THE ROBUST ROOF

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ABSTRACT

With each issue of Project Pinpoint, a roofing industry association's survey of contractor-reported roofing system problems, recurring problems are reported in the performance of flat roofing systems. Many of the problems noted in the survey in 1988 are again reported in 1994. Problems such as failure of single-ply seams, blistering and splits in built-up roofing (BUR) membranes, and flashing problems in all systems are found in the studies year after year. These problems cost this country millions of dollars in lost energy because the underlying insulation gets wet and loses R-value. Additional energy is consumed in the repair and replacement of materials due to these failures.

There are solutions to these recurrent problems, and the costs for the solutions can be calculated and applied to the original cost of the roof with the expected life extension included. These techniques have been developed to study recurrent problems with automobiles and have been applied to other industries. The Tagucci techniques can be applied to flat roofing and the most economical solutions can be demonstrated.

Tagucci has shown that by making just some parts more robust the entire automobile will last longer and perform better. The Tagucci technique uses statistics developed from warranty repair records and then focuses on the areas that are most vulnerable. The success is shown in the significantly improved Japanese automobile, and now the same results are being realized in the manufacture of American automobiles.

This paper will use the data from Project Pinpoint and other sources to statistically quantify the problem. Suggestions to help fix or eliminate the problems will be explored. Costs will be developed for the various solutions and their long-term impact will be applied. The corrective measures for the specific problems will be cost evaluated and ranked.

INTRODUCTION

What is quality in roofing systems? According to W. Edward Deming, "Quality can be defined only by the agent" (Deming 1991). Deming further explains that the agent may be the producer, the consumer, or someone else in the chain from production to consumption, and that each agent may have a different perspective of the "quality" of the product or system.

Deming suggests that "the way to provide quality is to design the product, test its performance in the laboratory, test its performance in the field, make corrections in response to the field information, and repeat the cycle with never ending improvement in quality."

Genichi Taguchi (Taguchi and Clausing 1990) emphasizes that "quality is a virtue of design. The robustness of products is more a function of good design than on-line control, however stringent, of the manufacturing processes."

Project Pinpoint (NRCA 1993) has given us a limited look at some of the statistics of roofing problems for the years 1983 to 1993. During this time of massive changes in the roofing industry some of the problems recur year after year, and at about the same level. This suggests that the design may be the problem. Whipping or rewarding the mechanic, changing material, and the conditions around the country have not eliminated some of the major problems with roof systems.

Roofing problems result in energy loss due to the loss of R-value of wet insulation beneath the membrane, the costs of labor and transportation for replacement of material, and the energy related to making all-new product. In this paper the design problems are addressed and their projected causes are reviewed. Costs related to the problems are developed and alternate solutions are suggested and their costs compared for a few of the most prevalent problems in flat roofing today.

Most experts on problem-solving techniques suggest weighting of problems relative to their consequences. This will help direct those trying to solve the problems to the truly important problems—solve the highest weighted problem first, and then work down and correct through the list of problems until all or most of the problems are eliminated.

Often correcting the most serious problems also will reduce or eliminate other problems, or, in some cases, help uncover real causes that were not apparent when looking at the overall statistics of problem occurrence. In the following tables the percentages of problem occurrence are provided from Project Pinpoint and the weighting from experience are used to derive a weighted response. The weighted response is used to select the problems addressed in this paper. The problems are

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TABLE 1 Critical Problems from Project Pinpoint

BUR, Reported Problems	% of Roofs With Problems 1983 to 1992	Likely to Have Significant Energy Related Consequences	Weighted Response
Blistering	24	4	96
Splitting	19	10	190
Ridging Bucking	14	4	56
Flashing	14	7	98
Slippage	6	1	6
Wind	2	10	20
Others	22	?	?

addressed to determine if cost-effective changes can be made to eliminate or reduce the problem.

Understanding Tables 1, 3, and 4

Tables 1, 3, and 4 are derived from Project Pinpoint. The percentage of the roofs of the type referenced that had problems during the period are taken from the Project Pinpoint data. The column titled "Likely to Have Significant Related Problems" is an estimate of the area (in ft^2) of insulation under a membrane that could get wet from a single incident.

As an example, one pinhole through one blister is estimated to wet 4 ft^2 of insulation beneath the membrane, resulting in a rating of 4. A split is estimated to wet 5 ft^2 on each side of one linear ft of split, resulting in a rating of 10. Multiplying the percentage of problem by the square footage gives an energy loss weighted response for that problem. The numbers represent only the author's experience-based opinion as to the extent of damage from the problem type reported.

