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PROTECTION OF FOAM PLASTIC THERMAL INSULATION IN LOW SLOPED ROOFING SYSTEMS

Robert J. Booth, Hansed Booth Inc
Clinton DeRushie, Natural Resources Canada
Karen Liu, National Research Council Canada

Foam plastic thermal insulations have substantially replaced traditional insulations in low sloped roofing systems in North America. Foam plastic thermal insulations used in low sloped roofs are low density (typically 16 to 48 kg/m^3) materials with low permeability to air and water vapour. In many roofs these materials have been directly substituted for traditional (wood and glass fibre) insulations without due attention to the different material characteristics. Moist air movement within roofs, condensation protection (air and vapour barriers), steel deck corrosion, roof membrane blistering and roof traffic damage are discussed. This paper discusses protection of foam plastic thermal insulations in roofing systems, why the protection is needed, and what consequences result if these materials are not protected. Case studies demonstrate the importance of condensation protection in reducing corrosion of galvanized steel in roofs containing closed cell phenolic foam roof insulation in Canada.

Keywords:

Air-vapour barriers, condensation, foam plastic thermal insulation, low sloped roofing, moisture, phenolic foam insulation, polyisocyanurate foam insulation, polystyrene foam insulation, roof, roof membrane blistering, roofing, roof traffic damage, galvanized steel roof deck corrosion, galvanized steel fastener corrosion, thermal insulation.

Introduction:

Foam plastic thermal insulation boards have been used in low sloped roofs since the 1950s. A record of 450 bonded roofs constructed in1958 in eastern Canada indicated that 96% of insulated roofs contained wood fibre, glass fibre or cork, and that 3% contained polystyrene foam insulation. The energy crisis of the early 1970's led to an increased use of foam plastic roof insulations (primarily polystyrene, phenolic and polyurethane, and most recently polyisocyanurate insulations) in Canada, and today the majority of low sloped roofs contain foam plastic insulation. [1]

Notwithstanding their widespread use, the material properties of foam plastic roof insulations are sometimes not fully appreciated, and in some instances this has led to inappropriate roof design and misidentification of the causes of roof problems.

The plastic foam insulations considered in this paper include unfaced polystyrene, and faced polyisocyanurate and phenolic rigid foam insulations, with densities ranging from 16 to 48 kg/m^3 that are widely used in low sloped conventional roofing systems in Canada. Conventional roofing systems refer to warm deck roofs, where the insulation is positioned above the roof deck and below the roofing membrane.

The scope of protection of foam plastic roof insulations considered in this paper includes protection from roof leaks and roof traffic damage from above, and from condensation (air and water vapour infiltration) from below. In cold climates such as Canada=s protection from condensation can be critical and this paper includes studies of galvanized steel deck and fastener plate corrosion in roofs with and without condensation protection in Canada. The relative importance of condensation protection and the physical (and chemical) characteristics of (closed cell phenolic) foam insulation with respect to galvanized steel deck corrosion are compared through case studies.

Some physical properties of foam plastic insulations:

Foam plastic roof insulations are generally characterized by low density, low air permeability, low water vapour permeability and low water absorption [Table 1]. These properties result in thermally resistive, airtight boards that are lightweight and easily cut and shaped. Their low permeability and water absorption properties render them less accommodating to water compared to glass and wood fibre roof insulations.

Wood fibre and glass fibre insulation boards are generally characterized by moderate density, high air permeability, high water vapour permeability and high water absorption. These properties result in robust boards with moderate thermal resistivity. Their permeability to air and water vapour, together with their ability to absorb and retain moisture, make such insulations "forgiving" in that they can absorb and store small amounts of water with little distress to a roof. Such insulations are useful in "Self drying" roof systems.[1]

[1] Self drying roof systems may be appropriate for climates with long hot summers and short mild winters. Self drying roofs are constructed without air-vapour barriers on the interior side of the insulation. The concept is that any wintertime condensation will be small and short lived, and this may be stored within porous absorptive types of insulation such a wood or glass fibre boards. In spring the absence of an interior air-vapour barrier will allow rapid (downwards) drying of the insulation, rendering it dry (and thermally efficient) when the long cooling season commences. Such roofing systems do not comply with Canadian Building Codes - they would "Self wet" during long cold winters, rendering the insulation wet and thermally inefficient when it was most needed.

Table 1. Some properties of Canadian closed cell phenolic foam roof insulation compared with Canadian glass fibre roof insulation.

Property	Closed cell phenolic foam	Glass fibre roof board	Reference
Density (kg/m^3)	44	145	2,3
Thermal resistivity (K.m/W)	57	27	2,3,4
Water vapour permeance (at 25mm thickness) [$ng/(Pa.s.m^2)$]	118	5,150	2,3
Air permeability with facer. [ng/(Pa.s.m)]	<0.2	5,800,000	5
Air permeability without facer. [ng/(Pa.s.m)]	<0.2	5.5×10^{10}	5

In this paper the phenolic foam insulation used in laboratory tests and experiments, as well as that inspected in the 172 roofs, was a closed cell phenolic foam roof insulation with glass mat facings on each side. The glass fibre insulation was a rigid board with a bitumen Kraft paper wrapped over one face and two edges.

