IMPACT OF HEATING AND COOLING OF EXPANDED POLYSTYRENE AND STONE WOOL INSULATIONS ON CONVENTIONAL ROOF PERFORMANCE

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ABSTRACT

The thermal expansion and contraction of insulation products within conventional roof assemblies has been identified as a potential performance concern in the roofing industry. This movement can create gaps between insulation boards, which can short-circuit the insulation with respect to heat flow, and in conventional roof assemblies where the insulation also provides the substrate for the roofing membrane, insulation movement can also adversely affect the durability and integrity of the membrane and roofing system. Problems with creasing and ridging of membranes have been observed in the field, along with stress concentrations and holes around fixed penetrations. In particular, field observations have indicated that shrinkage of expanded polystyrene (EPS) insulation products may put undue stress on the roof membranes and could potentially affect the durability of styrene-butadiene-styrene (SBS) roof membranes.

To investigate these industry concerns regarding the potential effect of dimensional movement of EPS insulation on the performance of SBS membranes, laboratory testing was performed on conventional roof specimens in a purpose-built climate chamber. The roof assemblies were cooled and heated to evaluate the amount of insulation movement, and to then observe the impact of these temperature cycles on the roof assembly. This portion of the investigation in to this issue focused on recreation of the observed field condition (e.g., wrinkled membrane), and direct comparison of the relative performance of different insulation types as a first step towards determining the cause of the observed in-service wrinkling.

INTRODUCTION

The thermal expansion and contraction of insulation products within conventional roof assemblies has been identified as a potential performance concern in the roofing industry. This movement can create gaps between insulation boards, which can short-circuit the insulation with respect to heat flow. Problems with creasing and ridging of membranes have been observed in the field, along with stress concentrations and holes around fixed penetrations. In particular, anecdotal field observations have indicated that shrinkage of expanded polystyrene (EPS) insulation products may put undue stress on the roof membranes in conventional roof assemblies where the insulation also provides the substrate for the roofing membrane and potentially create wrinkles of the membrane.

To investigate these industry concerns regarding the potential effect of dimensional movement of EPS insulation on the performance of SBS membranes, laboratory testing was performed on conventional roof specimens in a purpose-built climate chamber. The primary intent of this first phase of the study was to attempt to reproduce the creasing observed in the field and to evaluate the hypothesis that this may be the result of dimensional movement of insulation within the assembly. The impact of asphaltic and fiberboard cover boards on the creasing of the roof membrane was also investigated. Results of this testing are largely comparative.

The results and analysis presented in this paper form a portion of the work performed as part of a larger study (Tatara & Ricketts, 2017) which evaluates how a number of potential factors may impact the performance of 2-ply SBS roof membranes in conventional roof systems including reinforcement types within the SBS roof membrane, and attachment techniques. Later phases of this work (currently not published) also investigate more realistic exposure conditions for the roof assemblies.

METHODOLOGY

This section provides an overview of the roof specimen selection, the climate chamber and instrumentation, the test procedure, and interpretation of the displacement measurements.

Roof Specimen Selection

Five roof specimens, approximately 1220 mm x 2440 mm (4' x 8'), were selected to isolate the impact of insulation type (EPS vs. SW) on the comparative performance of SBS roof membrane and roof assembly as provided in Table 1. Note that the similar materials and assemblies are highlighted with the same color.

Table 1: Summary of Roof Specimen Selection

	Roof 1	Roof 2	Roof 3	Roof 4	Roof 5
Exterior	SBS Cap Sheet (Non-Woven Polyester Reinforced)				
	SBS Base Sheet (Non-Woven Polyester Reinforced)				
	Cover Board[1] (Mechanically Fastened)	Cover Board[1] (Ribbon-Adhered)	Cover Board[1] (Mechanically Fastened)	Cover Board[2] (Mechanically Fastened)	Cover Board[1] (Ribbon-Adhered)
	4" EPS	4" EPS	4" Stone Wool	4" EPS	4" Stone Wool
	Self-Adhered Vapour Barrier				
Interior	1/2" Plywood				

Cover board[1]: 4.8 mm (3/16", Glass mat-reinforced)
Cover board[2]: 12.7 mm (1/2") High density fire-resistant fiberboard

The test specimens were constructed by a certified roofer intimately familiar with roofing products and installation techniques. Per typical construction, the SBS cap sheet membrane was torch-adhered to the SBS base sheet membrane and the base sheet membrane was torch-adhered to an asphaltic cover board. The only exception to this is Roof 3 in which the SBS base sheet (non-woven polyester reinforced) is factory laminated to the fiberboard cover board. The insulation layers and cover board are either mechanically fastened or ribbon adhered with a polyurethane foam adhesive, as noted in Table 1.

Each roof specimen was constructed such that there was a continuous joint between insulation boards in the middle of the insulation layer perpendicular to the length of the specimen as shown in Figure 1. This joint separates the insulation into two separate halves. The cover board and roof membrane were installed continuously across the insulation joint.

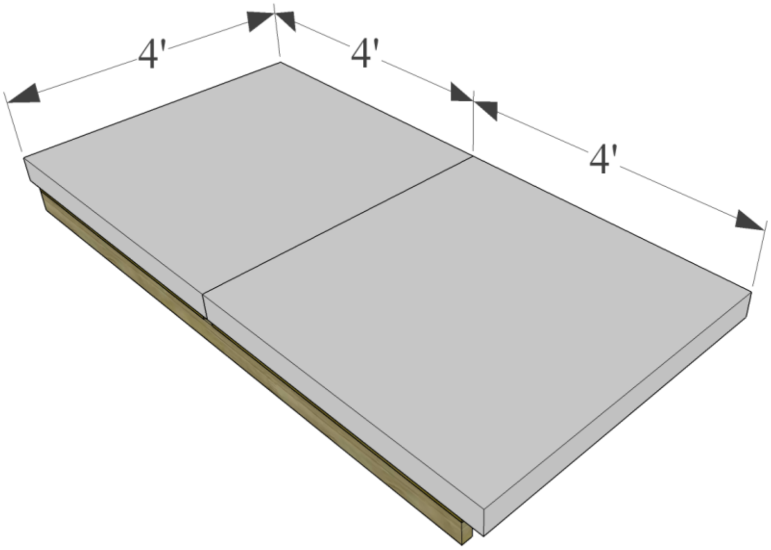


Figure 1: Schematic drawing of roof specimen showing insulation layout with central joint between insulation boards (EPS roof specimen shown)

A gap was created in the plywood substrates and self-adhered vapour barrier that aligns with the joint in the insulation boards. This gap was created to facilitate sensor installation, as shown in Figure 2.

