FIELD SURVEY OF MOISTURE GAIN BEHAVIOR WITHIN SINGLE-PLY ROOF SYSTEMS

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A field and laboratory program studied the moisture accumulation behavior which has been observed to occur in single-ply roof assemblies. The research program assessed each variable which could contribute to the moisture accumulation problem. This included interior and exterior temperature and humidity, a laboratory study of the permeance values of new and aged EPDM membranes, and documentation of moisture gain in insulation samples taken from the field.

Laboratory testing has shown that EPDM membranes have a nonlinearly increasing permeance above 90F permitting water vapor diffusion when high vapor pressure drives are present. Given the variables in a roof system, a computer progam was developed to accurately assess the amount of time needed to accumulate moisture. This paper presents a partial correlation of data from the field study and laboratory findings with computer prediction. It also provides data for refining material standards for EPDM roof systems.

SINGLE-PLY MEMBRANES

The use of single-ply roof membranes in commercial and industrial low slope roofing has grown significantly. It is estimated that at least 35 percent of the commercial and industrial roofing market will use a single-ply membrane in 1984. This includes both plastic and elastomeric membranes such as polyvinylchloride (PVC), chlorinated polyethylene (CPE), ethylene propylene diene monomer (EPDM), neoprene, chlorosulfanated polyethylene (CSPE), polysiobutylene (PIB) and other polymer based compositions. Currently these sheets range in thickness from 30-60 mils, with the vast majority between 45 and 60 mils.

These membranes are used in three types of roof systems: loose-laid and ballasted, mechanically fastened or fully adhered. The roof systems use a variety of insulation materials such as fiberglass, isocyanurate, perlite, polystyrene, urethane and wood fiberboard.

Some of the most recent surveys show that 60 to 70 per cent of single-ply membranes in use are installed in reroofing situations. This is probably due to their attractive applied cost. A loose-laid and ballasted system is the most economical. The mechanically fastened sheet and fully adhered membrane systems have the next lowest in-place cost.

MOISTURE PROBLEMS REPORTED

The installation of elastomeric and plastomeric roof membranes began in the 1960s. As more in-service time accumulates, there are reports of entrapped moisture. Preliminary reports from the field indicated that some single-ply roof systems were found to:

- have entrapped moisture, yet are performing satisfactorily with no reported loss of watertight integrity;
- exhibit leakage problems in February and March in the northern climates and in July and August in the southern states, where loose-laid insulation was placed directly on a steel deck with a ballasted membrane;
- have small amounts of entrapped moisture upon initial investigation, yet when examined later, no moisture was present.

Roofing contractors have expressed concern over entrapped moisture. A number of membrane manufacturers have also expressed interest in investigating the moisture accumulation behavior of single-ply membranes. A research program was undertaken to identify the variables present and evaluate their impact on, or potential for, moisture gain. A field survey was initiated to look at the short-term, two-year, and long-term, two- to ten-year, moisture gain behavior. This report outlines the findings to date on roofs observed during less than two years of in-service performance. This part of the field study is primarily concerned with EPDM roof systems. Other membrane types will be studied separately in order to minimize the number of variables under study.

SOURCES OF MOISTURE ENTRY

Three separate variables were identified for study: moisture from the building interior; membrane characteristics including permeance and possible defects; and moisture trapped during construction. Any one of these variables could account for the presence of moisture within an elastoplastic roof system. It should be noted that a loose-laid and a mechanically fastened single-ply roof system will have air leakage and void spaces built in.

In contrast, a fully adhered system is tighter and generally has smaller void spaces present, especially when applied over mechanically secured insulation over steel deck. A small void within a built-up roof membrane is known to cause blistering. The addition of a small amount of moisture into this void space will ensure that a significant blister develops.

It also should be recognized that the roof deck and insulation board materials used under single-ply membranes have been used with built-up roof membranes for quite some time. The only new variables are the elastomeric or plastomeric membrane itself and its method of attachment.

Interior/Exterior Moisture

Interior temperature and relative humidity constantly relate to exterior temperature and relative humidity conditions by heat flow and water vapor diffusion. The roof system normally receives two design considerations: membrane type and the amount of thermal resistance required to retard heat flow. The consequences of vapor pressure drive do not ordinarily receive the same design emphasis, except where there are high temperatures and/or high humidity inside the building.

As shown in Table 1, a roof system is subjected to upward or downward vapor pressure drives depending on interior and exterior conditions. If an interior temperature of 70F and 50 percent relative humidity is maintained against 20F and 80 percent relative humidity found during winter weather, a net vapor pressure drive of 0.133 psi will occur upward into the roof system. By simply raising the interior temperature to 80F and maintaining the same relative humidity a 54 per cent increase in the vapor pressure drive will occur.