Protection board overlay of foam plastic roof insulation:

Foam plastic roof insulations are lightweight, low density materials (typically 2 to 4% solid and 96 to 98% gas). The low density is important for thermal resistivity but it renders the materials prone to roof traffic damage. It is good roofing practice to provide a protection board (typically 12.5 mm thick wood fibreboard in Canada) over foam plastic roof insulation underneath hot applied bituminous roofing membranes. It has been shown that foam plastic roof insulation can be damaged by repeated foot traffic without adequate protection [6]. In this study [6], roof insulation samples were subjected to cyclic compression by the heel of a work boot positioned at different angles. Foot traffic was simulated by a haver-sine compression loading function with a magnitude of 45.4kg and a frequency of 1 Hz using a MTS universal testing machine, i.e. the specimen was subjected to a cyclic compression loading between 0 and 45.4kg every second. The load of 45.4kg represented half the mass of a 90.8kg person while the frequency of 1Hz approximated the time between two steps during a walk. Crosshead displacement at the peak of each loading and unloading cycle were measured. Figure 1 shows the permanent indentation (defined as the crosshead displacement at the end of each unloading cycle) of different test assemblies after 6000 compression cycles of simulated foot traffic (work boot heel positioned at an angle of 30°). The first assembly consisted of an insulation specimen placed directly underneath a polyester-reinforced PVC roofing membrane (1.2mm thick) while a 12.5mm-thick fibreboard was placed between the insulation and the roofing membrane in the second assembly. Three roof insulations were tested:

polyisocyanurate (76.2mm thick with an apparent density of 33.2kg/m^3 including fibrous felt facers about 1mm thick), phenolic (76.2 mm thick with an apparent density of 44.3kg/m^3 including thin glass fibre mat facers of less than 0.1mm thick) and expanded polystyrene (50.8 mm thick with a density of 23.0kg/m^3). The indentation was reduced by half with the protection of a 12.5mm fibreboard. Table 2 compares the permanent indentation recorded at 2000 compression cycles of different roof assemblies: unprotected roofing insulation, roofing insulation placed under 2-ply modified bituminous roofing membrane (approximately 7mm thick), roofing insulation placed under a 1.2mm reinforced PVC membrane, and roofing insulation placed under a 12.5mm wood fibreboard and a 1.2mm reinforced PVC roofing membrane. Much of the indentation of insulation was not visible with a roof membrane in place.

Adhering, rather than screw fastening, the protection board removes the potential for membrane puncture by screw fasteners. With single ply membranes the protective layer (eg. paving slabs) is often placed over the finished roof surface to protect both membrane and insulation.

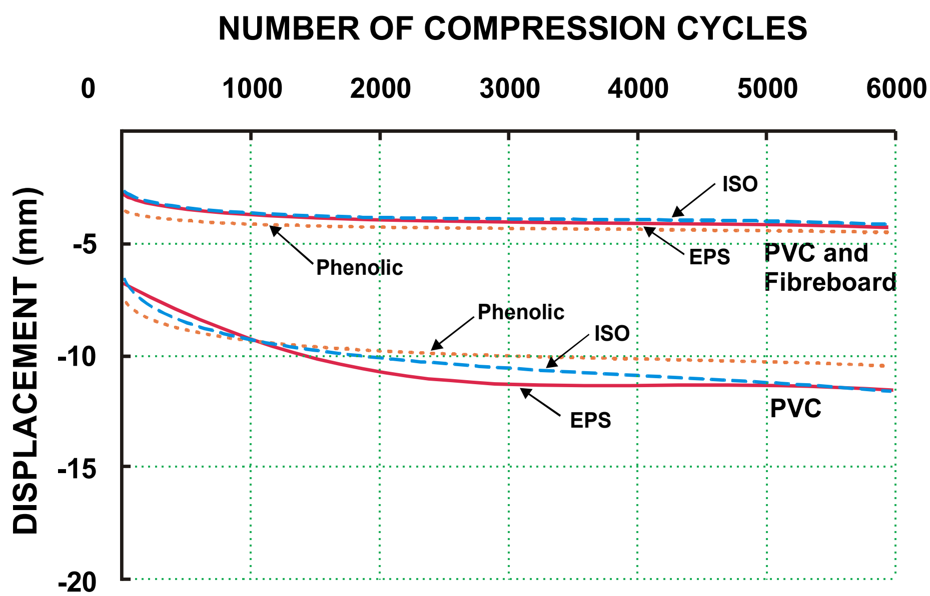


Figure 1 Indentations of polyisocyanurate (ISO), phenolic and expanded polystyrene insulation (EPS) specimens covered with a PVC membrane, with and without a fibreboard, subjected to cyclic compression testing from 0 to 45.4 kg over a work boot heel angled at 30° [6].

Table 2 Permanent indentation on plastic foam insulations subjected to cyclic compression testing from 0 to 45.4 kg over a work boot heel angled at 30° [6].

Sample	Permanent Indentation at 2000 compression cycles (mm)			
	Unprotected	Underneath a 2-ply modified bitumen roofing membrane	Underneath a PVC roofing membrane	Underneath a 12.5mm wood fibreboard and a PVC roofing membrane*
Polyisocyanurate	14.62	5.11	9.89	3.94
Phenolic	13.81	4.24	9.54	4.18
Expanded Polystyrene	15.71	4.68	10.70	4.03

* only the PVC membrane and the fibreboard were indented, the foam insulation was not

Protection from roof membrane blistering:

In the 1970's it became apparent that blistering of hot bituminous roofing membranes was more common over foam plastic roof insulations than over fibrous insulations. Initially it was thought that cell gases emitted from foam cells caused these blisters but research [7-10] proved otherwise. Other factors were found to be important, including moisture on the surface of plastic foam roof insulations coupled with the low air and water vapour permeability of these materials, which made it more difficult to vent gases downwards and outwards when hot bituminous roofing membranes were applied. The US National Roofing Contractors' Association's recommendation for a fibrous overlay board when plastic foam insulations are used in hot bituminous built up roofs is longstanding [11].