Figure 2: Underside of ribbon-adhered stone wool roof specimen showing gap in plywood and location of the displacement sensors (yellow dashed circles) which were installed at the joint in insulation boards from the underside of the roof specimen.

During construction of the roof specimens, the insulation boards were butted together, per typical construction practices. After construction of the roof specimens was complete, a gap of typically 1 mm to 3 mm at the insulation joint was evident with the exception of Roof 5 which had a 6 mm gap on one side. These unintentional gaps were likely created during construction of the specimen as a result of forces applied during application of subsequent layers of the assembly, though this was not confirmed. These gaps are likely generally representative of gaps that would occur in real-world roof assemblies during construction.

Climate Chamber and Instrumentation

The test roof specimens were exposed to both cold (-15 °C) and hot (90°C~105°C) temperatures using a custom-built climate chamber while the change in the gap size between insulation boards was measured. An overview photo of the climate chamber is provided in Figure 3 with key components labeled. It should be noted that no control over relative humidity was provided as part of this testing and it is possible that some materials will have responded to changes in relative humidity. This is a potential area for further investigation.

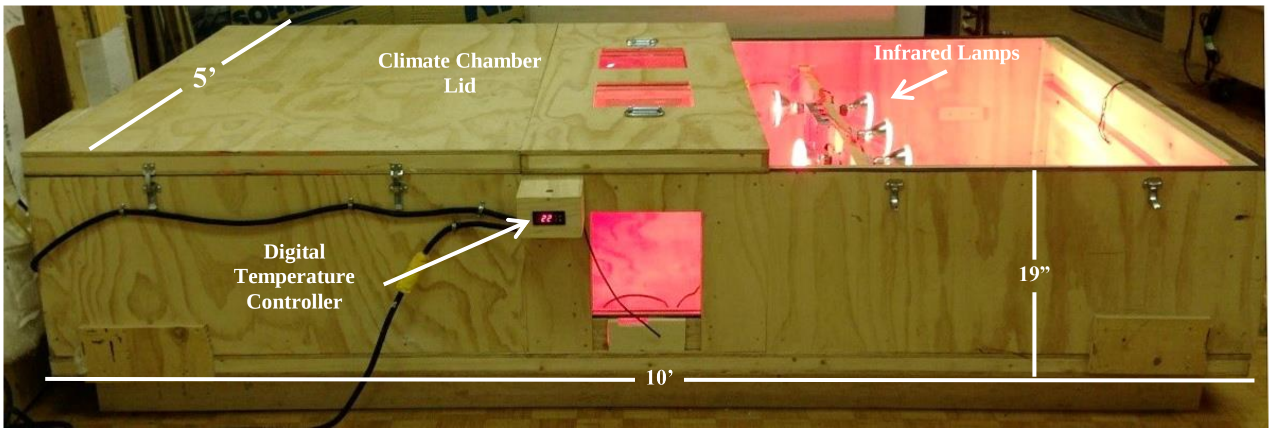


Figure 3: Overview of the climate chamber used for exposing roof specimens to hot and cold temperatures while monitoring performance characteristics such as dimensional movement and membrane strain (Shown with infrared lamps turned on).

Temperature, relative humidity, displacement at the insulation joint, strain on the SBS roof membrane, and load exerted by the specimen on the climate chamber were monitored to evaluate the performance of the roof specimens during testing. Figure 4 shows a schematic diagram of the arrangement of a roof specimen with sensors installed.

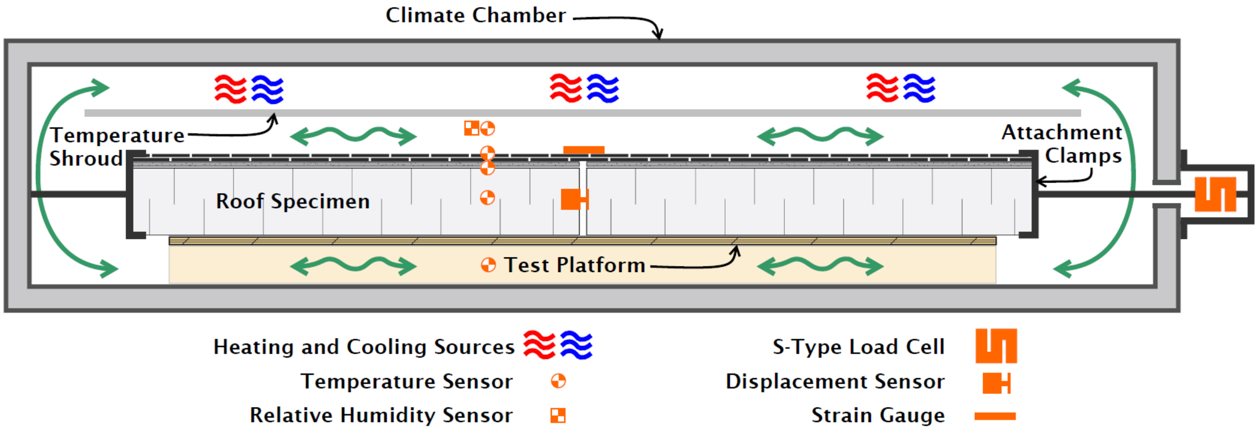


Figure 4: Schematic diagram showing sensor layouts within climate chamber and roof test specimen.
Note that all sensors recorded measurements at 1-minute intervals throughout the duration of the test procedure. Green arrows indicate air circulation, which was provided using fans in order to minimize temperature stratification within the chamber.

