THE PROTECTED MEMBRANE ROOF—MEMBRANES AND INSULATIONS

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"The ultimate goal of research on roofing materials is to develop information that permits selection of materials and designs for 'permanent' roofs, i.e., roofs that last as long as the foundation and walls of buildings." These words were written by Messers. Haldor W. C. Aamot and David Schaefer in CRREL Report 76-2, March 1976. The report was entitled "Protected Membrane Roofs in Cold Regions."

The report stated that while the initial cost may be greater, the life cycle cost of a protected membrane roof (PMR) is considerably less than that of a conventional membrane roof. The protected membrane roof performs longer with less maintenance required to keep it functional. The report concluded from durability and chemical stability tests that the life expectancy of protected membrane roofs was measurably greater than that of conventional roofs. Ii would seem this is an important step towards the long-sought goal of the permanent roof.

The advantages of the protected membrane roof over the conventional membrane roof are many. The greatest destroyers of a roofing membrane are environmental and physical abuse. Environmental abuse is caused by solar radiation, including infrared and ultraviolet, high temperatures and thermal stresses. Physical abuse results from roof traffic and heavy loads imposed on the roof membrane. In a conventional roof configuration, the membrane is generally over a substrate with low compressive strength, such as insulation. The protected membrane roof eliminates all of these stresses on the membrane. Furthermore, the PMR offers the advantages of placing the dew point above the membrane, and placement of the membrane on a dimensionally and stable substrate rather than on insulation. However, the protected membrane roof places other requirements on the membrane and the insulation not found in a conventional roof.

This paper is a result of research and experience with the performance characteristics of various roofing membranes and insulations; a review of international papers on the subject of protected membrane roofs; information gathered through attendance at roofing symposiums; work with the National Roofing Contractors Association over the past decade; and 30 years experience in installing roofing and waterproofing materials. My company has installed over 5 million square feet of protected membrane roofing in the Washington, DC area over the past 13 years, using a variety of roofing membranes and a few insulations. The purpose of this paper is to share experience and insight into the performance characteristics required of the various components that have been used in PMR's.

PERFORMANCE REQUIREMENTS OF THE MEMBRANE

While the PMR system is more forgiving of the membrane than any conventional roof system, it still makes demands not found in a conventional roof.

The PMR membrane must be better prepared to accept a damp or wet environment than a membrane in a conventional roof. While all membrane manufacturers and roof designers recommend a slope in the structural roof deck to encourage roof drainage, the simple truth is that few low-slope roofs actually slope. They are generally flat and, due to construction variations, they pond water in various locations. This is particularly true of cast-in-place concrete where most PMR's are employed. Ponded water may evaporate fairly quickly on a conventional roof membrane exposed to sun and wind, but water and moisture may remain weeks longer when the membrane is covered by insulation and ballast. On the plus side, ponded water will not freeze in the PMR. In addition, most of the water is displaced by the insulation and ballast. Therefore, the PMR is often reported to drain by displacement.

In a 1981 paper entitled "The Inverted Roof System: Progress and Experience to Date," A. F. Constantine of the United Kingdom states, "an increasing number of inverted roofs have been constructed on a 'no falls' (slope) basis and to date no problems have been reported arising from this practice". Based on the reality of no slope and ponding of some water in the PMR, it is my experience that the roofing membrane should be selected based on its ability to function in this environment. I warn against using membranes that the manufacturer states only can be used on sloped surfaces, or on surfaces that pond for no longer than 48 hours. Conversely, there are many manufacturers of elastoplastic membranes whose products evolved from pond and lagoon liners. They have no reservations about using their products in ponded roof situations, and backing them up with 10-year performance warranties.

The membrane also should be compatible with the existing environmental and air pollutants in the area it will inhabit. Heavy manufacturing areas may exhaust acidic pollutants. These can accumulate on the membrane beneath the insulation and remain there, since the membrane surface cannot be flushed in heavy rains as in a conventional roof configuration.

