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In-situ Performance Evaluation of Spray Polyurethane Foam in the Exterior Insulation Basement System (EIBS)

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

In 1995, a joint research project¹ with the Institute for Research in Construction was initiated to assess the in-situ thermal performance of a number of insulation products used as exterior basement insulation in contact with the ground.

Sixteen insulation specimens measuring 610 mm and 1220 mm wide were installed on the exterior basement walls of an experimental building, Test Hut #1, located on NRC campus in Ottawa. These specimens were instrumented prior to backfilling and their thermal performance was monitored over two full years. Soil temperatures and moisture content were monitored concurrently. Weather events were recorded daily. This paper focuses on the performance of the two Spray Polyurethane Foam (SPF) specimens assessed in this experiment.

Through analysis of the surface temperatures of the specimens, water movement was detected at the insulation/soil interface through various periods of heavy rain and major thaws throughout the two-year period. Over the same periods, the surface of the concrete on the inside of the insulation showed no evidence of water penetration through the SPF layer. The insulation specimens were retrieved after 31 months of exposure in the soil. Good and continuous surface adhesion was also noted on removal. Samples were taken from these exposed specimens. When tested in the lab after recovery and drying of the specimens, the compressive strengths of the SPF samples were slightly higher than those tested at the beginning of the experiment.

For the conditions recorded over two years of monitoring, the thermal performance of each insulation specimen was found to be stable through the heating season. The thermal performance appeared not to be significantly affected by water movement at the exterior face of the insulation. One SPF specimen showed steady thermal performance through two heating seasons while the other actually improved in the second year. It was concluded that the key performance factors of the 76-mm thick SPF specimens sprayed on the exterior surfaces of the concrete basement wall all remained at a very good level, i.e., the in-situ thermal resistance, the compressive strength, and the moisture contents of the specimens.

Keywords: Exterior insulation, basement walls, thermal resistance, spray polyurethane foam, in-situ measurement, thermal performance, heat transfer, analysis, temperature, heat flow, heat loss.

¹ The consortium included Canadian Plastics Industry Association, Expanded Polystyrene Association of Canada, Canadian Urethane Foam Contractors Association, Owens Corning Inc. and Roxul Inc

Introduction

Consumer expectations of the use and performance of basements have evolved over the years in Canada. More and more, basements are being built or converted into liveable space, with the expectation that their performance and comfort will match or even exceed those of above grade spaces. For this to be achieved, the basement envelope system needs to perform in a durable fashion, within the below-grade environment.

In an effort to focus the development of performance guidelines for basement envelope systems, a survey of new home warranty programs across Canada was undertaken in 1994 and 1995 [1]. Results showed that the combined action of water and soils on basements was a mechanism involved in the majority of major basement failures in new homes. The resulting repairs were generally expensive. Provision of the moisture and water protective elements of the basement envelope formed a substantial portion of the repair costs incurred by warranty programs for basement repairs, as shown in Figure 1.

Previous efforts [2 and 3] to establish the suitability of insulation products for below-grade application had focussed on analysis of lab tested properties after exposure, and have not addressed the in-situ thermal performance nor have these looked at the performance of different insulation products such as Spray Polyurethane Foam (SPF) in unprotected below-grade applications. In an effort to assess how well those products perform as exterior basement insulation, a joint research project was initiated with industry.

This research project was undertaken to determine the effect of the below-grade environment on the in-situ thermal performance of exterior basement insulation systems. It involved a number of material and system issues. Material considerations involved the selection of existing and new thermal insulation products (being under development). These products were placed side-by-side on the basement wall to create virtual test compartments. The insulation was exposed to the Ottawa climate, including below-grade conditions, over a two and half-year period from October 1995 to June 1998. Over this period, ten Expanded Polystyrene (EPS), two Spray Polyurethane Foam (SPF), two Mineral Fibre Insulation (MFI) and two Glass Fibre Insulation (GFI) specimens were placed on the exterior of the basement wall in the experimental building Test Hut #1 located on NRC Campus in Ottawa.