Test Procedure

To evaluate the impact of hot and cold temperatures on the roof assembly, each roof specimen was installed in the climate chamber and left undisturbed for 24 hours. After this time, the cooling cycle was performed. The specimen was allowed to return to equilibrium temperature before the heating cycle. The heating cycle was performed until insulation temperature reached 90°C (Figure 5). This heating temperature set point was determined based on roof monitoring data from an on-going field monitoring study of a large roof on an industrial building in Chilliwack, within the Lower Mainland of British Columbia. The data from a 4-year monitoring period (2013 to 2016) indicate that on a typical year, cap sheet temperatures of the black SBS membrane experienced approximately 102 hours of temperature above 70°C and approximately 5 hours above 80°C.

Figure 5: Cold test being performed with dry ice (left) and hot test being performed with heat lamps (right).

In order to highlight differences in each roof specimen and their overall impact on the roof assemblies, a worst-case condition was simulated by cooling and heating the roof specimen uniformly without a temperature differential across the insulation. In other words, the entire assembly was heated or cooled all the way through the thickness of the assembly, which is not indicative of in-service conditions. While it is recognized that this conditioning arrangement and the selected heating temperature range are not directly indicative of in-service conditions, this methodology was selected as intentionally extreme to provide a boundary on the problem as the first phase of evaluating whether dimensional stability of the roof assemblies at these temperature extremes could potentially be the cause of observed membrane creases in the field.

To avoid uneven temperature gradients during the heating cycle, the temperature set point was increased incrementally (in 10°C increments), allowing the roof specimen and the climate chamber to reach equilibrium. While efforts were made to ensure even temperature distribution (temperature shroud and air circulation fans), some hot spots did occur.

The testing was considered complete when the roof specimen returned to equilibrium laboratory temperature (22°C) after the heating cycle. When testing was complete, roof specimens were inspected and disassembled for visual and physical observations.

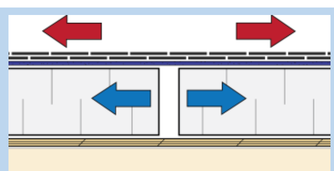
Note that both the cooling and the heating cycle durations were not set to fixed time intervals and instead were based on the insulation temperature, and as such the duration of the test varies for each specimen as different durations were required to achieve equilibrium. The variation in test duration is likely primarily due to the difference in the thermal capacity (specific heat) between EPS and stone wool (SW) insulation material, and as such, typically the stone wool roof specimens were exposed to high temperatures for a longer duration than were the EPS roof specimens.

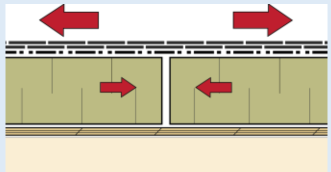
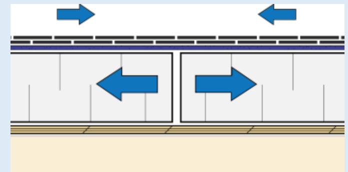
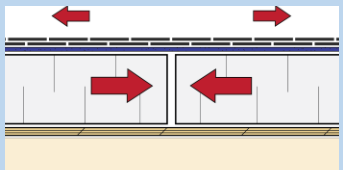
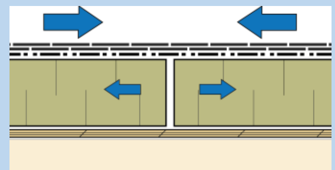
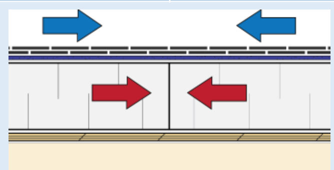
Gap Size Measurements

One of the most meaningful measurements made as part of this testing work is of the gap size between the insulation boards. This section provides a summary of how the displacement sensor measurements will be interpreted and possible causes of the measured changes in gap size.

There are potentially a number of different movements which could cause a measured change in the gap size between insulation boards, and these are summarized in Table 2. The arrows in this table indicate the direction of movement and the size of the arrows indicates the relative rate or the magnitude of movement (i.e., the larger the arrow, the greater the movement). The color of the arrows indicates thermal expansion in red and thermal contraction or shrinkage of material in blue.

Table 2: Summary of Movements at The Insulation Joint

Rapid and larger increase in the gap width	 SBS roof membrane expands and pulls insulation boards away from each other while insulation contracts/shrinks.

Small increase in the gap width	 SBS roof membrane expands and pulls insulation boards away from each other. The rate of expansion of SBS roof membrane is **greater** than the rate of expansion of insulation	 Insulation contracts/shrinks and widens the gap. The rate of contraction/shrinkage of the SBS roof membrane is **smaller** than the rate of contraction/shrinkage of the insulation
Small decrease in the gap width	 Insulation expands and narrows the gap The rate of expansion of SBS is **smaller** than the rate of expansion of insulation	 SBS roof membrane contracts/shrinks and pulls insulation boards closer together The rate of contraction/shrinkage of SBS is **greater** than the rate of contraction/shrinkage of insulation
Rapid and larger decrease in the gap width	 SBS roof membrane contracts/shrinks and pulls insulation boards closer together while insulation contracts/shrinks	

Note that the main cause of dimensional change in wood products is due to moisture content. The expansion and contraction of wood products due to temperature is much smaller by comparison. It is unlikely that thermal expansion and contraction of wood material in the roof specimen significantly influenced displacement sensor measurements, and therefore it is not considered in the summary of movements provided.