BUILT-UP ROOFING (BUR)

An analysis of the reported problems with BUR roofs gives us insight into problems that have been resistant to change even though the organic reinforcement felts have been largely replaced by glass felt and most roofers have purchased new and better equipment in the last 10 years.

The Blister Problem

Blistering is reported in 24% of the roofs. Why does blistering occur? Experiments in the 1980s by a coalition of roofers failed to eliminate blistering in a series of carefully installed BUR roofs. Although many causes are suspected, it appears that voids in the lamination of roofing plys or the lamination of roofing to a substrate are unavoidable with existing materials.

Roofers installing a BUR on what appeared to be a smooth, dry, clean, well-primed concrete deck have returned to the roof after 24 hours and found blisters over the entire system. Well-made multi-ply BUR roofs over wood fiber or other acceptable substrates have developed blisters within three to four years.

Blisters can result in blow-off and leak problems and eventually the roof fails. Project Pinpoint estimates that 24% of roof problems with BURs are blisters. It has been a consistent problem for decades. Standard BUR field fabrication results in some roofs blistering. Each blister has a potential to leak, and eventually that leak is likely to wet 4 ft^2 or more of insulation. It is often the slow leak type that does not initially enter the building but results in lost R-value.

The heating energy cost of an individual blister is low (using the assumption of Kyle and Desjarlais [1994]), about \$.16 per ft^2 per year or \$.64 per blister. Typically, however, roofs that blister have hundreds of individual blisters. A 20,000-ft^2 roof easily could have 200 blisters, which would result in a heating energy loss of \$128 per year, if and when the blister leaked water into the insulation below the membrane. This still is not a cost that would drive an owner to repair the roof. Making a somewhat weak but possible assumption from the Project Pinpoint data, 24% of the roofs installed in a given year could have blisters. The gross heating energy loss of 24% of the problem BUR roofs produced in any one year is significant. Using an average size of 20,000 ft^2 per roof, more than 259,000 BUR roofs could be projected to have blisters. If the cost of the heating energy loss is \$128 per year per roof, the blistered roofs installed in one year alone could cost approximately \$33 million per year.

Interestingly, the aesthetics of the blisters or just a few drops of water in a work area will get the roofing crew out to make the fix. The repair most often may be just to stop the leak and not change out the insulation. With no leaks, as is likely if a vapor barrier is present in the roof composite, the energy loss is likely to continue for many years before the problem is corrected.

Causes of Blisters

Why do blisters occur? Their occurrence may be related to a void of some finite dimension, which were created during the installation. Elimination of these voids is nearly impossible in the conditions normally experienced during roof construction. The voids contain air and sometimes water vapor. Normal permeability of asphalt allows more air and or moisture to enter the void over time. When the air-filled void is heated, it expands. The interlayer bonds are insufficient to prevent the blister from expanding, and eventually a large blister develops.

Because a tremendous amount of blistering was encountered when membranes were installed directly over insulation containing volatile blowing agents, it was believed that blowing agents were released during the roofing process or as the system aged. It was suspected that the blowing agents were trapped in voids in and between the membrane and insulation, resulting in the blisters. Little evidence has been obtained that supports this hypothesis. The cell walls in the commonly available thermal insulations are excellent barriers to the migration of the blowing agents used, hence, the long-term retained R-values of the insulation and the low diffusion potential of the gases to the voids in the membrane.

An argument for the blowing agents creating the blisters is that insulation cell walls can be broken or crushed when loaded during roofing. This allows the blowing agent to escape, creating nucleating sites for the initiation of the blisters. A blister then would have a little blowing agent entrapped, but could collect air and moisture and eventually expand with heat.

The cause of more blisters over thermal insulation is more likely to be from the much higher temperature of the membrane when well insulated from the moderating effects of the interior of the building by the efficient thermal insulation.

Elimination of Blisters

We know the cause of blisters to be the expansion of voids created during roof membrane installation. We know they grow in the presence of heat. How can blisters be eliminated? Looking at the roof assembly process, doing more of the roofing steps in a more controlled environment would be expected to reduce the voids created in field-built systems. Therefore, factory-fabricated modified bitumen membranes should have a better performance history than BUR. Project Pinpoint's gross data do not include blistering as a category of problems for polymer-modified bitumen membranes. An assumption can be made that using a polymer-modified bitumen will significantly reduce or eliminate the blistering. However, when the roofing coalition made a study of modified bitumen roofs, it found 14% of the APP and 31% of the SBS modified bitumen problems were blisters. The use of modified bitumen does not eliminate blisters.