During the summer the net vapor pressure drive downward into the roof system occurs as shown in Table 1. For example, if both the exterior and interior temperatures are 80F with 80 per cent relative humidity outside and 50 percent relative humidity inside, the vapor pressure drive is 0.153 psi downward. This assumes no air conditioning, only dehumidification of interior air.

If air conditioning maintains a 70F and 50 percent relative humidity during the same summer exterior conditions, the vapor pressure drive downward increases 46 per cent.

In a more severe case, air conditioning may be used to maintain interior conditons of 70F, 50 percent relative humidity against a hot, humid exterior condition of 95F, 80 percent relative humidity. This results in a 0.472 psi vapor pressure drive downward, a 110 percent increase over the summer exterior conditions of 80F, 80 percent relative humidity.

Vapor pressure drive is constant and present as long as stated conditions hold. Therefore, a time rate of moisture gain must be considered. In loose-laid single-ply systems, an upward vapor drive will cause ice lenses to grow beneath the membrane if sufficient time elapses under winter conditions.[3] Void spaces and air leakage into the roof system are required for this to occur. There is little doubt that steel deck construction with a loose-laid roof system provide this condition. Perhaps a vapor retarder has more significance for a loose-laid system than for a totally adhered system, such as a built-up roof.

Membrane Characteristics

Another source of moisture entry into a roof system is through the single-ply sheet or through membrane defects. Obvious defects in a single-ply membrane are imperfect side and end laps, which provide a point of water entry. Other obvious points of entry occur at imperfect flashings, roof terminations or mechanical fastener heads which break through and puncture the membrane.

Several manufacturing defects leading to possible moisture entry also could be present in EPDM membranes in particular. They include pin holes and pock marks. To prevent pin holes or pock marks, which result from calendering, a finished EPDM sheet is composed of two separate sheets brought together in the manufacturing process. If one sheet has an imperfection or pin hole, it does not constitute a total membrane defect since the second sheet is assumed to be defect free at that point. Thus, pock marks will, we hope, affect only one-half the total sheet thickness.

Water vapor transmission occurs through the roof membrane under the conditions described in Table 1. While most EPDM manufacturers publish a single permeance value for their EPDM sheet, it is well known that a smooth surface EPDM membrane will experience a wide range of temperatures. In fact, a smooth surface EPDM membrane under direct sunlight experiences the same high temperatures as a smooth surface built-up roof. Ballasted EPDM membranes do not experience as high membrane temperatures because the ballast, or pavers, are light in color and provide high reflectance and low absorption.

A study was undertaken to determine the permeance of different types of EPDM membranes at 70F, 90F and 158F. A series of water vapor transmission tests were run according to ASTM E-96, using the dry cup method at 50 per cent relative humidity at the test temperatures. As shown in Table 2, the test results for 45-mil and 60-mil black EPDM increase by at least a factor of ten between 90F and 158F. At 40F, the perm ratings generally drop to one-half of the 90F value. The new 60-mil black EPDM showed a relatively low perm rating of 0.011 at 90F. However, all the aged field samples had an average perm value of 0.414 at 90F. The perm rating for all the EPDM samples tested at 158F are well above 0.1, the value assumed for a vapor retarder.

The data suggests that EPDM membranes may have a non-linear vapor permeance which is highly temperature dependent above 90F. Given the downward vapor pressure drive that could be present during summer with an air conditioned interior, it is possible to have water vapor diffuse through the membrane at a very low rate. Due to the time dependency of the downward water vapor diffusion, a computer model is needed to accurately assess the temperature, humidity, permeance and other physical properties of a roof system using an EPDM membrane. A computer model was developed and used to simulate a year-by-year analysis of moisture accumulation for a specified weather system. The analysis showed that moisture can accumulate, but not a significant amount.

The computer model also predicted that moisture will condense under single-ply membranes when high internal temperature and humidity conditions combine with winter temperatures.

Moisture Trapped During Construction

New roof construction occasionally encounters wet, uncured decks, with water trapped in deck flutes or insulation becoming wet while stored on-site. Reroofing activities quite often involve recovering existing built-up roofs, often without removing water-soaked materials.

After examining the test results and considering the interior and exterior conditions available for vapor pressure drive, it is easy to see why some recovered old roofs will never dry out. Depending on their climate location and interior temperatures and humidities, vapor pressure forces may do nothing but cause entrapped moisture in an old built-up roof system to stratify.