The displacement sensor used in this testing has a total mechanical travel of 14.2 ± 0.38 mm (0.56" ±0.015") (SMT Research Ltd.). Efforts were made to install the sensors in the same location relative to the insulation joint; however, the actual installation location determined the allowable sensor plunger travel distance and, consequently, the upper measurable limit of the gap width.

RESULTS AND DISCUSSION

To evaluate the relative performance of roof assemblies with EPS insulation and stone wool insulation, a comparison was made between roof assemblies with similar construction other than the insulation type. Comparisons were also made to assess the impact of asphaltic cover board versus fiberboard cover board.

The directly comparable roofs for these variables are described below.

- Insulation type for ribbon-adhered assemblies: Roof 2 (EPS) and Roof 5 (SW)
- Insulation type for mechanically fastened assemblies: Roof 1 (EPS) and Roof 3 (SW)
- Cover board type (mechanically fastened EPS): Roof 2 (asphaltic cover board) and Roof 4 (fiberboard cover board)

The graph provided in Figure 6 compares insulation temperature and change in gap width of ribbon-adhered roof specimens with EPS insulation (Roof 2) and SW insulation (Roof 5). The graph indicates that while the gap between the insulation boards generally reacted more to the change in temperature in the roof specimen with EPS insulation, this change was particularly significant above approximately 80°C, where the gap between the EPS insulation boards began to increase dramatically. It is also interesting to note that during the cooling cycle, while the gap between the EPS insulation boards widened, the gap between the SW insulation boards narrowed. It is theorized that this narrowing is due to contraction of the roof membrane, rather than movement of the mineral wool insulation. For the roof with EPS insulation, the movement of the SBS membrane is likely overwhelmed by shrinkage of the EPS insulation during cooling, thus resulting in a net increase in the gap size.

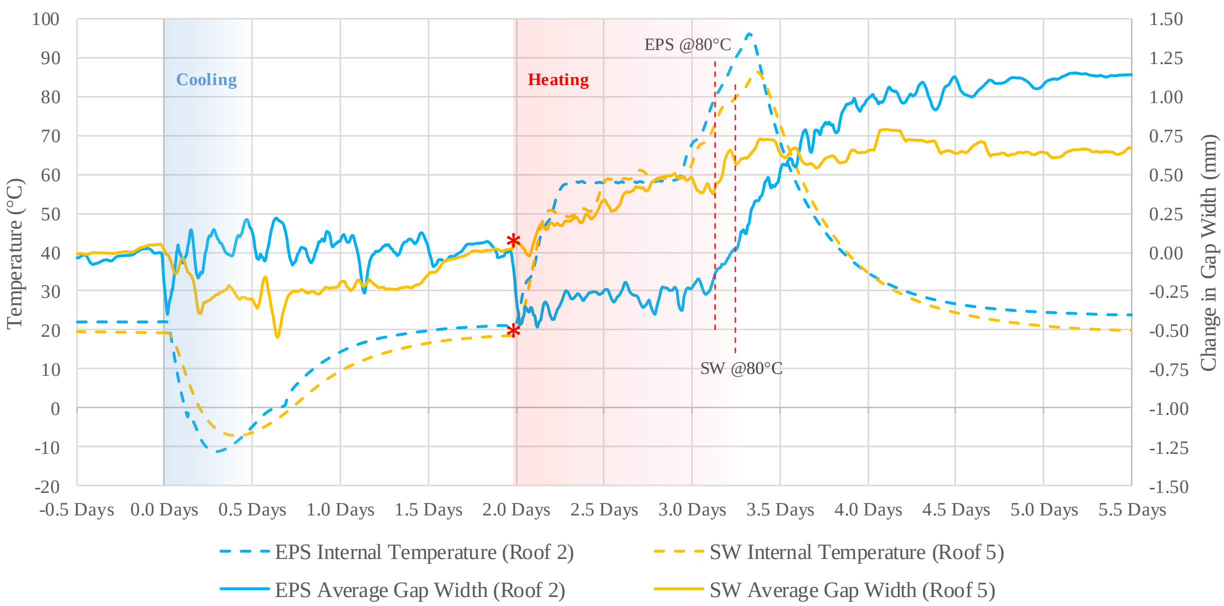


Figure 6: Graph comparing insulation temperature and change in gap width of **ribbon-adhered** roof specimens with EPS insulation (Roof 2) and SW insulation (Roof 5).

The data provided here is plotted at a moving average of 45min (9 readings) to filter out sensor noise. Additionally, while the size of the gap between insulation boards for the SW roof was measured with one displacement sensors (due to malfunction of one of the sensors), the gap between the EPS insulation boards is an average of two sensors up until the insulation temperature reached 80°C (indicated by red dashed line), at which point the gap became unmeasurable at one of the sensor locations due to EPS insulation shrinkage.
Note that the test duration varied as previously discussed. SW insulation took slightly longer to cool, heat, and reach equilibrium temperature; therefore, data between the end of the cold cycle and the start of the hot cycle (as indicated by red asterisk) were omitted in this figure to facilitate easier comparison. All modifications were made to facilitate comparisons and are intended to not

impact the analysis.
The red dashed lines indicate when the insulation temperature reached 80°C.

Figure 7 compares the insulation temperature and change in gap width for the mechanically fastened roof specimens with EPS insulation (Roof 1) and SW insulation (Roof 3), both using asphaltic cover board. Roof 4 is also shown, which include EPS insulation and a fiberboard cover board. Unlike with the ribbon-adhered specimens, displacement sensors measured significant movement in the roof specimen with EPS insulation while minimal change in gap width was measured between SW insulation boards. Note that the right vertical axis (change in gap width) in Figure 7 has a significantly larger scale compared to Figure 6 (-1.50 to 1.50 vs. -4.50 to 13.50), as the change in gap width in the mechanically fastened roof specimens (especially roof specimens with EPS insulation) were much larger than for the ribbon-adhered roof specimens.