Protection from condensation:

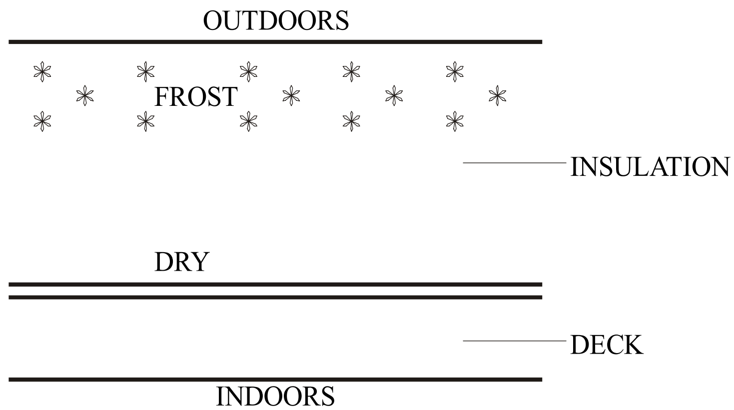
Condensation in roofs is essentially prevented by air and vapour barriers. There is nowhere in Canada where the January design temperature is above freezing. Canadian building codes require continuous air barriers and vapour barriers to be placed at a location that will prevent condensation, this is normally at or near roof deck level. Vapour barriers are commonly used in roofs to provide both air and vapour barrier functions, hence the term air-vapour *barriers*[2].

While most people appreciate the 2 times difference in thermal resistivity and 4 times

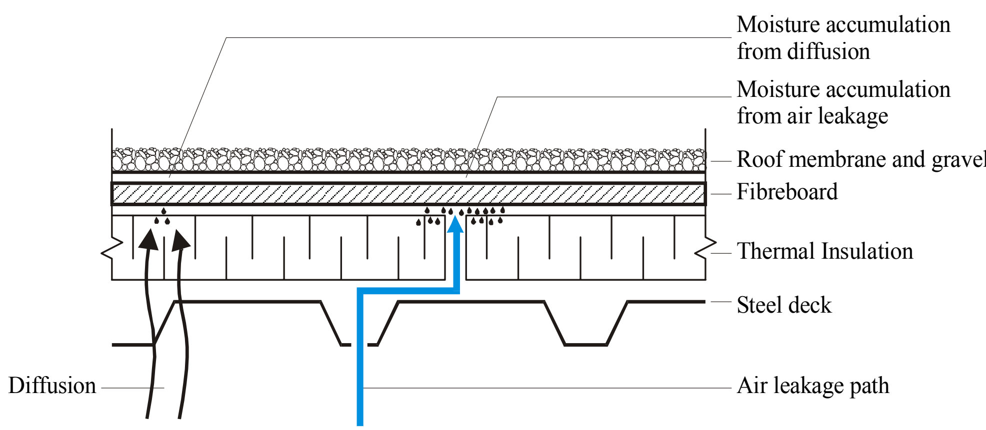
[2] The term air-vapour barrier is used throughout this report.

difference in lightness between most foam plastic roof insulations and fibrous roof insulations, the ramifications of the 40 times difference in water vapour permeability and millions to billions times difference in air permeability of foam plastic versus fibre roof insulations is sometimes overlooked. [Table 1].

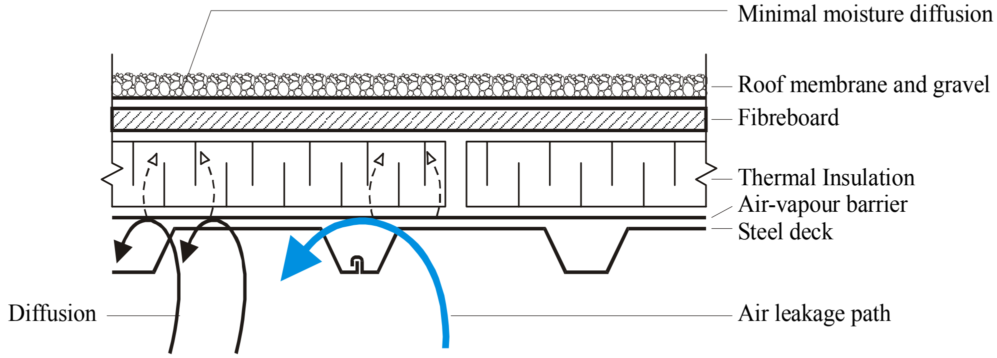
Permeability and absorption properties of thermal insulations have a large effect upon condensation in roofs without air/vapour barriers. In test roofs Hedlin [12,13] showed how air and water vapour can pass largely unhindered into glass fibre insulation. In winter moist air entered the insulation, water condensed in the cold upper layers of the insulation and it was stored there.



Substitute glass fibre with phenolic or other plastic foam insulation and essentially no air will enter the insulation, instead moist air enters the network of insulation joints and, in winter, water will condense on or in the cold (membrane or overlay) surface over the joints between the insulation boards. Board joints are about 1% of the area of insulation boards in a roof, depending upon board sizes and board gaps. Condensation is concentrated between the insulation boards and this can result in "pencil line" corrosion on steel deck below foam insulation joints. [Figures 4(a) and 4(b)].