Objectives

The objective of this paper is to examine the in-situ performance of the SPF specimens and record the effect of their exposure when SPF is used as exterior basement insulation. The key performance factors of the SPF insulation (such as in-situ thermal resistance, laboratory tested thermal conductivity, water vapour permeability and compressive strength) were investigated. By examining the thermal performance of Spray Polyurethane Foam (SPF) in-ground over an extended period, the characteristics of what constitutes acceptable performance was established.

Approach

The SPF specimens were sprayed in accordance with the Canadian General Standard Board (CAN/CGSB) standards covering this product [4]. The foam insulation was sprayed over the full height of the exterior basement walls of Test Hut #1, at NRC's main Campus in Ottawa. Their performance was monitored using a strategy developed to monitor the in-situ thermal performance of roof insulation [5 and 6]: a thermally calibrated, 25 mm layer of expanded polystyrene board was installed over the entire surface of the interior of the basement wall. Thermocouples were systematically placed at the surface of each element in the wall, in a vertical array consisting of 16 points per specimen. A schematic diagram of this arrangement is shown in Figure 2. As well, heat flux transducers were installed at three vertical locations.

The monitored temperature difference across the calibrated insulation layer was used to calculate the heat flux profile into the wall on a continuous basis. Detailed analysis of heat transfer through the wall was used to assess the resulting heat flux into each exterior insulation specimen. Using this heat flux and temperature difference across the specimens, the apparent in-situ thermal resistance of the specimens was deduced. Details of the analysis approach are recorded in references [7, 8 and 9].

The boundary conditions, including soil temperatures and moisture content were recorded [10], as well as observations of weather extremes. Four separate soil analyses were performed to characterize the soil environment, including vertical profiles of moisture content. This information was used to qualify differences in observed thermal performance of the specimens.

Specimens & Installation

The field experiment consisted of installing an SPF specimen on each of the East and West basement wall of Test Hut #1. The specimens were instrumented as shown in Figure 2. The SPF specimens were sprayed on after the other specimens were installed. The concrete wall had been pressure washed and allowed to dry. All specimens were in direct contact with the soil below grade, with the exception that the fibre cement board, used for above-grade protection, extended about 300 mm below grade.

Two different installation methods were used on the East and West wall configurations, labelled System 1 and System 2 respectively. System 1 on the West wall (Figure 3) featured two horizontal rows of metal z-bars, separated by a wood spacer, all fastened to the header. Once the insulation was in place, the cementitious covering boards were fastened to the z-bars and wood space. No other fasteners were used, so the cementitious board was effectively 'cantilevered' over the insulation specimens. The soil was sloped at 5% grade towards the wall, to simulate a settled condition.

System 2 on the East wall (Figure 4) featured metal z-bar supports placed vertically between each insulation specimen. The z-bars were fastened directly to the concrete wall and wood header on the inside, and fastened to the cementitious board on the outside. Each metal z-bar was therefore a thermal bridge around the insulation. System 2 also featured an initial 5% sloped grade away from the basement wall.

Control of Interior Conditions

The test hut was heated in the winter and air-conditioned in the summer. The indoor temperature was initially set at 21°C. After an initial monitoring period through the first summer, this temperature was reset to 23°C, to increase the accuracy of the monitoring in the shoulder seasons.

The indoor RH was not controlled, although some summertime dehumidification probably occurred as a by-product of air-conditioning.

The drainage system featured a sump pump in the middle of the basement, connected below the footing to the drainpipe at the middle of the West wall. The level of water in the sump was observed to be quite high (at footing level) for the first 200 days of monitoring. At day 215, the sump pump controls were reset to maintain the water level in the sump at about 300 mm below the footings.

Results

Temperature Profiles Through the Wall at Mid-Height

Figure 5 shows the two-year temperature record at four locations through the wall at specimen W6: the interior surface, both sides of the concrete, and the exterior surface of the specimen in contact with the soil. The inner surface of the wall is kept near 21°C, with small variations throughout the two years. Main control events such as power outages and changes from heating to air conditioning and back are evident from these temperature readings. The temperatures at both sides of the concrete are quite close to one another (concrete being a poor thermal insulator), and these vary from about 15°C to 20°C, from winter to summer.

The lowest curve in the graph is the temperature record for the insulation/soil interface. These vary between about 5°C in winter up to a maximum of about 20°C in summer.