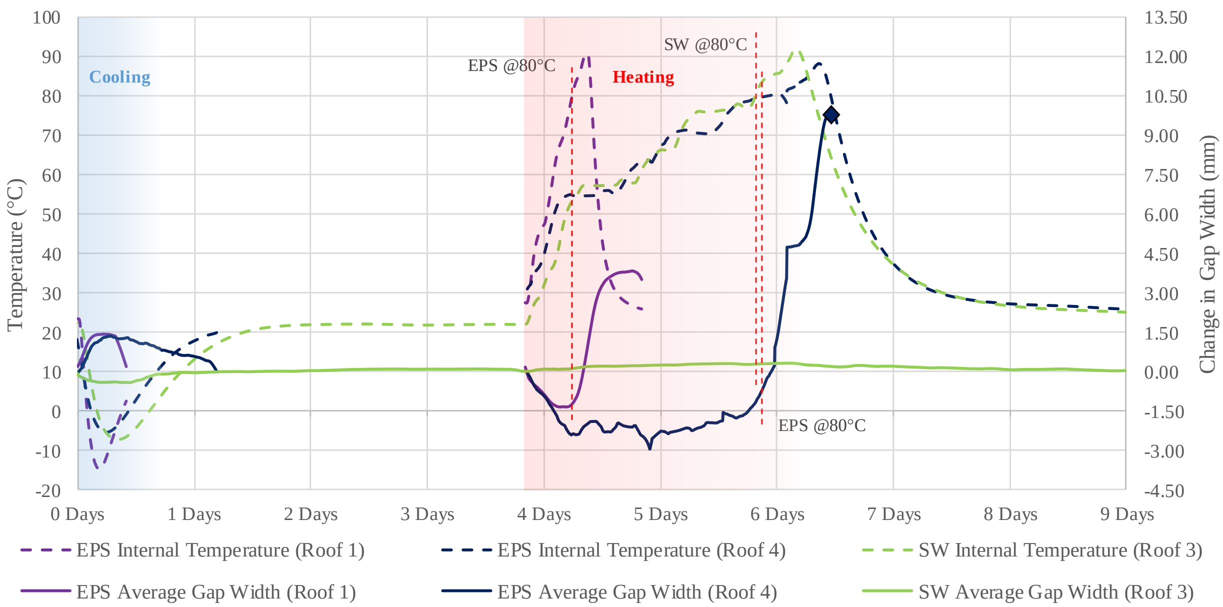


Figure 7: Graph comparing insulation temperature and change in gap width of **mechanically fastened** roof specimens with EPS insulation (Roof 1 and Roof 4) and SW insulation (Roof 3).
The data provided here is analyzed and plotted at a moving average of 180 min (36 readings) of two sensors to filter out sensor noise.
The insulation in Roof 4 was held for an extended period at 70°C and 75°C, then raised to 90°C more gradually than the other specimens; therefore, some of the data during these periods indicated by red asterisks were omitted in this figure. Also, note that the shorter duration plot for Roof 1 is due to Roof 1 being cooled and heated more rapidly than the other specimens as illustrated in this figure. Additionally, gaps in EPS roof specimens' (Roof 1 and Roof 4) plots were created at the beginning of the heating cycle to aligned with the start of the heating cycle for SW roof specimen' (Roof 3) plot for a better comparison of the measured data. All modifications were made to facilitate comparisons and are intended to not impact the analysis.
The red dashed lines indicate when the insulation temperature reached 80°C.

Thermal expansion and contraction of materials is typically proportional to its temperature and thus linear when plotted as temperature versus change in dimension. Figure 8 plots gap measurement between the EPS and SW insulation boards in mechanically fastened roof specimens (Roof 1 and Roof 3) as a function of insulation temperature. The plot illustrating the relationship of SW insulation temperature and change in gap width is approximately linear, whereas the EPS insulation plot clearly displays that the change in the gap width is not proportional to the change in temperature, thus indicating that a different process is occurring. It should also be noted that upon cooling of these roof specimens at the end of the heating cycle, the SW roof assembly returned nearly the same gap size as was originally present whereas the gap in the EPS roof assembly had permanently increased in size.