Roofs with air-vapour barriers are protected from condensation and “pencil line” corrosion has not been seen in such roofs.



Steel deck corrosion:

Steel roof deck corrosion is not new, but it has recently been associated with phenolic foam insulation[3], a material manufactured with acid catalysts. From 1994 through 2000 a research program was undertaken to assess galvanized steel deck corrosion in Canadian roofs containing phenolic foam insulation. The program included:

- field inspections of 172 roofs. [Appendix A]
- phenolic insulation chemistry and corrosion chemistry. [Appendix B]
- quantitative laboratory analyses of phenolic insulation and steel deck samples removed from some roofs. [Appendix C]
- laboratory experiment comparing corrosion of galvanized steel roof deck in contact with polyisocyanurate and phenolic foam roof insulation. [Appendix D]

Galvanized steel roof deck is used in Canada. Galvanized is commonly used to refer to all zinc coatings (electrolytic zinc, galvaneal, galvalume, etc). The minimum coating required for steel roof decks in Canada is ZF075, a 75 g/m^2 (total both sides) galvaneal coating. This type of coating was used for all laboratory tests and it was on all of the roofs inspected where the coating was identified and/or tested.

The field inspections produced results that were expected from scientific text books. Metal will corrode in the presence of air and water, and prolonged roof leaks can perforate steel roof deck with corrosion regardless of the insulation type and presence or absence of an air-vapour barrier. However, "Without water the metal will not corrode" [17], and steel deck will not corrode if roofs are kept dry, e.g. in non-leaking roofs with air-vapour barriers.

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3 An association between steel deck corrosion and phenolic insulation in roofs exists primarily in the USA where the majority of steel roof deck is prime painted without metallized (eg. galvanized) corrosion protection. [14-16].

During the study it was found that phenolic foam roof insulation contained 0.09% of acidic hydrogen by weight and that the acid had remained substantially within phenolic foam except where there had been prolonged roof leaks. The maximum amount of steel that could be consumed if all the acid in the thickest available phenolic insulation were released would be 1.1% of the thinnest steel roof deck allowed in Canada [Appendix B]. Figures 2a and 2b show the condition of 0.76 mm thick, 75g/m^2 galvaneal coated (22 gauge, ZF075) steel deck underneath phenolic insulation in an 8 year old roof that had one section with an air-vapour barrier and the other without. This Toronto area roof had not leaked but interior humidification created a condensation potential of approximately 4,000 hours per year. The condensation potential was realized in the roof section without an air-vapour barrier, where all materials showed water damage and the deck was rusted. The condensation potential was not realized in the roof section protected by the air-vapour barrier, where all materials including the steel deck were pristine. Leachates of phenolic insulation removed from roof sections with and without air-vapour barriers had essentially the same acidity (82 & 83% of theoretical maximum) and this was similar to the acidity of leachate of unused phenolic insulation of the same thickness and similar age (86% of the theoretical maximum).

On this same 8 year old roof, corrosion protected screws and galvanized steel fastener plates had been used to secure both the phenolic foam as well as a 12.5 mm thick overlay of wood fibreboard. The fastener plates had four times thicker galvanization protection than the steel deck. In the roof section with an air-vapour barrier the screws and fastener plates exhibited no rust. In the roof section without an air-vapour barrier the screws exhibited little to no rust and the top sides of the galvanized fastener plates (directly underneath the roof membrane) exhibited no rust, but the undersides of the galvanized fastener plates (directly on top of the wood fibreboard overlay) exhibited more rusting than the steel deck beneath. This rusting was attributed to the absence of condensation protection and the greater ability of wood fibreboard to take on and store water.

In another roof phenolic foam roof insulation had been screwed to steel deck without an air-vapour barrier and a 12.5 mm thick wood fibreboard overlay had been adhered with widely spaced strips of adhesive. On this roof the lower surfaces of the fastener plates (in contact with the foam insulation) exhibited no rust and the upper surfaces of the fastener plates (in contact with the wood fibreboard) exhibited rusting over approximately half of their surface area. The galvanized steel deck underneath this roof was approximately 40 years old (it had been re-roofed at least twice) and exhibited little rust. The rusting of the galvanized fastener plate surfaces in contact with the wood fibreboard insulation was attributed to the absence of condensation protection and the ability of wood fibreboard to take on and store water.

During the roof inspections it was found that phenolic foam exposed to wet and soaking conditions could loose much of its acid content without it causing unusual corrosion. Figures 3a and 3b show the condition of steel deck underneath a leaking roof without an air-vapour barrier, the phenolic insulation underneath the leak had lost approximately 70% of its acid content at the time of inspection yet the thin galvanizing layer (0.7% of total deck thickness) was still largely intact. Accelerated laboratory experiments showed similar results. [Appendix D].