Again, field lamination of the modified bitumen membrane to the substrate, or multi-ply systems of modified bitumens can create voids that result in blisters when heat is present. The voids that can start blisters are created whenever a membrane is field produced. Factory lamination also can create voids if the conditions are not totally controlled.

Blisters are much more evident during the heat of the day than at night. Simple physics gives the answer, in that the volume multiplied by pressure of a gas increases with temperature (Boyle's Law). Therefore, elimination of the increased temperature may be expected to eliminate blisters. The answer is to keep the surface of the membrane cool. The mechanism is to keep the membrane in the shade or to provide a reflective surface that keeps the surface temperature low and is permanent for the life of the roof.

One technology for keeping the roof in the shade is known as the *protected membrane roof.* Protected membrane roofs have been sold commercially in the United States, Canada, and Europe for 25 years. Blistering does not occur with protected membrane roofs. Many roofers have witnessed the elimination of blisters when insulation is installed over a blistered membrane. On several occasions the author has witnessed the dissipation of blisters 24 hours after the roof was covered with insulation.

Providing a permanent reflective surface, although difficult, also has been demonstrated. A company developed a proprietary formulation of emulsifiers, limestone, and titanium dioxide. This coating has been demonstrated to keep a BUR membrane at 105°F on a 105°F August day in Phoenix, Ariz. No blisters were found during an inspection of five coated BUR roofs, which, at inspection, were more than 10 years old. The coating was still bright white and the surface during the 105°F day was cool to the touch. These roofs were installed over minimum R-10 insulation; therefore, there were negligible effects of interior cooling. This is a practical system in areas of high temperature and limited freeze thaw conditions.

Economics of Blister Elimination

Economic justification for systems that eliminate blistering require consideration of the original cost of the roofing system and adding to those costs the current value of the costs of lost energy and repairs. Kyle and Desjarlais (1994) estimated that an additional cost of $2.40 could be added to an original roof and be economically justified if the system stayed dry for 15 years. This, of course, opens the opportunity for many solutions, including an interior drying system.

One solution to be examined is the use of a protected membrane roof (PMR). In this example, the cost of the extruded polystyrene insulation was assumed to be 37% more expensive than the insulation (equal long-term R-values) used in the conventional roof. The PMR used fabric and stone ballast that cost $.36 per ft^2 more than the replaced pea gravel. Both roofs had routine maintenance; the cost of maintenance for the BUR was 5% of the original installed cost and the cost of the PMR (BUR) was 1% of original installed cost (Aamot 1976). Maintenance costs were deferred until the fifth year for the BUR roof and until the second year for the PMR. The energy loss due to blisters was assumed to begin during the fifth year for the BUR roof only. In the eighth year net present value (NPV) was positive for the PMR roof. That is, if both roofs lasted eight years it would be more economical to install a PMR roof. Assuming no energy loss, just the projected maintenance difference, the NPV of the stone-ballasted PMR roof would be positive in year 10. Continuing only the maintenance portion of the cost equation (no energy loss), the NPV of the PMR system would be 13% less expensive than the conventional BUR for a 15-year roof. Adding the energy loss component due to blisters that result in leaks after the fifth year makes the PMR system 33% less costly, assuming both roofs were replaced after year 15.

TABLE 2 **Net Present Value Calculations**

Energy Loss = NPV (interest rate, loss year 1, (Energy loss year 2 × energy inflation rate), (Energy loss year 3 × energy inflation rate), year 4...)
Maintenance cost = NPV (interest rate, maintenance year 1 (maintenance cost year 2* maintenance inflation), year 3...)

These results would vary based on the installed cost of materials, overhead, and profit. Whether the assumptions of Kyle and Desjarlais or the far more conservative assumptions above are used, additional first costs of \$1.20 to \$2.40 per ft^2 are justified over a 15-year life span. At year 15, there is little likelihood that the PMR would have to be replaced.

Original design can, therefore, make a difference. Paying a greater initial cost can be justified if the power of using economic tools is considered when the installation is being designed. By focusing on initial cost or expecting that roofing crews can install a blister-free system using conventional materials or techniques eliminates outside-the-box thinking and obtains better solutions. A PMR roof becomes a robust design that will eliminate the problem of blistering and associated leaks.