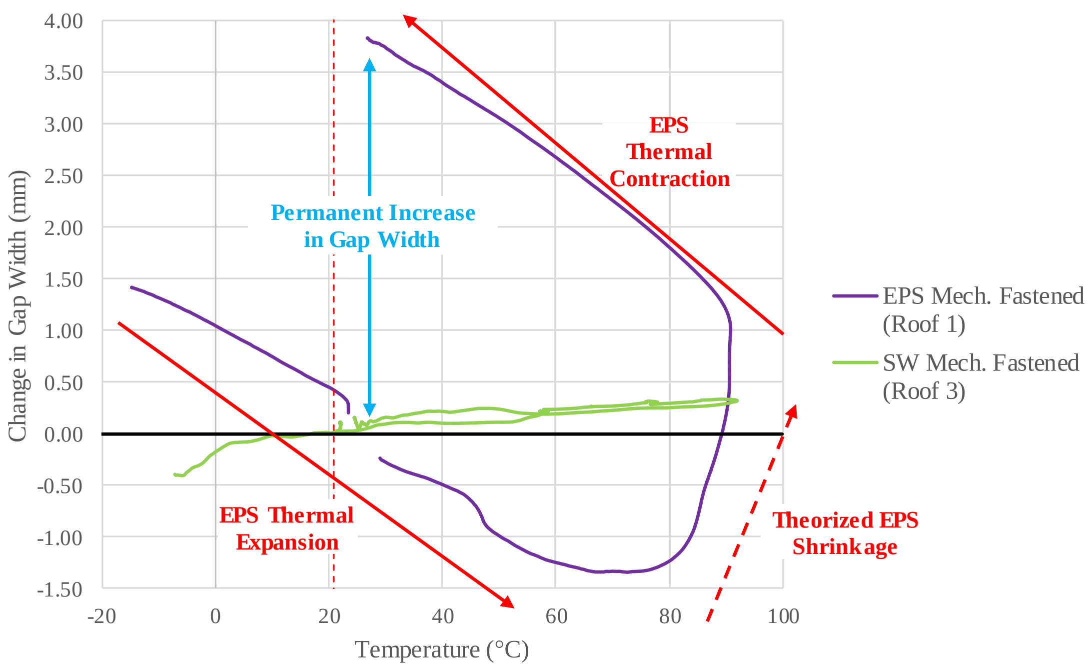


Figure 8: Gap width in mechanically fastened roof specimens with EPS insulation (Roof 1) and SW insulation (Roof 3) is plotted as a function of temperature.
Note that initial gap width is highlighted in black bold horizontal line and initial/room temperature is indicated by red dotted vertical line.
The data provided here are analyzed and plotted at a moving average of 30min of two sensors to filter out sensor noise.

In general, the insulation gap in the EPS roof specimens (Roof 1, Roof 2, and Roof 4) widened as insulation temperature lowered, while the gap narrowed as the insulation temperature increased—until approximately 80°C, at which point the gap widened at a significant rate. This change in dimension at high temperature was permanent as the gap did not return to its original size upon cooling. This gap measurement trend over the testing period is consistent with previous investigations performed by RDH Building Science Inc. (Bowden, Ricketts, & Finch, 2015) that EPS insulation typically expands up to approximately 80°C and experiences a rapid permanent shrinkage above 80°C. This is understandable given that the manufacturing requirement for EPS insulation provided by the Standards Council of Canada states that the intended service temperature range of this types of insulation is between -54°C and +75°C (Standards Council of Canada, 2005). Figure 9 provides photos of the gap between insulation boards at a range of insulation temperatures.

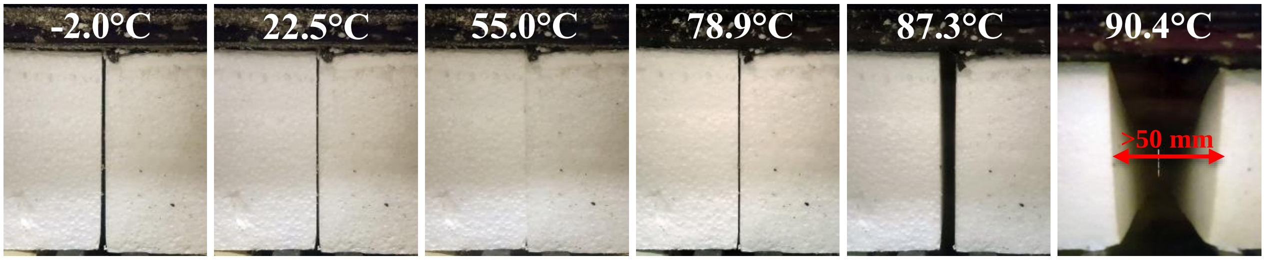


Figure 9: Lapse photos taken at the EPS insulation joint in the mechanically fastened EPS roof specimen (Roof 4) during cooling and heating cycle. Note that the temperature provided for each photo indicates the insulation core temperature. Surface temperature may have been slightly higher.

Roof specimens with SW insulation (Roof 3 and Roof 5) showed generally little to no change in gap width, and when changes in gap width occurred the change was linear. Upon cooling after the heating cycle, the gap in insulation boards in the test specimens with mineral wool typically returned to approximately its original dimension, Since SW insulation is known to be relatively dimensionally stable (Bowden, Ricketts, & Finch, 2015), it is likely that the expansion and contraction of the SBS roof membrane and asphalt-based cover board attributed to the gap measurements.

While the largest gap measurement between the EPS insulation boards was more than 50 mm (Roof 4), the gap between SW insulation boards increased at most by 0.8 mm (Roof 5), an order of magnitude difference. As the time lapse photos of the SW insulation joint in Roof 5 taken during heating cycle provided in Figure 10 indicate, the change in gap width of roof specimens with SW insulation was not visually noticeable.

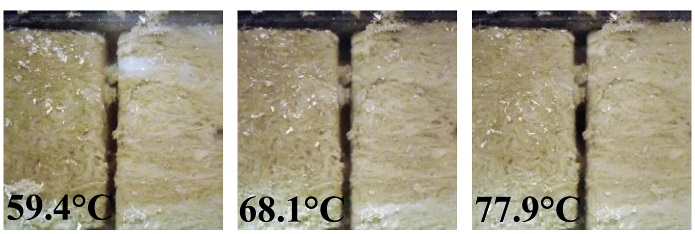


Figure 10: Lapse photos taken at SW insulation joint in ribbon-adhered SW roof specimen (Roof 5) during heating cycle. Note that the temperature provided for each photo indicates the insulation core temperature and a gap of approximately 6 mm between SW insulation was present before the test. Surface temperature may have been slightly higher. Unforutnately photos were not taken at cooler temperatures due to the lack of movement of the specimen.

Thermal expansion and contraction, as well as shrinkage of EPS insulation takes place in all three dimensions (Figure 11); however, the gap measurements only illustrate one-dimensional movement. Once the roof specimens were allowed to cool down to 22°C after the heating cycle, they were disassembled to make visual and physical observations. The original dimension of the EPS insulation is approximately indicated by red dashed line.