Furthermore, the roofing membrane should be compatible with the insulation to be placed above it. Otherwise, consideration must be given to the use of a separation sheet.

TYPES OF ROOFING MEMBRANES USED IN PMR'S

In Situ Built-Up Roofing Membranes

In the 1960s, a major United States manufacturer of extruded expanded polystyrene insulation acquired a patent on the concept of placing insulation above a roofing membrane rather than below it. In order to gain market acceptance for the concept and their insulation, they offered the first systems performance warranty in the United States. They guaranteed for 10 years that the roof wouldn't blow off in winds up to 70 miles per hour, that the insulation would retain 80 percent of its insulating value and that any type of three-ply conventional BUR membrane, that they did not manufacture, would not leak. They gave a 10-year guarantee against leakage through a roofing membrane that the manufacturers of the membrane would not give, and most still will not give. Even today, all BUR manufacturers in the United States insist in their literature that the deck must slope, and their BUR membrane not be subject to ponded water for longer than 48 hours. All elastoplastic membranes used in the PMR are guaranteed by the membrane manufacturers, not the insulation manufacturer. Quite a gamble at that time, but it paid off because it gave designers and contractors the needed assurance to try such a drastic innovation. The PMR is now well known and used throughout the United States and the world. But over the years, there have been a number of significant changes in the BUR membrane that the insulation manufacturer will now accept in his warranty.

Originally all types of bitumens (coal tar or asphalt) and reinforcements (organic, asbestos, glass felts and fabrics) could be used. Today, the insulation manufacturer will warrant only glass felts. In the late 1970s, some membrane failures caused by rotting or deterioration of organic felts were experienced, particularly in areas of light asphalt moppings. In the wet environment of the PMR, any moisture touching the felt would wick into the felt like a blotter. Because of the insulation and ballast above it, the felt couldn't dry out as it could if it were above the insulation as in a conventional roof. This led to accelerated membrane deterioration and the eventual realization that BUR membranes used in the PMR must be more resistant to moisture and capillary action.

Concerns have been expressed by participants in some technical meetings sponsored by the National Roofing Contractors Association about the long-term performance of some fiberglass felts in a wet environment. Certain binders used by some glass felt manufacturers have been known to be water soluble. I have been advised that unless these felts are encapsulated in full moppings of bitumen, we again may see some PMR membrane failures. Remember, the manufacturers of the fiberglas felts do not recommend their products in the wet, ponded environment found in the PMR. The membrane is being guaranteed not by the membrane manufacturer, but by the insulation manufacturer.

A benefit of the BUR membrane, and many of the other elastoplastic membranes we will be discussing, lies in its ability to totally adhere to the structural roof deck. Membrane adhesion to the deck permits ready location of any leakage that might occur because water cannot migrate laterally between the underside of the membrane and the top of the structural deck as it can in conventional roofs.

FLUID-APPLIED ELASTOMERIC MEMBRANES

Cold-applied fluid membranes can be either single- or two-component systems and can be applied by pressure spray, trowel or squeegee in a single application to a dry-film thickness of usually 60 mils. They offer the advantage of total adhesion to the structural deck and self-flashing characteristics. Again, this makes location of any leaks a relatively simple matter. These membranes generally have elongation characteristics greater than 400 percent to accommodate any movement in the deck. The manufacturers of the fluid-applied membranes guarantee the performance of their product for a 10-year period in the PMR. The insulation manufacturer guarantees thermal performance and that the insulation won't blow off in winds up to 70 miles per hour.

Most of the cold fluid-applied membranes used in the PMR are polyurethane or modified polyurethane elastomers. Problems have been experienced in my market area with certain formulations and they have been withdrawn from the market. The coal tar modifiers in some products attacked the insulation board. Other formulations could not perform in the wet environment of the PMR and, after a few years service, would swell and lose adhesion to the deck. Exposed flashings in some cases were attached by solar radiation and failed prematurely. In other instances, problems were created when workmen did not install proper membrane thicknesses, making the job more profitable for the contractor. This resulted in performance problems and damaged reputations for both the cold fluid-applied membranes and their manufacturers.