Figures 4a and 4b show "pencil lines" of rust that occurred underneath polystyrene and phenolic insulations in roofs without air-vapour barriers. Such lines are not typically seen in roofs with fibrous insulations because air moves freely into fibrous materials and condensation is stored (within the insulation) over the entire roof area. Air impermeable foams prevent air movement and force (moist) air to the insulation joints where condensation occurs. Joints represent approximately 1% of total roof area and there is a 100 times concentration effect of condensation and corrosion at the joints of plastic foam boards compared to fibrous insulations. The acid content of the phenolic insulation removed from this 9 year old roof indicated that little, if any, acid loss had occurred and the acidity was essentially identical at board edges and board centres. This suggests that "pencil lines" of steel deck corrosion underneath phenolic insulation board joints were related to the insulation=s physical properties, rather than to acid loss. [Appendix C]

Conclusion:

Proper protection of foamed plastic insulations in low sloped roofs includes the use of a fibrous layer between the insulation and roofing membranes, and careful attention to condensation protection. Specifically:

1 Protection from roof traffic damage. Overlay boards protect lightweight foam plastic insulations from roof traffic damage, especially underneath thin flexible roof membranes. By providing a less compressible substrate, roof membranes are less likely to puncture and this helps protect insulation from membrane leaks.

2 Reducing chances for blisters. Without good workmanship and dry weather vapours and gases may become trapped between hot applied roofing membranes and airtight foam insulations, resulting in voids and blisters. A fibrous layer between hot applied roofing membranes and foam insulations facilitates venting of vapours and gases emitted during membrane application, thus improving waterproofing protection for the insulation.

3 Protection from condensation/corrosion. Condensation protection with air-vapour barriers is especially important in roofs with foam insulations. Foam insulations resist condensation transport mechanisms (air and water vapour movement/diffusion) and little moist air and water vapour will flow into and condense within foam insulation. Instead moist air and water vapour movement, condensation and steel deck corrosion is concentrated at the joints between foam insulation boards.

Figure 2 Steel deck over high humidity building (a) section with air/vapour barrier (b) section without air/vapour barrier.

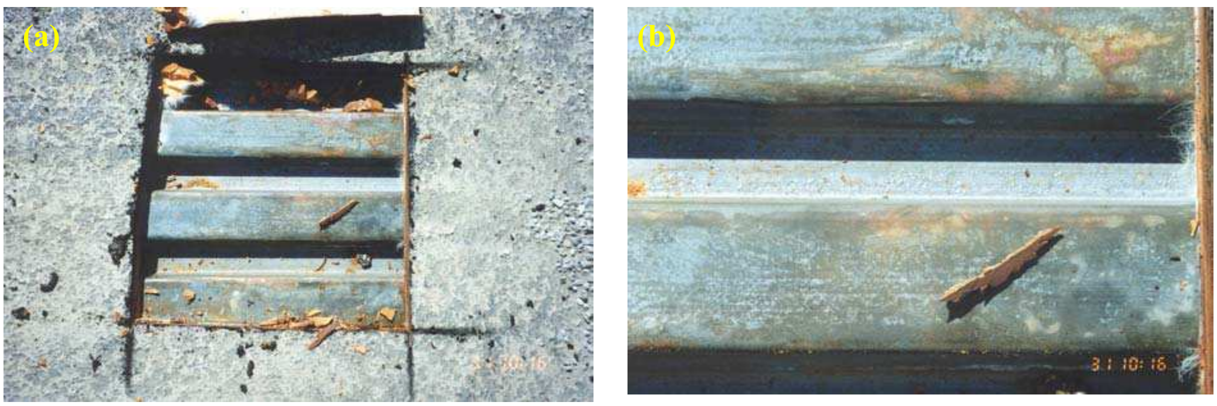

Figure 3 (a) Steel deck underneath roof leak where approximately 70% of acid content had been leached out of the phenolic insulation (b) close up of steel deck.

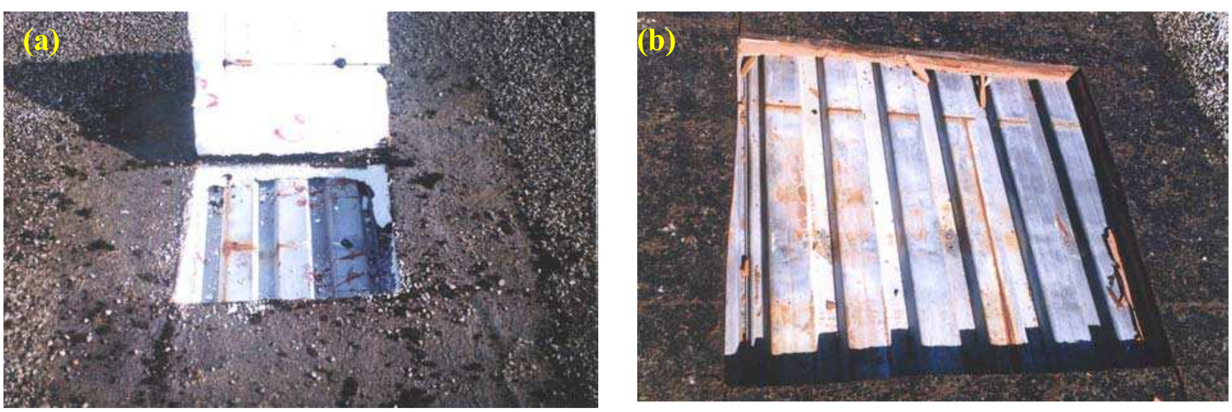

Figure 4 Pencil line rust under joints of foam insulation (a) polystyrene and (b) phenolic.