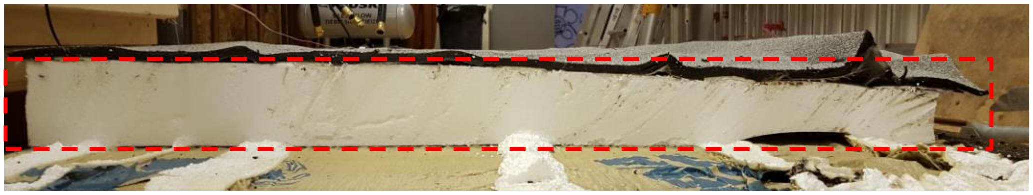


Figure 11: Cross-section (perpendicular to length of specimen) view of ribbon-adhered EPS roof specimen (Roof 2) after heating test. The red dashed line indicates the original dimension of the EPS insulation.
Note that uneven shrinkage of EPS insulation is likely due to slightly uneven heating in the climate chamber, and it is likely that there was a hot spot where the shrinkage is largest (right side).

Upon visual inspection, significant ridging and wrinkling of the SBS roof membrane along the length of the ribbon-adhered roof specimen with EPS insulation (Roof 2) was observed—as indicated by the red dashed box in Figure 12—while the SBS roof membrane on the ribbon-adhered SW roof specimen remained flat.

Figure 12: Photos of the ribbon-adhered EPS roof specimen (Roof 2, left) and SW roof specimen (Roof 5, right) after heating test showing creasing of the roof membrane in Roof 2 and no creasing in Roof 5. These two roof specimens are identical in construction other than the insulation type.

The comparison of these specimens confirmed that it was possible in relatively extreme conditions to reproduce creasing of the SBS roof membrane similar to that observed in the field. Furthermore, it indicated that a potential cause of the wrinkling is the movement of the insulation within the assembly, as insulation type is the only difference between these two assemblies (Roofs 2 and Roof 5). This finding reinforces R.G. Turenne's speculation (although his paper focused on temperature induced stress on the roof membrane) that dimensional changes (moisture and/or thermal) and instability of insulation materials that provide the substrate for roof membranes may be responsible for premature failures of the membrane (Turenne, 1976).

It is likely that as the roof specimen temperature was raised, the SBS roof membrane and asphalt-based cover board softened and did little to resist movement (shrinkage) of the EPS insulation; while the SW insulation provided a more stable substrate throughout the test temperature range (-15°C to 90°C) and resulted in the difference in performance shown in photos taken after heating test provided in Figure 13.

Figure 13: Photos of Roof 2 (EPS, top) and Roof 5 (SW, bottom) after heating test.
Note that no deformation of SBS roof membrane was observed in either specimen after the cooling test before heating test.

The SBS roof membrane on the ribbon-adhered EPS roof specimen (Roof 2) experienced ridging along the length of the specimen typically between the ribbons of the adhesive as shown in Figure 14 and Figure 15.

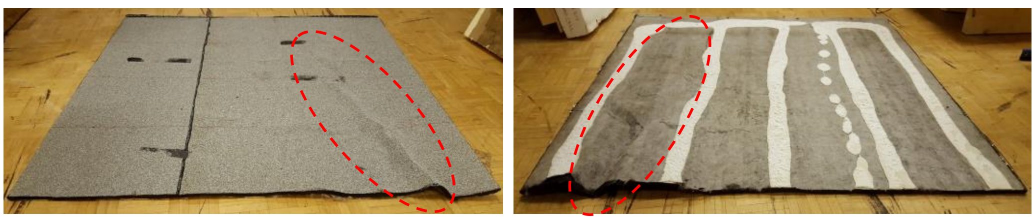


Figure 14: SBS roof membrane and asphalt-based cover board ridging on Roof 2 (EPS) after testing, highlighted with red dashed circle. Top surface view (left) and underside view (right).

Figure 15: Significant SBS roof membrane and cover board ridging observed with ribbon-adhered EPS roof specimen with asphalt-based cover board (Roof 2).
Note that ridging occurred adjacent to the location of an adhesive ribbon as indicated by the red dashed circle.

In contrast to the ribbon-adhered roof specimen with EPS insulation, the SBS roof membrane on both mechanically fastened specimen with EPS (Roof 1 and Roof 4) remained relatively flat after being heated though some deformation, mainly sagging of SBS roof membrane, was observed in the mechanically fastened EPS roof specimen with asphalt-based cover board (Roof 1) (as shown in Figure 16).

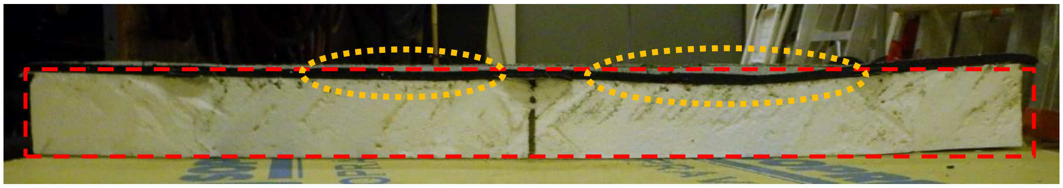


Figure 16: While no significant ridging similar to ribbon-adhered roof specimen (Roof 2) was observed with the mechanically fastened roof specimen with asphalt-based cover board (Roof 1), the SBS roof membrane was noted to sag in some locations as a result of a loss in thickness of the EPS and indicated with orange dotted circles.
Note that the red dashed line indicates approximate original dimension of the EPS insulation.

Additionally, the fasteners were easily located even through the cap sheet membrane while disassembling the mechanically fastened EPS roof specimens (Roof 1 and Roof 4) because the surface of the SBS roof membrane was slightly bulging at the locations of the fasteners. This is likely a result of the EPS insulation reducing in thickness and causing the surface of the EPS to be lower than the height of the fasteners.

Despite Roof 4 having measured the largest insulation displacement, this roof specimen had the least amount of SBS roof membrane ridging and sagging compared to the other two EPS roof specimens (Roof 1 and Roof 2)—almost comparable to the SBS roof membrane on roof specimens with SW insulation except for bulges at screw heads. Upon removing the SBS roof membrane and the fiberboard cover board, it was noted that while the membrane remained relatively flat, significant permanent deformation (shrinkage) of the EPS insulation had occurred underneath, which was not visually apparent unless the SBS roof membrane and the cover board were removed (Figure 17).