The periodic ‘spikes’ in this curve correspond to recorded events of heavy precipitation or winter thaws. The August 8, 1996 rain was a 1 in 75 year event for Ottawa, which caused local flooding around the test hut. During this storm, the temperature profile at the insulation/soil interface deflected upwards, apparently due to warm rainwater moving down the wall. Such deflections (spikes) were observed at the mid, low and bottom thermocouple positions during the same period, tracing the path of the water. These deflections were much less noticeable at the high position, where the soil temperature would be closer to the temperature of the moving water.

The temperature profile deflections in winter at the soil/insulation interface are downward because the melt water temperature is initially 0°C, which would cool the soil and insulation at the interface.

Figure 6 shows temperature measurements at mid-height on the East wall of the test hut for the same insulation product that was shown on the West side in Figure 5. In the first

year, these periodic temperature profile deflections were often smaller or absent on the East wall where the ground surface was properly graded outward. In the second year however, the differences between East and West were less noticeable, with the temperature profile deflections on the East wall being as large, and showing up in greater numbers compared to those on the West wall. A final review of soil slopes near the wall revealed that by the end of the second year, most of the soil adjacent to the East wall had settled. As a result, the slope adjacent to the East wall was mostly inward, and this was presumed to be the cause of the increased numbers of observations of spikes in the temperature profiles that we associated with water movement at the insulation/soil interface.

In-Situ Thermal Performance

Figures 7 and 8 show the resulting thermal performance plots for the specimens on the West face (a) and the East face (b). The change in thermal resistance adjustment is shown on a weekly basis over two heating seasons. Key observations are as follows:

- all specimens show relatively steady performance through the heating seasons
- the second heating season shows equal or improved performance for all specimens
- the results for the warm periods are unreliable, since the temperature difference across the specimens are very small ($< 0.5^{\circ}\text{C}$). During such periods, thermocouple errors can be as large as the actual temperature difference.
- On day 215, modifications were made to faulty controls on the sump pump. Water levels around the footing were lowered over time. The sump pump connection is nearest specimens W5 & W6.
- Major rain and thaw periods do not appear to significantly affect the thermal performance of the specimens during these episodes.

Discussion

The following general observations are made as a result of these experiments.

The in-situ tracking of thermal performance of the specimens indicated stable thermal performance² over the two years of monitoring. In most cases there was an improvement in specimen thermal performance in the second heating season. This correlates with dryer prevailing soil conditions in the second year.

Based on the temperature profiles at the specimen/soil interface, and corresponding observations of heavy rainfall or thaw periods, the specimens are apparently ‘handling’ moving water at the specimen surface. This appears to have negligible effect on thermal performance of the specimen. There is also independent evidence that the SPF insulation protected the concrete structure during these events (no temperature spikes in the

² The aging process is slowed because the polyurethane foam was sprayed on dry surface of old concrete. In principle, one may consider that the 76-mm thick medium density SPF is exposed to one-sided aging only.

temperature profiles on the inside face, and clean interior surfaces observed on removal of the insulation).

The measured values of water vapour permeability of the retrieved SPF samples were consistent with those published in literature. The measured moisture contents of the retrieved SPF samples were very low. Small variations were noted from top to bottom of the original specimens and these were all at a low range of moisture content. When tested in the lab after recovery and drying of the specimens, the compressive strengths of the SPF samples were slightly higher than those of samples tested at the beginning of the test.

Other samples wrapped with a polyethylene cover appeared to have similar water handling and thermal characteristics as the samples without this protection. The data suggests that, by whatever mechanism, there may be even more water movement at the soil/polyethylene interface than at the interfaces of the other specimens.

Installation System #1 (Horizontal z-bars attached to header) yielded consistently superior thermal performance of the system compared to Installation System #2 (vertical z-bars attached to concrete).