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Appendix A. Summary of 172 roof inspections

From 1994 to 2000, 172 commercial roofs containing glass mat faced phenolic insulation over galvanized steel roof deck were inspected to determine the extent of steel deck corrosion. Condition assessment included review of roof history, interior inspection, infra-red thermography, removal of 935 test cuts, and removal of approximately 20,000 m^2 of roofing. Roof ages ranged from 19 months to 132 months at the time of inspection and most roofs were reinspected (after an average of 3 years). The intent was to inspect roofs without air-vapour barriers but 52 of the 172 roofs had air-vapour barriers.

Eighty two percent (82%) of the roofs with air-vapour barriers exhibited no abnormal steel deck corrosion, 12% exhibited isolated patches of moderate steel deck corrosion where the air-vapour barriers had been cut, torn or improperly overlapped, and 6% exhibited serious steel deck corrosion where prolonged roof leaks had disintegrated the air-vapour barriers. Roof leaks repaired in a timely fashion did not cause steel deck corrosion on roofs with air-vapour barriers.

One hundred and twenty (120) roofs, covering a roof area of 493,000 m^2, had no air-vapour barriers. January design temperatures in Canada range from -2°C to -50°C [18] and wintertime condensation can be expected. Thirty four percent (34%) of these roofs exhibited no abnormal steel deck corrosion, 52% exhibited moderate corrosion and 14% exhibited serious steel deck corrosion due to condensation and/or roof leaks. Condensation induced steel deck corrosion was typically wider spread and shallower than that caused by roof leaks, and with the exception of 3 highly humid occupancies it was not serious.

In addition to the 120 phenolic roofs without air-vapour barriers, 3 roofs thought to contain phenolic insulation were found to contain extruded polystyrene foam and wood fibreboard insulation. Moderate steel deck corrosion was seen on these roofs.

<u>Appendix B. Calculation of the maximum acid content of phenolic foam and its impact upon corrosion</u>

The research program focused on roofs with Domtar phenolic insulation. Domtar patents show examples of phenolic foam recipes with mixed toluene sulphonic and xylene sulphonic acid (TXS) catalysts used in production. [Examples 5 & 13 of Canadian Patents 1,209,747 & 1,209,748]. The examples use a total acid content of 0.054 g of acidic hydrogen (H^+ ion) per 100 g of foam. Production recipes from Domtar manufacturing operations show the total acid content in 100 g of foam could be up to 0.087 g of acidic hydrogen.

Domtar phenolic foam density was 44 kg/m^3 and the thickest insulation manufactured was 90 mm. The weight per area of 90 mm foam was almost 3.96 kg/m^2 and its total acid content could be up to 3.45 g/m^2 of acidic hydrogen.

If phenolic insulation became sufficiently wet to release acid, the water would become acidic. Acidic corrosion of metal (hydrogen reduction and metal oxidation) is the predominant corrosion mechanism in acidic conditions. Steel is predominantly iron (Fe). Acidic corrosion of iron (Fe) requires two or three acidic hydrogen ions (H^+) to form rust (Fe^{2+} or Fe^{3+}). Chemical reaction equations representing acidic corrosion are below.

$$2H^+ + Fe = H_2 + Fe^{2+} \quad \text{(Ferrous ion product)}$$
$$6H^+ + 2Fe = 3H_2 + 2Fe^{3+} \quad \text{(Ferric ion product)}$$

The atomic weights of hydrogen and iron are 1 and 56 respectively. It takes 2 or 3 grams of acidic hydrogen to oxidize 56 grams of iron (or steel). Assuming the worst case, 3.45 g/m^2 of acidic hydrogen could oxidize (56 x 3.45/2) = 96.5 g/m^2 area of steel roof deck.

The thinnest steel roof deck in Canada (0.76mm/37 mm flute) weighs approximately 8.5 kg/m^2. The maximum thickness of steel deck that could be consumed if all of the acid in the thickest available phenolic insulation board were released is 1.1% of the thinnest roof deck allowed in Canada. This assumes even corrosion.

Appendix C. Steel deck corrosion and acidity of phenolic foam insulation samples removed from two roofs.

Both of these roofs were near Toronto, Canada that has winter design temperatures of -18 to -20°C.[4]

C1. Steel deck corrosion

Three 38 mm thick samples of phenolic foam insulation were removed from a 9 year old roof (R1) that had no air-vapour barrier. The building was not purposely humidified. The roof had been constructed in October (a cold month) and the concrete floor slab had been laid immediately after the building had been "closed in". Due to late season construction more condensation could be expected throughout the first winter, thereafter condensation would be reduced. After 9 years corrosion of the roof deck was limited to lines of shallow rust underneath the insulation board joints similar to that shown in Figure 4. Ultrasonic thickness measurements showed the steel deck underneath the rust to be within the thickness range specified for new steel deck..

Four samples of 51 mm thick phenolic foam insulation were removed from an 8 year old roof . Three samples were removed from an area that had no air-vapour barrier (R2) and one sample was removed from an area that had a vapour barrier (R2av). The roof had not leaked but the interior space beneath was purposely humidified. The steel deck was in pristine condition where there was an air-vapour barrier but rusted where there wasn't, as shown in Figures 2(a) and 2(b) respectively. Corrosion products from the steel deck underneath roof (R2) were analyzed. Scanning electron microscopy (SEM) with energy dispersive x-ray (EDX) identified corrosion product as mainly iron oxide, sometimes with zinc oxide, iron and elevated levels of sulphur. X-ray diffraction identified no sulphonate, which would have been expected if toluene and xylene sulphonic acids had leached from the insulation. Anion chromatography identified formate in a concentration of less than 1%. This could have been leached from the phenolic insulation or the wood fibreboard overlay on this roof, or from elsewhere. The wood fibreboard had a higher formate concentration and a higher capacity to absorb water than the phenolic insulation. It was impossible to identify the exact source of formate but its concentration was small.