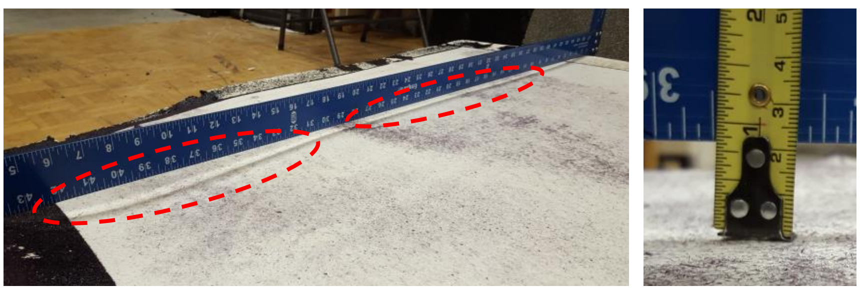


Figure 17: EPS insulation thickness shrinkage, which was not apparent due to fiberboard cover board in Roof 4, indicated with red dashed circles (left). The EPS insulation lost up to 20 mm (3/4") in thickness (right, same roof specimen shown).

Overall, while the use of mechanical fasteners with cover board appears to reduce the influence of the movement of insulation on the performance of the roof membrane, likely due to a decoupling of the membrane from the substrate. While this method may prevent creasing of the membrane, it may also conceal underlying gaps between insulation boards.

An initially confusing finding of this investigation was that the ribbon-adhered roof specimen (Roof 2) was measured to have experienced significantly less change in the gap size between insulation boards than the mechanically fastened specimen with EPS (Roof 1), but the ribbon-adhered arrangement experienced significantly more wrinkling of the membrane. Upon disassembly of the roof specimens it became clear that this finding was likely the result of the placement of the displacement sensor in close proximity to a ribbon of adhesive which appears to have held the EPS in place at the location of the adhesive, but allowed much larger movement of the insulation between the ribbons of adhesive. Figure 18 compares EPS insulation joints in the ribbon-adhered EPS roof specimen (Roof 2, top) and the mechanically fastened EPS roof specimen (Roof 4, bottom) after the heating test. The red dashed line and the yellow square indicate the center-line of the roof specimen where the insulation boards were butted together and the location where the displacement sensor was installed respectively. Additionally, purple shaded strips indicate the location of the adhesive in the ribbon-adhered roof specimen (Roof 2).

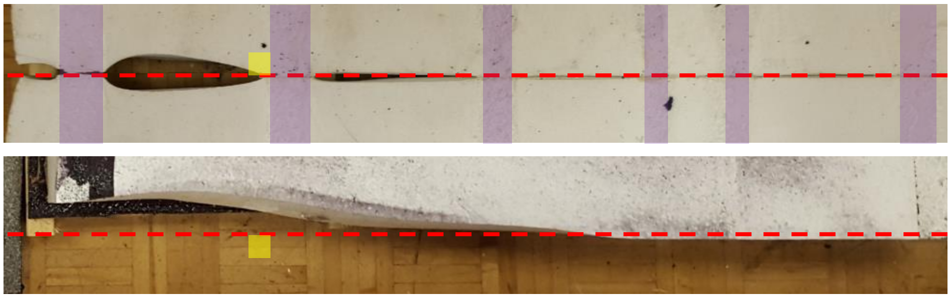


Figure 18: EPS insulation joints in ribbon-adhered EPS roof specimen (Roof 2, top) and mechanically fastened EPS roof specimen (Roof 4, bottom) after heating test.
Note that the red dashed line indicates the center line of the roof specimen where the insulation boards were butted together, the purple shading approximately indicates the locations where the adhesive was applied, and the yellow square indicates the approximate location where the displacement sensor was installed.

FINDINGS AND CONCLUSIONS

The primary objective of this testing was to assess dimensional changes in insulation as a potential cause of observed wrinkling of 2-ply SBS roof membranes in conventional roofs. To investigate this, five roof specimens were tested in order to isolate the impact of insulation type (EPS and SW) and attachment technique (mechanically fastened and ribbon-adhered). The impact of an alternate cover board was also examined (asphaltic cover board and fiberboard cover board). Testing was conducted in a worst-case condition with equal temperature on all sides of the specimen as a first attempt at replicating the issues observed in the field. Key conclusions of this study are summarized below.

1) EPS insulation is less thermally stable than SW insulation, and the relatively low temperature at which permanent shrinkage occurs creates a potential challenge for its use in roofing applications where high temperatures can be experienced.
2) Although SBS roof membranes experience thermal expansion and contraction, this study reinforced speculation made by R.G. Turenne (1976)that components below the membrane have a significant impact on movement and performance of the SBS roof membrane in a roof system.
3) This study reinforced general construction knowledge that having a dimensionally stable substrate in a conventional roof system is important to the performance and durability of SBS roof membranes as well as to the overall performance of a roof system. In a conventional roof, this is often provided by the insulation material.
4) Ribbon-adhered approaches appears to limit insulation movement at the location of the adhesive, but neither of the attachment methods (ribbon-adhered or mechanically fastened) prevented the

SBS roof membrane from deformation (ridging, sagging and/or bulging).

5) The use of a mechanically fastened cover board above EPS insulation was most successful at limiting wrinkling of the SBS roof membrane. While this method could potentially protect the SBS roof membrane from damage, it could also potentially conceal gaps in the insulation boards and potential associated performance issues.

Areas for further investigation include: exposure of the roof specimens to more realistic conditions including arrangements with a temperature gradient, evaluation of other common insulations in conventional roofs such as polyisocyanurate insulation, and examination of potential methods to protect temperature sensitive insulation layers from extreme temperatures such as using multiple types of insulation within the roof assembly. Companion phases of this study seek to address these areas for further investigation, and also to conduct field monitoring of roof system performance to validate laboratory based findings.

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