Hot-applied fluid membranes must be melted on the job site in special double-jacketed kettles. The membrane is generally installed, 120 mils thick, with a squeegee. The membrane offers all the advantages outlined for the cold-applied membranes without many of the disadvantages. Perimeter exposed flashings generally consist of sheets of neoprene or polymer-modified bitumen membrane. The membrane is classified as a rubberized asphalt, is guaranteed by the manufacturer for 10 years and has achieved a respectable success record in the PMR. The major manufacturer marketing this membrane offers a single-source guaranty covering the membrane, insulation integrity and against wind blow-off.

ELASTOMERIC SHEET MEMBRANES (VULCANIZED)

These include polychloroprene (neoprene) and ethylene propylene diene monomer (EPDM) sheets. EPDM is the one most widely used in the PMR, primarily because of the higher cost of neoprene. The EPDM sheet used in the PMR is usually 45 mils thick and is loose-laid. This membrane has excellent weathering characteristics, great elongation and a good track record in PMR and conventional roofs. The CR-REL Report 76-2, March 1976, by Aamot and Schaefer, reported they had enjoyed success with EPDM membranes in cold regions because of its ability to be installed in cold temperatures that would have precluded installation of a conventional BUR membrane. Furthermore, it is considerably safer and easier to install than a BUR, while being less affected by moisture during storage and application. It also is possible to install the EPDM to the structural deck with adhesive to gain the advantage of isolating any leakage. However, in practice most installations are laid loose on the

structural deck. The manufacturer guarantees membrane performance for 10 years and some manufacturers offer a single-source warranty guaranteeing insulation performance as well.

The major concern with an EPDM membrane in a PMR is in achievement of long-term, watertight seams. EPDM cannot be solvent or heat welded at the seams and must depend on adhesives, which can be affected by water if the seams are not carefully caulked at the edge.

ELASTOMERIC SHEET MEMBRANES (NON-VULCANIZED)

These include chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), polyisobutylene (PIB) and nitrile alloys (NBP). While all of these membranes can be used in a PMR, and a number have been used, they are not generally employed in this roof configuration due to economic considerations. Most of these products are produced with physical properties and weathering characteristics that make them well suited for conventional, membrane-on-top configurations. As a consequence, they have a higher installed cost than many of the other roofing membranes used in the PMR. Most of the manufacturers of these membranes offer 10-year material performance warranties in either roofing system.

THERMOPLASTIC SHEET MEMBRANES (PVC)

This membrane offers many of the same advantages offered by the elastomeric sheet membranes. Achieving good seams is a relatively simple matter as this membrane can be solvent or heat-welded. Again, the manufacturer guarantees membrane performance for 10 years. Care must be exercised to be certain the membrane is compatible with the insulation, particularly PVC and polystyrene. Plasticizer retention is an important criteria for long-term performance in a PVC membrane, even for use in a PMR.

POLYMER-MODIFIED BITUMEN MEMBRANES

Cold-applied self-adhering membrane is usually 50 to 60 mils thick and has a long and successful track record in the PMR in my area. It is installed by priming the structural deck, removing a release paper from the bottom of the membrane sheet and pressing the sheet onto the deck. Laps and seams are easy to achieve since the membrane bonds very well to itself. Furthermore, flashing details are simple to install because they use the same membrane as the roof. In addition, the self-adhesion of the membrane to the roof eliminates the possibility of water migration beneath the membrane sheet. Success with this membrane the PMR has encouraged the primary manufacturer of this product to market a complete PMR system and guarantee its performance for 10 years. At this writing, it is the only other extruded, expanded polystyrene insulation offered in the PMR roof system in competition with the original insulation manufacturer. This competition has had a positive effect on the cost of insulation in the PMR in my area, making the roofing system even more cost effective.