Well-designed reflective coatings also can be used to keep the membrane cooler. Although lowering the temperature of the membrane does not entirely eliminate blistering, coatings can be relatively inexpensive and cost justified.

Focusing on first cost keeps many owners from taking the next step to designing a robust roof. More robust roofs, combined with a good maintenance program, can substantially save in energy costs and increase the system's life.

Splitting

The second largest consistent problem area in BUR roofs is splitting. Splitting is most likely to cause a leak that will be repaired fairly quickly. The typical repair, however, is to fix the split to make it watertight, but this fix does not take out the wet insulation. R-value will continue to be lost in the split area long after the leak has stopped. Assuming that one split in a 200-ft^2 roof about 40 ft long with the insulation 5 ft on either side of the split getting wet results in an area of 400 ft^2 per roof with reduced R-value. The \$64 per year that this split costs in lost energy is not adequate to fund a repair or design change. Using the argument that Project Pinpoint reflects the total BUR population, if 19% of the problem roofs installed in a given year were to split some time after their fifth year, the total energy loss from this problem would exceed \$13 million for one year.

When a split results in an interior leak, the loss in production from the leak or potential interior damage may be serious. Repairing the split is likely to cost more than \$2,000. This is the area of most economic loss for the total population of roofs. The cost of repairing 19% of the BUR roofs would exceed \$400 million.

Causes of Splits

Splits are caused when the tensile forces exceed the strength of the membrane. The tensile forces are created when the membrane temperature drops suddenly. The membrane coefficient of expansion results in strong shrinkage forces. This force can be resisted when the membrane is solidly attached to a substrate that cannot move. Typically, however, the membrane attachment is not solid or the substrate does not resist the forces created. Another factor may be the destruction of the bond of the membrane to the substrate over time due to roof traffic or the repeated cycling of loads caused by extreme temperature swings.

Elimination or Reduction of Splits

Splits can be reduced by properly sizing the roof areas and using control dividers. Solid bonding to substrates reduces the tendency to split. This can be accomplished by bonding the membrane to a moisture-resistant material with a low coefficient of expansion. Siliconized gypsum board is a new material that may provide a stable substrate. Eliminating sharp temperature changes with coatings that keep the membrane cool can eliminate or sharply reduce the effects of cold rain or sudden temperature drops. Using a PMR system eliminates the sharp temperature swings that cause splitting and it protects the membrane bond to the substrate by spreading the force on the membrane.

Economics of Elimination of Splits

The economic justification for design changes is not energy savings but the cost of repairs and lost productivity. Elimination of the cost of repairs alone is worth at least \$.10 per ft^2 (\$2,000/20,000 ft^2). If leaks are likely to cause internal disruption, the potential cost of that disruption must be added to the cost of the problem. Siliconized gypsum board offers promise as a more stable substrate. Its advantage in preventing splitting has yet to be proved, but it appears to be cost effective. PMR systems eliminate splitting; when the payback of eliminating splitting and blistering is added together the PMR has a positive NPV in the seventh year.

Options exist for eliminating this problem from our list. Workmanship change is not the answer. Design and material change can cost-effectively eliminate splitting if costs other than first costs are considered.

Ridging and Buckling

Project Pinpoint identifies ridging and buckling and flashing problems as tied for the third most prevalent problems with BUR roofs. Ridging and buckling are less likely to initially cause leaks than a split, but after a few years leaks will develop at these stress points. If significant roof traffic occurs, the membrane is likely to fail at these points.

Causes of Ridging and Buckling

The causes of ridging and buckling are the same as those for splitting. The membrane is not solidly attached to a solid substrate. The coefficient of expansion stretches the membrane when the temperature is high and then shrinks when cooled. This results in slippage and partial sticking of the membrane if it is not well adhered. Wherever this can occur a ridge or buckle is possible.

Elimination of Ridging and Buckling

The elimination of this problem is the same as for splitting. Adhesion of the membrane to a solid substrate requires two things: good adhesion and a solid substrate. Siliconized gypsum board is a solid substrate. It can be used as an insulation cover board or as the base over a steel deck. The other solutions—keeping the roof cool with a permanently effective light-reflective coating or using ballasted PMR systems—also are cost effective.

