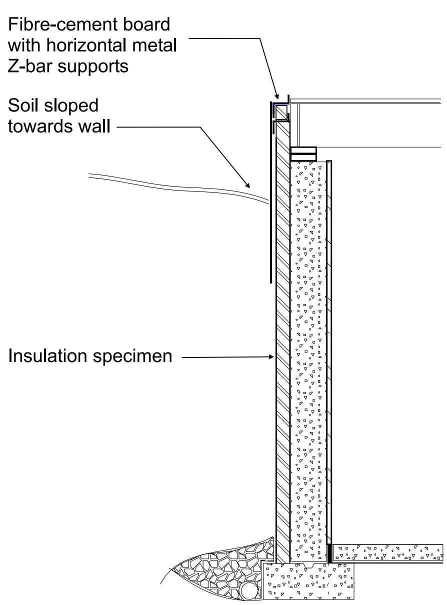

Figure 2. Section of one basement wall, with horizontal metal supports for fibre-cement board and soil sloped towards the wall (poor landscaping practice)

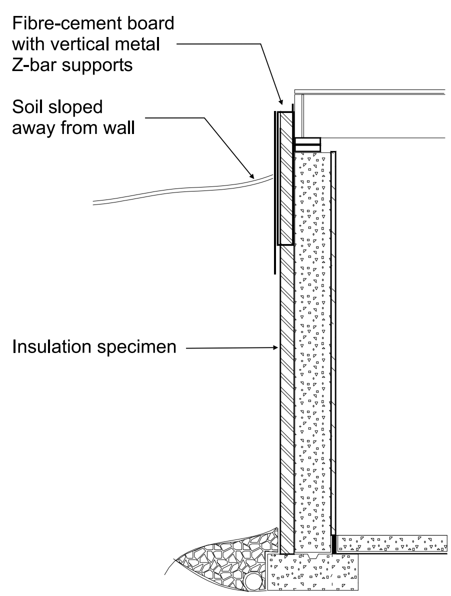

Figure 3. Section of the other experimental basement wall, with vertical metal supports for fibre-cement board and soil sloped away from the wall (good landscaping practice)

Text Box 2
Functions of the Basement Envelope System

The exterior basement insulation system can effectively perform up to 10 key functions (shown below in bold), including the provision of thermal insulation, thus eliminating the need for the multiple layers of material that would be required to address these functions separately. (List adapted from Reference 7.)

The basement envelope system must

- Provide
  - support for the building
  - earth retention
  - **protection of the foundation from the exterior environment (i.e., water, moisture, freeze-thaw action, etc.)**
- Control
  - **heat flow**
  - **air flow, including soil gas entry**
  - surface emissions
  - **interior surface condensation**
  - **interstitial condensation**
  - **vapour flow into the envelope from the interior**
  - **vapour flow into the envelope from the exterior**
  - **construction moisture** (The placement of the insulation on the exterior allows moisture generated during construction to evaporate.)
  - **rainwater and groundwater flow into the envelope**

As well as providing the key functions listed above, the basement envelope system has a role to play with respect to controlling

- service water (supply and sewer water)
- light, solar and other radiation
- noise
- fire

In addition, the basement envelope system is expected to be

- **durable** (i.e., provide the above functions over the service life of the envelope)
- aesthetically pleasing (i.e., have an appropriate finish)

Figure 4. IRC Test House #1 with above-ground portion of basement visible

(cast-in-place concrete, concrete block, or wood sheathing in a permanent wood foundation), which can handle the incidental quantities of water that may get by the first line of defence.

Prior to this study, designers and builders had little factual information about how the insulations they specified would perform when placed on the outside of a basement wall in contact with the earth. But IRC's continuous monitoring of the thermal performance of 13 different basement insulation systems throughout two heating seasons has provided some answers, including some understanding of how these systems manage water. The insulation systems were placed side by side on the exterior of two of the basement walls of IRC's Test House #1 (see Figure 4).

Thermal Performance

The key finding from the study is that all of the insulation products provided sustained thermal performance over two full heating seasons, with each of the specimens showing only small variations from its average value (Figure 5 shows the R-value for a typical specimen). The specimens sustained their performance even during major rain storms and winter thaws, when the effects of water movement were recorded at the outer face of the insulation specimens. This result was contrary to expectations that the R-value would decline under such circumstances, especially if water were to move through the insulation.