SUMMARY OF FIELD FINDINGS

Planning for the field study began in early 1984 with the objective of investigating the moisture gain behavior on roofs with less than two years service. According to vapor pressure drive calculations, smooth surface EPDM roofs would be examined during the summer of 1984 and ballasted loose-laid systems during the winter of 1984-85. The summer phase of the investigation allows for correlation of moisture gain due to downward vapor pressure drive, especially in air conditioned spaces. The winter survey would look for the effects of condensation and ice lenses directly beneath loose-laid membranes over a steel or concrete plank deck with no vapor retarder.

The 1984 summer survey included nine EPDM roof systems located in six different states. As shown in Table 3, the typical membrane specification was a 60-mil, mechanically fastened system. Three of the roofs were 60-mil adhered membranes. One 45-mil, mechanically fastened membrane also was investigated.

The roof survey included a review of the design specifications and a meeting with the owner or plant maintenance personnel beforehand. The rooftop investigation included a complete inspection of flashing and membrane termination details. Lap joints were checked, and any defects which might affect the moisture gain study were noted.

At the outset, it was decided to split all insulation boards into a top and bottom layer in the field and seal them separately in order to accurately determine if the bottom layer was gaining moisture due to downward vapor pressure drive. The results of the field study are shown in Table 4. Of the nine roofs surveyed six had a totally air conditioned environment beneath the roof, and one was partially air conditioned. Two of the buildings did not have any air conditioning present.

A directional correlation of water vapor diffusion was found. On three of the roofs with a two-layer insulation system, or a single board thickness cut in half, more moisture was found to have accumulated in the bottom layer than in the top. One of the non-air-conditioned buildings, roof sample number 8, with a double layer system, had higher moisture content in the top layer.

Nominal moisture content by weight of new, properly manufactured insulation materials are: perlite 1.4 percent, polystyrene 0.3 percent, wood fiberboard 3.6 to 4.7 percent and urethane 0.4 to 0.6 percent. Since the insulation was not checked for moisture content when installed, no absolute moisture gain values can be determined from the field survey data.

Eight of the nine roofs examined contained a built-up roof membrane left in place. Only one roof, roof sample number 3, had a vapor retarder. None of the EPDM membranes showed any signs of condensed moisture on the underside. However, the heads of screws used to anchor the insulation boards had, in many cases, small, red rust accumulations. While it could not be documented during the summer survey, it is suspected that topside, condensation did occur beneath the membrane during the winter, causing spot rusting of fastener heads.

Samples of each EPDM membrane were returned to the laboratory for testng of permeability. As shown in Table 4, the perm values ranged from 0.008 to 1.520 when tested at 90F according to the ASTM E-96 dry cup method. The lower values corresponded with the tests conducted on new EPDM membranes (Table 2).Two membranes, roof sample number 6 and roof sample number 1, had significantly higher perm ratings, with values of 0.462 and 1.520. This correlates with the higher moisture content found in the bottom layer of the two layer insulation systems on these roofs, as shown in Table 4.

EFFECTS OF MOISTURE GAIN

The field survey conducted during the summer of 1984 examined EPDM roof systems ranging in age from 12 to 27 months. Spot rusting of mechanical fastener heads was noted already in these roofs.

Entrapped moisture will be a concern to the long-term performance of mechanical fasteners, insulation materials and any adhesive system incorporated within the roof system assembly.

Plastic foam insulation materials are relatively non-absorbitive but will undergo a steady moisture gain if a sufficient vapor pressure drive is present. Wood fiber, perlite and fiberglass insulations will readily absorb, or wick, free moisture if it is present. The long-term effects of moisture will be studied in the next part of the field survey in which older single-ply roof systems will be examined. The primary area of concern is for moisture trapped during construction, especially when recovering existing built-up roof membranes. A wet built-up roof system only adds to the entrapped moisture problem. As the new roof system undergoes upward or downward vapor pressure drives, the built-up roof membrane will serve as a vapor retarder, trapping moisture between it and the new single-ply membrane.

CONCLUSIONS AND RECOMMENDATIONS

A field and laboratory study has shown that EPDM roof membranes can vary widely in permeability, depending on temperature. White EPDM and flame-retardant membranes also exhibit variation in permeability.

The study also indicated that any void space or air leakage within a loose-laid or mechanically fastened single-ply roof system may allow condensation immediately beneath the membrane. Exposed EPDM membranes will, under high downward vapor pressure drive, apparently allow a small moisture gain to occur, but only in one direction. When the vapor drive reverses in winter, the EPDM membrane changes its permeability and will not release water accumulated during the hot summer cycle.

Further field studies are planned on ballasted roofs to more fully document their winter condensation behavior. Some data already exists, and a computer model will be used to correlate these findings.

It is recommended that design temperatures be established with accompanying permeance values for EPDM roof systems. The data design should differentiate between loose-laid and fully adhered systems. Consideration also should be given to air leakage from different deck configurations.