Economics of Solutions

Ridging and buckling are not likely to create leaks in the early years of the roof's life. The energy losses related to ridging and buckling are likely to be greater than for splitting because small leaks can result in deteriorated insulation long before water intrudes into the working space of the building. Costs for repairs are likely to be equivalent to repairing a split (minimum $2,000 per occurrence); therefore, this is likely the engine that will drive the economic decision toward a system with a higher initial cost. Adding area dividers has always been considered a major route to elimination of the ridging and buckling of BUR roofs. Adding up to 200 linear ft at a cost of up to $10 per linear ft could be considered cost effective on many roofs. Area dividers also result in more flashings that are prone to aging, negating some of the gain from the use of area dividers.

FLASHING

Unfortunately, flashing is a wide category that can include many problems. This can vary from workmanship to design or normal weathering. The installation of flashing is clearly a skilled job. Training and experience results in fewer problems with flashing. New modified bitumen flashing materials are easier to install, but they are as likely to be deteriorated by weather as other parts of the roof. The trend is for more problems with flashing, so the change of materials does not appear to have solved or reduced this problem.

Without specific problems identified, it is difficult to suggest that there are one or two solutions for improved flashings. The same deteriorating effects of weather still apply to the flashing. Keeping the flashing cool by using a reflective material as a surface will increase the life of the flashing. Using the flashing covering techniques that are standard in Canada protects the flashing from physical abuse and weathering. Considering the costs of typical flashing repair, energy losses, and the damage that often is a result of flashing leaks it can be demonstrated that the protected flashing can be cost justified. The cost of energy losses for wet insulation is unlikely to result in economic justification for protected flashing, but could drive the use of products with improved reflectivity.

EPDM MEMBRANE SYSTEMS

EPDM membranes have demonstrated excellent weathering properties, and their inherent elongation and flexibility, combined with low price, have driven the market share of this membrane type from less than 7% of low-slope roofing in 1980 to nearly 40% in 1995. Its performance record has been marred by one key problem and that is the difficulty to make strong, permanently leaktight seams.

TABLE 3 **Critical Problems with EPDM Membranes From Project Pinpoint**

Single-Ply, EPDM, Reported Problems	% of Roofs with Problems 1983 to 1992	Likely to have Significant Energy-Related Consequences	Weighted Response
Lap/Seam	37	10	370
Flashing	21	7	147
Puncture/Tear	14	10	140
Shrinkage	8	1	8
Wind Uplift	8	10	80
Fastener	3	5	15
Blistering	3	4	14
Embrittlement	2	7	10
Other	3	?	?

The Lap Seam Problem

Lap seam problems are 37% of the problems identified by Project Pinpoint for single-ply EPDM roofs. This problem has not gone away over the past 10 years nor has the reports of problems declined. Lap seam problems can be traced to workmanship, materials, and design. Much has been learned about the relative performance of EPDM seams. Proper cleaning of seams has been found to be a critical variable in tests completed by Rossiter et al. (1991). Martin et al. (1990) reported that using thicker adhesive had a positive effect on EPDM seams and many early indications are that butyl seam tapes perform better over time than the previously used neoprene adhesives; however, this has yet to show up in the Project Pinpoint data.

Causes of the Seam Problems

All lab data stress that the seam area must be clean and the adhesive must be relatively thick. Optimum thickness suggested by EPDM manufacturers is 8 mils. This was found to be adequate for good performance when applied in a consistent manner on dry, clean membranes. However, the statistics show that this is not happening 37% of the time. There clearly is not just one cause for the failures, but to a large extent, the system for bonding the seams on EPDM membranes is a marginal process. It is not robust. The skill and care necessary to do the job can be taught, but often is not applied in the potentially bad conditions of roofing.

From field experience, roofers tend to push the envelope of operating conditions when installing EPDM. They often start to seam before the dew has dried in the morning. They rush the mating of surfaces because rain is coming. They hurry because they want to be more productive, and the seams are not fully rolled. This results in situations such as those noted at a new supermarket roof where there are now 200 reported leaks less than two years after installation of a new ballasted EPDM.

Seaming of EPDM membranes is difficult because the material is nonpolar, resulting in limited sites for adhesive bonding. In addition, the release coatings are not easily removed from the membrane, resulting in contamination of the seam. Proper cleaning takes time. It is easy to assume the seam is clean when contamination exists. Early indications are that the tape seams need a similar level of cleaning.