One plausible explanation for this relative stability in thermal performance lies in the stability of the temperature regime in the below-grade environment, in contrast to that of the above-grade environment. In the below-grade environment, the temperature differences across the insulation are

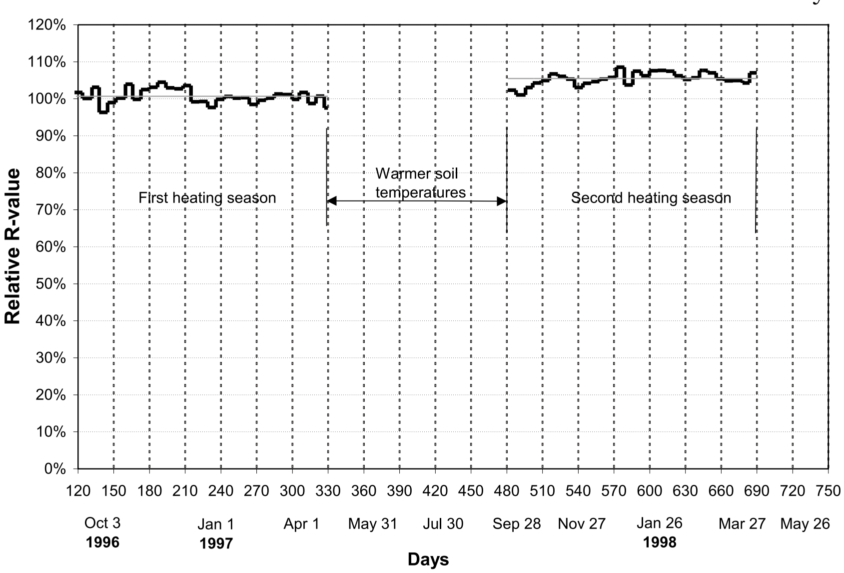

Figure 5. Typical in-situ R-value for a specimen over two heating seasons expressed as a percentage of its R-value in the initial month

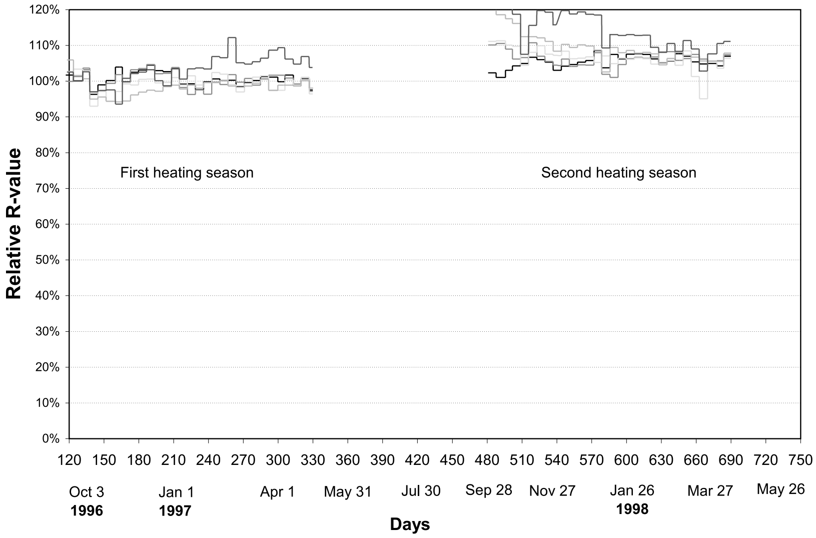

Figure 6. Range of results for all products assessed on one wall (EPS Type 1, EPS Type 2, glass fibre, mineral fibre and SPF)

always in one direction: heat flows outward through the insulation to the ground in a continuous fashion throughout the year. Even though there is obvious exposure to moisture in the soil, the relatively steady temperature regime likely assists in the establishment of moisture equilibrium within the insulation, resulting in the low moisture contents of the specimens observed upon their retrieval.

Conversely, when moisture moves in and out, the thermal properties of the insulation are short-circuited and the effectiveness of the material is compromised.[8,9] In addition to maintaining a steady temperature regime, the insulation systems evaluated in the study appeared to have the necessary attributes to keep water out of the basement wall system.