We also have enjoyed a great deal of success with torch-applied membranes in our market area. The torch-applied membranes are installed by melting the bitumen on the underside of the roll and unrolling the membrane into its own melted bitumen. Flashing is accomplished using the same product, and the membrane achieves the adhesion to the deck required to mimimize water migration beneath the sheet. Torch membranes usually are 160 mils thick, reinforced with polyester and/or fiberglass fabrics and modified with polypropylene or styrene butadiene. Laps and seams are easy to achieve by melting the product together and giving it a final check with a hot trowel. There are more than 30 companies marketing these products in the United States, and there has been a long and successful track record with these membranes in Europe, in both conventional and PMR installations. One United States manufacturer has such confidence in the performance of his product in the PMR that he is offering a 15-year material performance warranty as well as a single source 10-year warranty covering insulation thermal performance and wind blow-off. My experience with these membranes has been excellent and I have found them to be very environmentally adaptable. The action of torching will generally heat and surface-dry the structural deck, making membrane application possible when environmental conditions would prohibit the installation of most other roofing membranes.

Hot bitumen applied products consist of reinforced polymer-modified bitumen membrane sheets. They generally are applied in hot roofing asphalt in conjunction with a base sheet or additional plies of membrane. They are installed very much like a BUR and consequently share many of the advantages and disadvantages of a BUR membrane. They have been used in PMR's but have seen their primary usage in conventional roof configurations. When used in a PMR, the manufacturer would be responsible for the provision of the 10-year warranty for membrane performance.

PERFORMANCE REQUIREMENTS OF THE INSULATION

The PMR may be more forgiving of the membrane than any other roofing system, but it is decidedly more demanding of the insulation than any other roofing system. The insulation must be able to retain the majority of its long-term thermal efficiency while exposed to the elements and physical abuse. It will be resting on a wet or damp membrane with moisture vapor drives from above and below, depending on the time of year. In the winter, the top of the insulation can be below freezing and the bottom at room temperature, resting in water. In the summer the top of the insulation can be above 100F while the bottom remains at room temperature, still in water.

The insulation must accommodate acidic environmental contaminants in certain areas, and it must not be destroyed by plant roots that often grow on a PMR due to the moisture beneath the insulation. Furthermore, the insulation must have sufficient compressive strength to resist destruction by normal roof traffic required to service roof-top equipment. It must accommodate the type and weight of ballast placed over it to protect against wind blow-off, provide fire resistance and protection from ultraviolet degradation.

There have been various studies in numerous papers about the loss of insulating value during cold weather when water seeps through the joints of the insulation and runs across the top of the roof deck to the roof drains. To achieve the design R value in the cold cycle, there have been projections that insulation would need to be increased from 10 to

20 percent depending on the location. These studies all have been conducted with single-layer insulations. A study conducted by my company indicates that a double layer of insulation with staggered joints reduces the flow of water through the insulation to the roof deck by an average of 63 percent. This test was conducted by constructing a 10-foot square form with a wire mesh bottom, placing a single layer of 2-inch thick polystyrene insulation with tight butt joints in the form, pouring 10 gallons of water on top of the insulation and measuring the time required for the water to drain through. This same test then was conducted with two layers of 1-inch insulation with staggered joints. As a result of the test, it appears that there will be less thermal loss from water infiltration if double-layer insulation with staggered joints is used instead of a single layer. The reduction of water flow through insulation joints on a large roof probably would be less than achieved in the test. However, double layers of insulation with staggered joints reduce cold bridging through gaps between boards, further improving thermal efficiency.

Another factor that has a significant effect on the thermal performance of insulation in the PMR lies in the fact that the insulation sits on a wet or damp membrane most of the time. In the cold cycle, when the deck and the water on it is warm and the top of the insulation is cold and dry, moisture is drawn through the insulation, affecting thermal efficiency. There are developments under way in the United States to lift the insulation out of the water, thereby reducing loss of thermal resistance and improving the performance of the PMR.

There are very few insulating materials that can meet the demands of a PMR, and very few that have been successfully employed in this roof configuration. I will mention some of those tried in various parts of the world and in my own market area.