Considering Martin et al. (1990), an EPDM seam is a marginal product whenever peel loads are applied. These peel loads occur inadvertently more often than would be expected. Beyond reducing the potential for peel loads, the need exists to provide overall stronger seams. This can occur if better cleaning processes and adhesive systems are developed. They are not commercially available today, so we should use the best of today's technology.

Improved Seaming

Standard industry seaming procedure is to clean an area about 3 in. to 6 in. wide and apply a 3- to 4-in.-wide strip of contact splice adhesive at the seam. The seam is than caulked to provide initial water resistance. One roofer with little callback history for EPDM seam problems cleans an area of 7 in. to 10 in. wide and applies a 6-in.-wide strip of splice adhesive. This may cost as much as \$.25 per linear ft of seam for labor and materials. The real cost is only about $\$.01/ft^2$ on a system that uses large (50-ft-wide) sheets and up to \$.05 per ft^2 for jobs where narrow sheets are used (10-ft-wide sheets).

Does the wide seam pay for itself? This roofer believes that it will eliminate one callback that could easily cost \$500. His data show that it pays for itself in reduced costs and improved goodwill.

An alternate seaming technique proposed by Sheahan and Johnson (1991) is the double seam. The technique used is, again, to clean an area of 6 in. to 10 in. wide. Then place two strips of splice adhesive, each 3 in. wide, on each side of a 1-in.-wide release tape. The tape is required only on one side of the mating surfaces. This effectively creates an inner-tube-like area between the seams. The space between the seams can then be inflated and the seams tested for leaks. The cost is the same as for the wider seams. The advantage is that all potential leaks are eliminated when the contractor leaves the job.

Both of the above techniques can be carried out with tape or with adhesive. The result is redundancy and the potential of a nondestructive test when split seams are involved. The cost is measurable but in the range of .5% to 5% of the cost of the roof installation. This attention to detail and slight modification of specifications will result in a more robust EPDM seam. It is likely that this small and not very costly change could result in at least a 50% reduction in seam-related problems. There is no doubt that this change would pay for itself in reduced energy losses, happier customers, and a better reputation for quality systems.

Lap seams made with modern lap seam tapes have performed well for many suppliers but, to date, their use has not been widespread enough to affect the overall roof performance statistics. There is a belief that the taped systems will outperform adhesives in most applications, and this will make their use cost effective.

Economics of More Redundant Seams

Robustness could go a step further and add a cover tape over all seam splices. This could add as much as 35% to the labor and materials portion of the seaming costs. The true systems cost increases are less than 10% on most roofs. For an owner with a sensitive operation beneath the roof, a 10% premium is negligible.

A robust roof could have saved the owner a lot of money on that new supermarket roof. An infrared survey indicated wet insulation in more than 90% of the roof area. Using Tobiasson et al.'s (1991) wetting curves, this insulation has likely lost 50% of its original R-value. For the 80,000-ft^2 roof, an initial investment of \$.95 per ft^2 could be justified on just the lost energy for this past winter. If the cooling costs are added in, the costs of using a double seam and a cover tape could be included in the steps to make this a robust roof. Today the owner may require a complete tearoff because of the wet insulation. In this case, the tearoff and replacement costs will far exceed the initial investment in the minimal roof design and poor installation practice.

The design of EPDM seams is inherently limited. If the stress relationship considered for the design, that is shear load, is replaced with peel load, a limited finite life of the bond exists. Extending the life of the seam should be a key goal in both the design community and the contractor community. The specifiers need to have good information to be able to understand the cost-benefit ratio of redundancy. The mechanics installing the system need to know that getting peel forces on the EPDM membrane roof will result in problems. They then need to know how to prevent the problems. A good apprenticeship program would teach the mechanics of preventing problems and the theory of what is happening with the membrane.

EPDM Flashing Problems

The second most prevalent problem with EPDM is flashing related. As with BUR, the specific details are not included in Project Pinpoint data. However, this is likely to be a combination of workmanship and the limitations of the product and design. Minor up-front costs such as those encountered with diligently cleaning seams or making sure there is a termination bar and making sure it is properly installed will pay for themselves in lowered repair costs and energy savings.

The performance of flashing systems is now largely a measure of workmanship and the physical properties of the material used. The inherent flexibility of EPDM should allow good contact to all substrates. Maintaining full adhesion and making sure that all seams in the flashing areas are designed to only have peel loads will reduce the potential for failures in this area. All flashings can be made more robust by protecting them. It should be a prime consideration in providing long-lasting roofs.