Insulation Products Evaluated

All five insulation products assessed in the research are designed to deliver a sustained level of thermal resistance in ground, but they do so with different strategies (see Figure 6). In the figure, all R-values were referenced to their own average R-value of the first month; hence all graphs start at about 100%. The degree to which the graphs diverge from this common starting point is a measure of the difference in each product's ability to deliver sustained R-value. The figure demonstrates that all products sustained R-values very close to their starting R-values throughout the first year, and performed just as well, or even better, in the second year.

EPS Type 1 and EPS Type 2

Two types of moulded expanded polystyrene (EPS), a rigid board insulation, were assessed — EPS Type 1 and EPS Type 2. Each has slightly different thermal and mechanical properties. The compressive effects of the pressure developed in the soil around basements on both boards is small relative to the compressive strength of the boards, even for the lower density product, Type 1. The two types were placed side by side to see if any performance differences could be detected. Little difference in their ability to sustain R-value was found: on average, both types delivered sustained thermal performance over the two-year period (Figure 7).

While they are not classified as draining materials, the EPS products were able to handle water movement at their outer face in contact with the soil. There was no evidence of water reaching the concrete wall over most of its height, indicating that EPS products can provide protection from water ingress.

> *Text Box 3*
> ### Choice of EPS Type
> Prior to 1998, the National Building Code of Canada (NBC) had prohibited the specification of EPS Type 1 for use in contact with the ground for houses and small buildings, but in October 1998, the Canadian Commission on Building and Fire Codes approved the removal of this restriction.[10] This type of use was already permitted, and continues to be permitted, for all other types of EPS. While this change to the code was not based on the results described above, it is supported by them.

SPF

Spray-polyurethane foam (SPF) is a plastic insulation product that is foamed in place during its application. It is able to develop a higher R-value than other products of the same thickness. This higher thermal resistance was confirmed in the below-grade testing. By virtue of its application technique, SPF covers the basement wall in a continuous fashion around projections and penetrations. In fact, when the SPF samples were being recovered from the experimental walls, they had to be cut away from the wall and footing, since the foam was

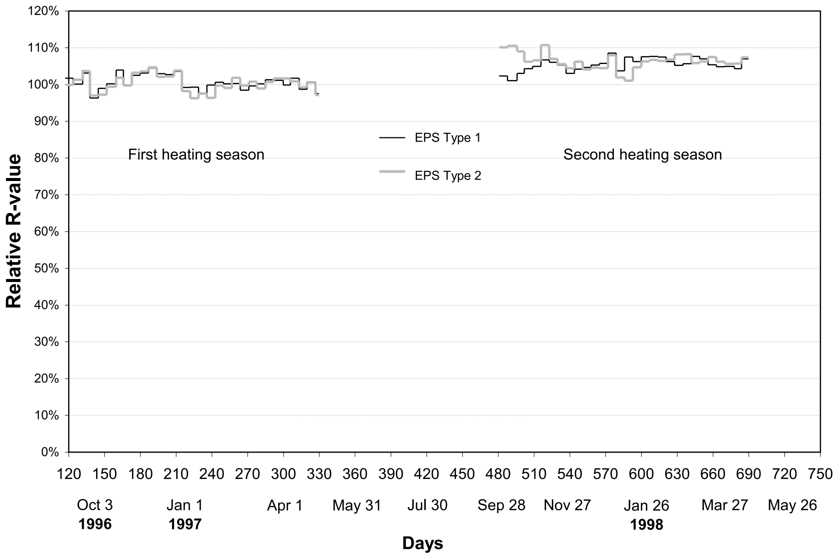

Figure 7. The measured performance of EPS Type 1 and EPS Type 2, which were side by side on the exterior of one basement wall, was basically the same — that is, both boards sustained thermal performance in this environment.

fully bonded to the concrete, forming a continuous protective layer over the wall, footing and joint (Figure 8).

The foam product is unique in its ability to protect the footing and direct water past it. It was the only product that showed no evidence of water around the footing. (The board and semi-rigid products simply rest on the footing and are not expected to control water movement in this area.) This finding suggests that when SPF is used, and the footing protected, dampproofing of the concrete is not required, even at the lowest level of the wall.

As with the EPS boards, water is managed at the surface of the SPF product, where it interfaces with the soil, and (as with the EPS) there appears to be less water movement at the outer surface than in the case of the fibrous insulations. Yet, in spite of the fact that there are no obvious voids to accommodate water, the basement wall system was able to manage water (see discussion of this issue in section entitled "Specimens with No Explicit Drainage Spaces").