EXPANDED POLYSTYRENE

Both extruded expanded and molded expanded polystyrenes have been successfully employed in the PMR. In a paper presented at the Second International Symposium on Roofing, Brighton, England, in September 1981, Mr. A. F. Constantine stated: "All the experience to date appears to relate to the use of polystyrene as the insulant and most of this experience to the use of extruded boards, although there is a growing experience of the use of molded boards." Both of these polystyrene insulations have been used as flotation products, indicating they have a reasonable chance of success in the wet or damp environment of the PMR.

The predominant product used in the United States has been extruded expanded polystyrene largely because of the patent held on the PMR concept by the largest manufacturer of this product (U.S. Patent No. 3411256 issued 11/19/68 to J. S. Best). In addition, this manufacturer has a reputation for comparing its product somewhat unfairly with its molded board competition. It attempts to prove the physical property advantages of its product by comparing 1.9-lb/ft^3 extruded board with 1.0-lb/ft^3 molded board. This is like comparing apples with oranges. A fair and accurate comparison would be to compare extruded and molded expanded polystyrene boards of the same density. Table 1 makes this comparison based on information contained in the "Commercial, Industrial and Institutional Roofing Materials Guide" published by the National Roofing Contractors Association. You will note that similar densities have very similar physical properties. Polystyrene insulation has enjoyed the longest successful track record in the PMR and appears to remain the preferred insulating material.

POLYURETHANE BOARD INSULATION

In the mid-1970s, a major U.S. roofing materials manufacturer attempted to market a PMR system consisting of a three-ply built-up roof applied to the structural deck, polyurethane board insulation set in hot bitumen over the membrane and standard roofing gravel set in hot bitumen over the insulation. After a couple of years of field experience, the system was withdrawn from the market. The manufacturer expressed concern for the long-term thermal efficiency of the polyurethane insulation in the PMR environment. To the best of my knowledge, no other polyurethane insulation has been tried. It might be theoretically possible to use high density polyurethane but the cost per R value would be too great compared with polystyrene.

INSULATING BITUMINOUS FILL

This product consists of an expanded aggregate mixed with hot asphalt and installed in a monolothic application that is screeded and rolled. This product was suggested in the March 1976 CRREL Report 76-2 and has been used on a few buildings in my market area. Long-term thermal efficiency is maintained better if a membrane of some type is installed above, as well as below, the insulation. It also is apparent the cost per R value of the insulation exceeds that of polystyrene.

OTHER INSULATIONS

My research found three other types of insulants said to have been employed in the PMR with which I have had no experience.

M. C. Baker in Technical Paper No. 308, September 1969, from the National Research Council of Canada reported experience with foamglass beads mixed with asphalt and placed in a thick continuous layer to provide insulation and drainage. Unfortunately, no other information was provided on installation or performance.

The CRREL Report 76-2 mentioned a protected membrane roof developed after World War II that used fly ash as the insulant. It was developed in the Soviet Union and Rumania. The fly ash was spread in a 6- to 8-inch layer on roofing felts and covered with sand and concrete pavers. No information was supplied on the performance of this insulant.

Both of the above publications and other articles have referred to sod, the original PMR insulant. Sod roofs have been built in many northern countries for centuries. The sod provided insulation and protection for the birch bark shingle membrane and provided the principles that have led to the opportunity to build superior roofs with today's high performance materials.

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	Extruded	**Molded**
Density (ASTM C-303) lbs/ft.^{3}	1.9 typ.	2.0
Compressive strength (ASTM D-1621) psi	40/25 min.	25-33
Water absorption (ASTM C-272) % by volume	.1 typ./.3 max.	<1.0
Flexural strength (ASTM C-203) psi	80 typ./60 min.	55-75
(R) Value @ 40°F—2-inch thickness	10.75	9.52

*Table 1 Typical physical properties of extruded and molded expanded polystyrene of similar densities. Reference: **Commercial, Industrial and Institutional Roofing Materials Guide,** Volume 5, August 1984, National Roofing Contractors Association.*