The following parameters of SPF used on the exterior of basement walls appeared to have little or no effect on the observed thermal performance of specimens within the scope of this experiment:

- duration of exposure
- mean temperature of the specimen
- water movement at the outer surface
- freeze and thaw cycles

Conclusions

For the conditions recorded over the two-year monitoring period in this experiment, the SPF insulation specimens installed as exterior basement insulation showed stable and sustained thermal performance in the soil. The moisture management capabilities of these unprotected SPF specimens below grade were confirmed, both by the sustained thermal performance over the two-year period and the low moisture contents of the specimens measured on retrieval. This has considerable implications for the performance and durability of the basement wall system as a whole, since this product can protect the foundation wall from water ingress in a continuous fashion, and keep it above freezing at the same time. Proper design of supports for the protective cover of the insulation system above grade is an essential element of the design. Thermal bridges in the form of metal studs above grade have a substantial effect on the below-grade thermal performance.

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References

- [1] Survey to characterize the causes of 1994 and 1995 basement failures in new residential construction, Contact Report by Cedaridge Consulting Ltd. for the Institute for Research in Construction, National Research Council of Canada, July 1997.
- [2] Nelson, B.D., 1989. "Conditions of a Sample of Minnesota Exterior Foundation Wall Insulation Materials". Conference proceedings of Thermal Performance of Exterior Envelopes of Buildings IV, ASHRAE/DOE/BTECC/CIBSE. Dec 4-7, 1989.
- [3] Sterling, R.L., 1986. "Moisture Absorption and its Effect on the Thermal Properties of EPS Insulation for Foundation Applications". Contract report by Underground Space Center, University of Minnesota, October, 1996.
- [4] "Spray Applied Rigid Polyurethane Cellular Plastic Thermal Insulation". Canadian General Standards Board, CAN/CGSB-51.23-92, 1992. (Standard replaced in 1998 by "Spray Applied Polyurethane Foam Insulation", CAN/ULC-S705.1-98.
- [5] Bomberg M.T. and Kumaran M.K., 1994, "Laboratory and roofing exposures of cellular plastic insulation to verify a model of aging", Roofing Research and Standards Development, ASTM STP 1224, T. J. Wallace and W. J. Rossiter, Jr., Eds., American Society for Testing and Materials, Philadelphia.
- [6] Muzychka Y., 1992, "A method to estimate thermal resistance under field conditions", NRC/IRC internal report No 638, Dec. 1992.
- [7] Swinton, M.C.; Bomberg, M.T.; Kumaran, M.K.; Maref, W. "In-situ performance of expanded molded polystyrene in the exterior insulation basement systems (EIBS)". Vol 23, *Journal of Thermal Envelope and Building Science* pp. 173-198. Oct 1999. (NRCC-43679)
- [8] Bomberg, M.T., Kumaran, M.K., Swinton, M.C., Maref, W., "Performance of exterior insulation over two-year exposure period," International Building Physics Conference (IBPC) (Eindhoven, 2000-09-00), pp. 1-8, (NRCC-44221)
- [9] Maref, W., Swinton, M.C., Kumaran, M.K., Bomberg, M.T., "3-D analysis of thermal resistance of exterior basement insulation systems (EIBS)" *Journal of Building and Environment* Vol. 36, No 4, PP. 407-419, 2001 (NRCC-43090)
- [10] Swinton, M.C.; Bomberg, M.T.; Maref, W.; Normandin, N.; Marchand, R.G.; In-Situ Performance Evaluation of Exterior Insulation Basement System (EIBS) – Spray Polyurethane Foam" Contract report by the Institute for Research in Construction, National Research Council Canada. Jan. 2000. 41 pp.(A-3132.3)

Types of Repair and Cost Distribution Nine Provinces Surveyed

New Home Warranty Program Survey of Basement Failures in 1994 & 95

Figure 1- Type of Repair and Cost Distribution Nine Provinces Surveyed

Figure 2- General Layout of Insulation Specimens and Sensors

Figure 3 – Installation System 1 for the Above-Grade Protective Assembly – West Wall

Figure 4 – Installation System 2 for the Above-Grade Protective Assembly – East Wall

Figure 5. Temperature Profiles at the Mid-Position of Specimen W6 on the West Wall

Figure 6. Temperature Profiles at the Mid-Position of Specimen E6 on the East Wall

**Figure 7. Trend in R-value for Two Heating Seasons.
(Normalized to Initial R-value for October 1996)**

Weekly Average R-value of the Specimen Relative to the R-value for October 1996

**Figure 8. Trend in R-value for Two Heating Seasons.
(Normalized to Initial R-value for October 1996)**