Analysis of the rusted steel deck samples removed from the above roofs showed that 97% of corrosion products were not associated with the phenolic insulation. Analysis of rusted steel deck samples from other roofs with phenolic foam insulation included in this study showed similar results.

[4] National Building Code Canada, Appendix C, 1995

C2. Acidity of phenolic insulation samples

The pH of leachates of foam specimens removed from the edges and away from the edges of the insulation boards were measured. The procedure used was to crush phenolic foam, dry it to constant weight at 60°C, screen the dry crushed foam through a 600 µm sieve and collect it on a 300 µm sieve, place 1 g of the 300 to 600 µm particle sized foam in a 250 ml beaker, add 100 mL of deionized water, cover the beaker, agitate continuously with a magnetic stirrer, and measure the pH periodically until a constant value was obtained. It was found that 27 hours of stirring was required to reach a constant pH. The constant pH was taken as an indication that most of the acid had been removed, or at least the rate of removal of acid had become tediously slow. The long time required to remove the acid from the foam is indicative of the molecular compatibility between the toluene and xylene sulphonic acids and the phenolic foam. The results are tabulated below.

Table C. pH of leachates of phenolic foam specimens removed from roofs and removed from unused boards of the same thickness and of similar age.

Description of the phenolic insulation samples			Sample 1		Sample 2		Sample 3	
			Acidity (pH) after:					
Roof	Sample	Specimen	2h	27h	2h	27h	2h	27h
R1	38 mm thick. From a 9 year old roof without an air-vapour barrier.	centre	2.59	2.24	2.67	2.30	2.58	2.21
		edge	2.62	2.23	2.67	2.24	2.66	2.25
R2	51 mm thick. From an 8 year old roof over high humidity without an air-vapour barrier	centre	2.52	2.10	2.67	2.17	2.28	2.17
		edge	2.53	2.12	2.62	2.17	2.31	2.17
R2av	51 mm thick. From an 8 year old roof over high humidity with an air-vapour barrier.	centre	2.33	2.16	-	-	-	-
		edge	2.27	2.13	-	-	-	-
	38 mm thick. Unused 12 year old board. (Note)	centre	2.25	2.14	-	-	-	-
		edge	2.14	2.07	-	-	-	-
	51 mm thick. Unused 10 year old boards. (Note)	centre	2.30	2.17	2.17	2.08	-	-
		edge	2.32	2.24	2.10	2.04	-	-

Note: The pH of leachate from unused boards were measured after 2 and 30 hours, not 2 and 27 hours. These boards had been stored inside since their production.

For reference, the maximum amount of acid in Domtar phenolic foam is 0.087 g of acidic hydrogen (H^+ ion) per 100 g of foam. If fully extracted, 1 gram of this foam would yield a minimum leachate pH of 2.06.[5] [Appendix B].

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5 The higher the acidity the lower the pH. $pH = -\log_{10}$ (H^+ ion concentration in grams per litre of water).

The pH values of leachates of phenolic foam removed from 8 and 9 year old roofs and from 10 and 12 year old boards from storage were within the range expected from newly manufactured phenolic foam[6] *. The leachate pH of the three unused insulation boards ranged from 2.04 to 2.24 after 30 hours of extraction. The leachate pH of the seven boards from roofs ranged from 2.10 to 2.30 after 27 hours of extraction.* [7]

There was no significant difference in the leachate pH values of phenolic insulation boards whether they had been used on roofs or not, or whether they were exposed to condensation or not.

There was no consistent trend nor any significant difference in leachate pH values between foam removed from the centre and edge of any insulation board, this suggests that acidic ingredients had remained within the phenolic foam and that the "pencil lines" of steel deck corrosion seen underneath insulation board joints were caused by water resulting from condensation at the joints between insulation boards.

6 Acid content varies with production factors such as resin viscosity.

7 The 3 hour extraction time difference is not significant.

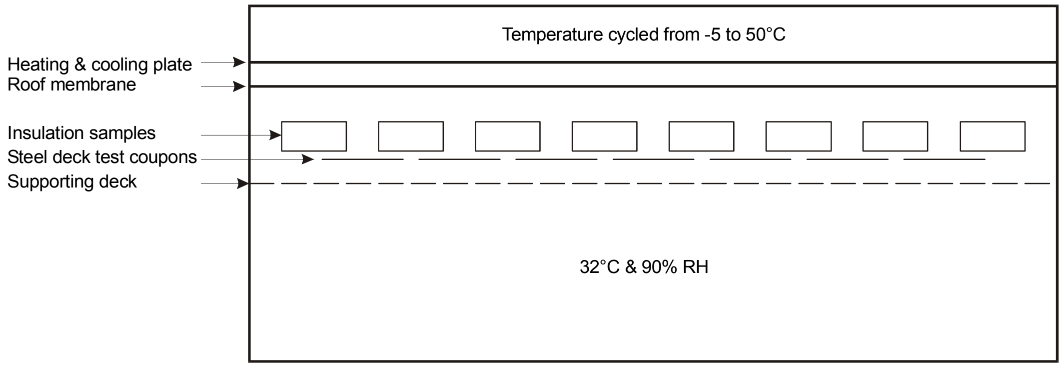
Appendix D. Laboratory experiment comparing corrosion of galvanized steel roof deck in contact with polyisocyanurate and phenolic foam roof insulations

An assembly comprising galvanized steel roof deck, foam roof insulation and a single ply EPDM rubber roofing membrane was constructed in the laboratory. This assembly was exposed to constant hot humid conditions (32°C, 90% RH) on the underside of the steel deck, and to a temperature cycle that varied from approximately -5 to 50°C four times a day on the upper (roof membrane) side of the assembly [Figure 5]. These conditions resulted in condensation within the roof system whenever the roof surface temperature fell below 28°C, and drying of the roof system when roof surface temperatures were above 28°C.