EPDM PUNCTURES AND TEARS

Punctures and tears make up 14% of the EPDM membrane problems noted in Project Pinpoint. Exposed-surface, single-ply membrane systems are all subject to this type of damage. Because of the nature of the polymer used, sharp objects will cut the membranes. It is not likely to be cost effective to toughen these materials. Roof traffic, equipment maintenance, and repair or vandalism are the main sources of punctures and tears. If any of the above factors are present on the roof it makes good sense to use a more robust material, such as modified bitumen or use a protected membrane system that protects the membrane from physical abuse.

MODIFIED BITUMEN

The last look at a roofing system in this report is the modified bitumen roofs. Modified bitumen systems encompass the familiarity of installation of BUR systems and the ruggedness of multi-layer systems with the factory fabrication of single-ply systems. When these membranes are made by experienced, knowledgeable manufacturers and installed with care by competent roofers with adequate plys for their intended use they are a robust system.

TABLE 4 **Critical Problems with Modified Bitumen From Project Pinpoint**

Modified Bitumen, Reported Problems	% of Roofs with Problems 1983 to 1992	Likely to have Significant Energy-Related Consequences	Weighted Response
Lap Seam	43	10	430
Flashing	18	7	126
Shrinkage	16	1	16
Puncture/Tear	7	10	70
Embrittlement	6	5	30
Wind Uplift	4	10	40
Other	7	?	?

The Lap Seam Problem

From Project Pinpoint data and the weighted response for this system lap seam problems are significant and are resulting in major energy losses. Lap seam failures surely relate to leaks and, following common practice, wet insulation is not removed when the seam is repaired. Thus the long-term implications of this problem are severe.

Properly made lap seams are watertight and not subject to deterioration. The problem is that of a false seam or seal that is not detected during field fabrication of the roof. Although this is a workmanship issue, it needs a solution that makes the system more fail safe and, hence, more robust. Multiple layers reduce the possibility of water entering the building but don't eliminate the potential membrane degradation due to leaks from the failed seam. The author does not have a proposed solution to the problem, but using Project Pinpoint data, it's clear that there needs to be a solution that goes beyond the training of the roof mechanics.

Modified Bitumen Blisters

Although Project Pinpoint does not specify blistering as a major problem with these systems, it has become a large enough problem to have several manufacturers issue technical bulletins recommending continuous installation; that is, no staging, no putting on the second layer after the first one has aged more than five days, etc. This is required because adding a layer after several days results in the real possibility of dirt contamination of the lamination bond and the development of blister sights. Because modified bitumen has proven to be a versatile material with some innate robustness, there is a tendency to get careless and create problems that would not be present if good roofing practice was always followed. Because of the widespread availability of modified bitumen and the larger percentage of untrained installers, this product, which can be part of an excellent system, frequently is misapplied, resulting in significant economic loss.

Robust Modified Bitumens

Current design practice of installing two or more layers of modified bitumen, fully adhered to solid or solidly attached substrates, with resultant thicknesses of 160 mils or more makes this a more robust system. Some of the problems reported in Project Pinpoint are related to inferior product, but in most cases all reports on modified bitumen problems focus much more on inexperienced installers.

THE MOST ROBUST ROOF

Using the techniques described in the sections above, all systems can be studied and the economic impact of various repairs can be evaluated. This evaluation should never be made on first cost, energy cost, or maintenance cost alone, but should be made on the NPV of all three added together. It is clear that this does not yield just one right roof for all situations.

Taking the best data available in the public domain on roof performance and weighting them with energy and maintenance concerns gives a place to start when evaluating systems for a given project. This technique highlights the areas for concern when installing a given system and where a few dollars spent up front can save thousands in the future.

Good maintenance has been shown to extend the life of all roofing systems. Maintenance costs are significantly different from one roof system to another. Lower maintenance costs may not be related to up-front capital costs. Roofing literature would be well served if documented maintenance costs that are available from many sources could enter the public domain.

CONCLUSIONS

Weighting the data from Project Pinpoint provides a focus point for attacking roofing problems. When this exercise was applied to three roofing systems it was shown that cost-effective systems could be used that will eliminate or significantly reduce the reported problems. In some cases, a few minutes per job or a few dollars worth of material makes a major impact on the life of the roofing system. Roofing is a competitive business, but first cost is not the answer to achieving the most robust roof.

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