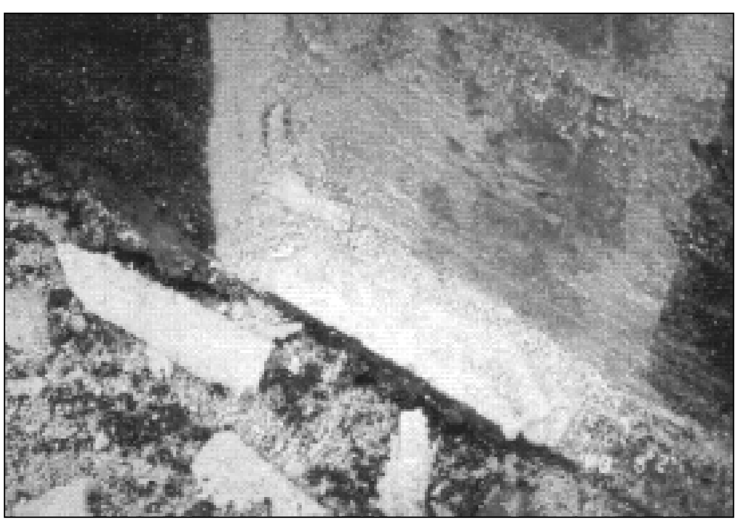

Figure 8. The spray-polyurethane foam bonded well to the concrete wall and footing. Remnants of the product still bonded to the concrete can be seen here.

Mineral Fibre Board

Mineral fibre board is a dense, semi-rigid material that provides a drainage function because of the stratification of fibres and the voids between these fibres. The research showed substantial water movement at the board's outer face, which was in contact with the ground during periods of heavy rain and thaw. There was no evidence of water reaching the concrete wall, or of a corresponding reduction in *in-situ* R-value. The steady thermal performance of the board throughout these periods of water movement suggests that only the outer fibres of the insulation are involved in managing the water.

Glass Fibre Board

Glass fibre board is also a semi-rigid draining fibrous insulation, but it is less dense than the mineral fibre product, and shows more compression under the same load. The manufacturer compensated for this by providing additional R-value in the uncompressed state, to achieve a claimed R-value for in-ground placement where it would be compressed. The research results confirm that the manufacturer's strategy works. The *in-situ* thermal performance of this product was similar to that of adjacent products that experienced less compression. Substantial water movement at the outer face of the insulation was documented, confirming that drainage was taking place.

Water-Management Capability of Different Insulation Specimens

There is no doubt that fibrous products can facilitate drainage, as recognized by at least one provincial building code and confirmed by the research for both mineral fibre and glass fibre products. Yet the success of the rigid insulation boards and the spray-foam product in excluding water from the basement wall system raises the question: Are voids or spaces for drainage necessary to provide adequate water management?

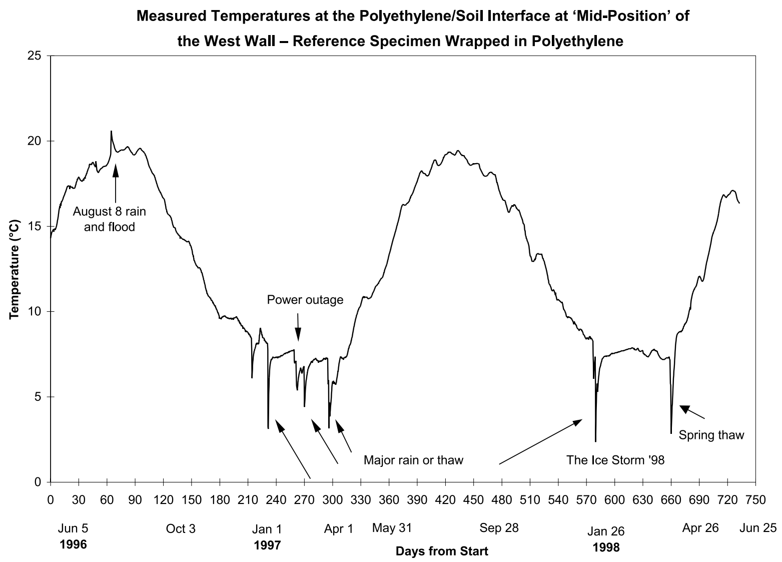

Figure 9. Measured temperatures at the polyethylene/soil interface at mid-position of the West wall — reference specimen wrapped in polyethylene

Specimens with No Explicit Drainage Spaces

The researchers investigated two different specimens, each wrapped in two layers of polyethylene, forming smooth surfaces with no drainage spaces. They found that in both cases, the specimens promoted water movement at the outer surface so that the water did not penetrate the basement wall system, demonstrating that drainage spaces are not necessary to protect basements from water ingress.