Two-layer insulations should be used where possible or practical. The offset or staggered joint pattern will help stop direct air passage.

High winds normally cause ballasted or mechanically attached systems to flutter, forcing an interaction with the interior air. The presence of a vapor retarder in a loose-laid system will be beneficial since it will help decrease direct air movement.

REFERENCES

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INTERIOR CONDITION		EXTERIOR CONDITION		DEW POINT (°F)	VAPOR PRESSURE DRIVE	
TEMPERATURE (°F)	RELATIVE HUMIDITY (%)	TEMPERATURE (°F)	RELATIVE HUMIDITY (%)		PSI	DIRECTION
WINTER						
70	50	20	80	51	0.133	UP
80	50	20	80	60	0.205	UP
SUMMER						
70	50	80	80	73	0.224	DOWN
80	50	80	80	73	0.153	DOWN
70	50	95	80	88	0.472	DOWN

Table 1 *Typical vapor pressure drive on a roof system*

MEMBRANE TYPE	TEST TEMPERATURES		
	40°F	90°F	158°F
45 MIL - BLACK	0.017	0.041	0.519
60 MIL - BLACK	0.030	0.011	0.345
60 MIL - WHITE	0.036	0.060	0.625
60 MIL - FLAME RETARDENT	0.028	0.051	0.366

NOTE: TEST METHOD ASTM E-96, DRY CUP AT 50% RELATIVE HUMIDITY; AVERAGE OF THREE SAMPLES.

Table 2 *Perm test results for new EPDM membranes*

NAME	LOCATION	MEMBRANE SPECIFICATION	
		THICKNESS	ATTACHMENT
JAMES ISLAND	SOUTH CAROLINA	60 MIL	ADHERED
NORTHWEST BANK	NORTH CAROLINA	60 MIL	MECHANICALLY FASTENED
KAYSER/ROTH	TENNESSEE	45 MIL	MECHANICALLY FASTENED
TERMINAL TRANSPORT	FLORIDA	60 MIL	MECHANICALLY FASTENED
GENERAL TELEPHONE	GEORGIA	60 MIL	ADHERED
BUCKMAN	FLORIDA	60 MIL	ADHERED
DUTCHESS COUNTY OFFICE BUILDING	NEW YORK	60 MIL	MECHANICALLY FASTENED
LELAND/GREY HIGH SCHOOL	NEW YORK	60 MIL	MECHANICALLY FASTENED
SULLIVAN COMMUNITY COLLEGE	NEW YORK	60 MIL	MECHANICALLY FASTENED

Table 3 *Summary of EPDM roof systems observed*

INSULATION TYPE/SOURCE	MOISTURE CONTENT (% BY WEIGHT) FIELD SAMPLE	AGE OF SYSTEM (MONTHS)	A/C	VAPOR RETARDER	MEMBRANE TYPE	PERM VALUE
POLYSTYRENE						
MOLDED-JAMES ISLAND	0.07%	17	YES	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	1.520
EXTRUDED-NORTHWEST BANK	0.24%	12	YES	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	0.049
PERLITE						
KAYSER-ROTH	1.60%	12	NO	YES	45 MIL	0.041
TERMINAL TRANSPORT	1.55%	10	YES	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	0.008
GENERAL TELE(BOTTOM LAYER)	1.48%	17	YES	OLD BUR MEMBRANE	60 MIL	0.040
WOOD FIBER						
JAMES ISLAND		17	YES	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	1.520
TOP LAYER	4.86%					
BOTTOM LAYER	5.90%					
GENERAL TELEPHONE(TOP LAYER)	2.60%	17	YES	OLD BUR MEMBRANE	60 MIL	0.040
URETHANES						
BUCKMAN		17	YES	OLD BUR MEMBRANE	60 MIL	0.462
TOP LAYER	1.76%					
BOTTOM LAYER	2.21%					
SULLIVAN CITY COMM. GYM.		27	PART.	OLD VAPOR RETARDED AND BUR MEMBRANE (PUNCTURED)	60 MIL	N.A.
TOP LAYER	2.20%					
BOTTOM LAYER	2.84%					
DUTCHESS CITY OFFICE BUILDING	2.61%	22	YES	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	0.052
LELAND/GRADE H.S.		24	NO	OLD BUR MEMBRANE (PUNCTURED)	60 MIL	0.034
TOP LAYER	1.53%					
BOTTOM LAYER	0.60%					

NOTES: 1) A/C - AIR CONDITIONED SPACES UNDER ROOF SYSTEM.

2) PERM VALUES DETERMINED BY ASTM METHOD E-96, DRY CUP AT 90°F, 50% RELATIVE HUMIDITY.

Table 4 *Comparison of moisture content and perm values from field samples*