The intent of the experiment was to determine the rate and severity of corrosion of steel roof deck exposed to these conditions. Phenolic and polyisocyanurate foam insulations were used in this experiment to determine whether the type of insulation affected the rate and severity of steel deck corrosion. Both insulations were 30 mm thick commercial products purchased in 1994 and 1995. The polyisocyanurate foam had black felt facers and the phenolic foam had limestone filled glass mat facers. Specimens were positioned with 4mm gaps between them to simulate joints between insulation boards.

The amount of steel deck corrosion was inspected visually after 4, 10, 18, 26 and 34 weeks of exposure. After 34 weeks of exposure to these conditions the pH of leachates indicated that 99% of the acid in the phenolic insulation samples had been removed. The amount of corrosion observed on the steel deck under both insulation types was superficial [Figure 6]. The rate and severity of corrosion was slightly worse underneath the polyisocyanurate insulation than underneath the phenolic insulation. Lines of discolouration were visible on the steel deck underneath the joints between insulation samples, this phenomenon has been seen in commercial sized roofs that have inadequate condensation protection.

(a)



(b)

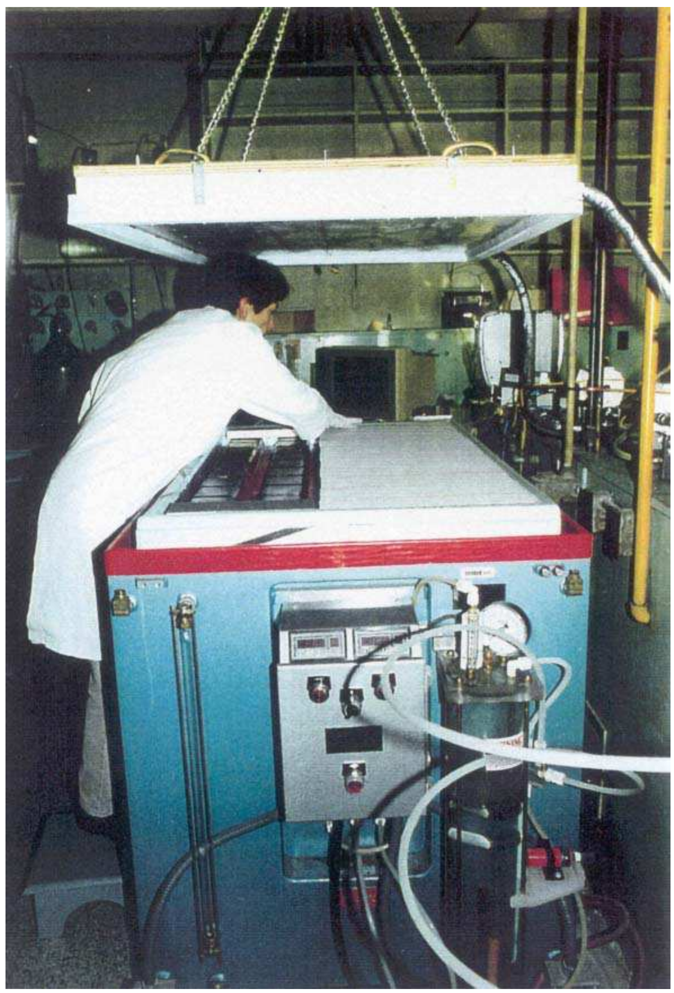


Figure 5 The apparatus used to simulate a low sloped industrial roof undergoing repeated cycles of condensation followed by drying (a) cross-section and (b) photo.

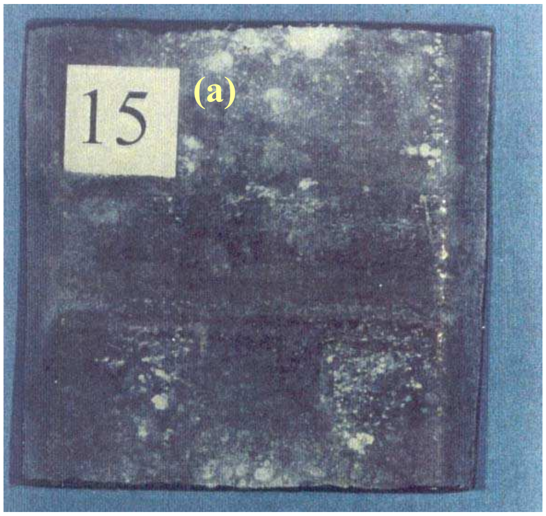


Figure 6 Typical condition of the steel deck after 34 weeks of exposure (a) underneath phenolic insulation and (b) underneath polyisocyanurate insulation.