The 'spikes' in the temperature profile at the insulation/soil interface (shown in Figure 9) are evidence of water movement. They always occurred during documented thaws or heavy rainfall. The glass fibre, mineral fibre and polyethylene-wrapped samples (results of the last-mentioned are shown in the figure) displayed the largest spikes. It can be inferred from the results, although not proven, that the greater the length of the spike, the greater the volume of water moving on the outer face of the basement wall assembly. (Note: The August 8, 1996 storm, which caused a "warm" peak in the temperature profile, was reported to be a 1-in-75-year event in Ottawa. The Ice Storm of 1998, an even rarer occurrence, showed up as the major "cold" peak in the graph, suggesting that there had been considerable water movement).

Drainage Grooves in Rigid Boards

In recent years, drainage grooves have been introduced in rigid insulation boards for below-grade applications, to provide vertical air spaces between the insulation and the foundation wall. These spaces were intended to relieve potential water pressure build-up by providing drainage openings at the insulation/foundation interface (Figure 10). As such, the grooves were designed to enhance the performance of the second line of defence — i.e., the cast-in-place concrete wall — against water ingress.

The research clearly showed that water does not normally reach the concrete wall when there is a properly installed insulation system with both above-grade drainage elements and a functioning drainpipe. As well, given the surface roughness of concrete walls, it is unlikely that rigid insulation boards would form a continuous fit against the concrete and cause the build-up of water head, or pressure, if a breach of the first line of defence were to occur. The grooves are at best an enhancement to the second line of defence, which only comes into play in cases where every other strategy or mechanism has failed.

Board Joining Technique

Several techniques can be used to prevent the ingress of water between adjacent insulation boards, including tightly installed butt joints and the use of ship-lap edges. Both were found to be effective in preventing water from reaching the back of the insulation and

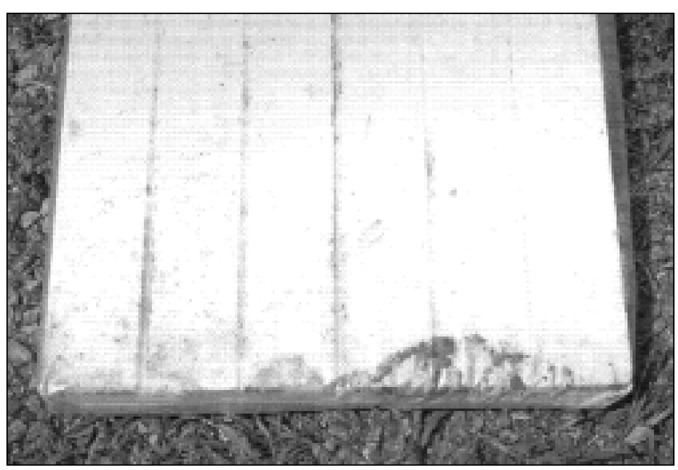

Figure 10. Grooves on the backside of a recovered EPS specimen. Except for the bottom 50 mm or so, the back of the board shows no evidence of water movement, which in the clay soil found on the test site would leave evidence through sedimentation. The fact that the grooves of the specimen are clean indicates that they played no role in handling water during the 30 months of exposure at this site.

the concrete wall. Some movement of water can be expected between the joints, but the lack of hydrostatic build-up apparently keeps the water from migrating to the back of the board and into the concrete wall.

There was only one instance in which water reached the concrete wall behind the insulation. This appeared to be the result of installing dissimilar fibrous insulations side by side, adjacent to a downspout that had been placed near the foundation, thus defeating the primary means of controlling surface water and directing it to the wall. The lack of a proper fit at the joint between these dissimilar products, combined with their fibrous nature, may have promoted the development of a free path for the water to reach the concrete wall over time.

The situation described above underlines the importance of maintaining all strategies for preventing water ingress into the basement envelope system — i.e., providing

- a primary path for shedding water over the ground, away from the building
- a continuous first line of defence (the exterior insulation), and
- a second line of defence (the concrete wall), which in this case turned out to be needed.

When insulation board products are used to provide the water-management function, the installation details and the fit between the joints are critical in ensuring an effective first line of defence.

Thermal Bridges

It is known good practice to avoid thermal bridges in construction, although they are inevitable in some cases. However, it is particularly important to avoid significant thermal bridges when connecting one thermally conductive material to another — especially to one with a large surface area.

Two different support techniques for the fibre-cement board used for above-grade protection were investigated (Figures 2 and 3). One design featured supports fastened horizontally to the wooden header at the top of the fibre-cement board (reference case). The horizontal Z-bars are thermal bridges but they are fastened to the wooden header, which is insulated on the inside so that the thermal bridge is broken. The other support system was more conventional: metal Z-bars fastened vertically to the concrete, providing a clear thermal bridge through the insulation.

Although the vertical Z-bars reached down only 270 mm below grade, their influence extended well below this level because they were fastened to the concrete, a thermally conductive material. Even at 740 mm below grade, which is well below the bottom of the Z-bars, the influence of the bars was quite noticeable. Measurements taken at the centre point of the insulation specimens showed that the effective thermal resistance of these assemblies was 13% lower on average than that of the assemblies with the thermally broken support system.

Grading That Lasts

The grading on one of the two basement walls of the Test House was sloped outward (5% positive slope, representing good practice) during the final landscaping, after a full winter and spring of soil settlement. The other wall was sloped inward towards the wall (5% negative slope, representing poor practice) for purposes of comparison.

When the grades were re-measured at the end of the experiment, researchers found that soil subsidence had resulted in negative slopes towards both walls. The initial 5% positive grade sloping away from the wall had become a negative grade sloping towards the wall — the primary means of diverting water away from the wall had been eradicated in one year. This finding indicates that steeper initial grades are needed to compensate for eventual soil settlement, or that a more reliable means of diverting surface water must be provided. Better backfill compaction would also help.

In the first year, there was little trace of water movement on the specimens on the properly graded wall even when there was evidence of water movement (during periods of thaw and rain) on the specimens on the improperly graded wall. In the second heating season, however, the specimens on both walls had to deal with similar quantities of water.

Gravel Treatment

Filter cloth was used to cover the gravel on one side of the Test House, but not on the other side. When the insulation systems were retrieved, the team was looking for signs of sedimentation in the drainpipes on both sides of the Test House. However, there was no sedimentation in either set of drainpipes, which means that this experiment did not yield any definitive information on the question of whether or not the filter cloth helps prevent the gravel from clogging the drain pipes.

Protecting Foundations from Freeze/Thaw Action

The coldest concrete temperature, measured at 270 mm below grade during the heating season, was about 11°C. Obviously, no freeze/thaw cycles were observed in the concrete. As well, portions of the wall system near grade that would normally experience freeze/thaw conditions were protected from melt or rainwater by the fibre-cement board.

Conclusions

A high-performance basement envelope system must address all the functions required of such a system. To achieve a high level of performance over time, it is particularly important to differentiate between the insulation system and the insulation product. All the insulation products assessed in the study delivered similar, sustained thermal performance. At the system level, some systems performed better than others — specifically, the thermal performance of those systems with horizontal Z-bars, in which the thermal bridge was broken, was superior to those with vertical Z-bars, in which it was not. All specimens also managed water well, using different, but equally successful, strategies.

Summary

- Only small differences were found among the different products in their ability to provide sustained thermal performance — each employs a different water-management strategy. EPS Type 1 was shown to be suitable for application to the exterior of basement walls.
- It is important to avoid thermal bridging — even limited contact with another thermally conductive element, such as concrete, can have a significant impact on the thermal performance of the entire basement wall system.
- Protective covering plays an important role at and just below grade level, where freeze-thaw action is likely to be most severe.
- The need for drainage grooves to enhance the performance of the second line of defence should be re-examined.
- Shallow sloping of landscaping cannot be counted on as a means of keeping water away from the basement wall, as it does not last. Diverting surface water is the primary means of controlling the amount of water that the basement envelope system has to deal with.
- Exterior insulation can provide a first line of defence for the basement envelope system if it has sufficient water-management capability. This capability was effectively delivered by all the insulation specimens evaluated.
- Attention to installation detailing is important with semi-rigid and board insulation products, to ensure continuity of the first line of defence at the joints and corners.

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Telephone: (613) 993-2607; Facsimile: (613) 952-7673; Internet: http://irc.nrc-cnrc.gc.ca

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