

WHITE PAPER



Service Life Assessment of Low-Slope Unpainted 55%Al-Zn Alloy-Coated Steel Standing Seam Metal Roof Systems

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Executive Summary

This report documents and summarizes the work conducted to determine with reasonable certainty the roof service life that can be expected of a “like-in-kind”, low-slope 55%Al-Zn alloy-coated steel Standing Seam Roof (SSR) system when installed today in a like environment using best practices. It incorporates the results of multiple field inspections, independent laboratory analyses of metallic corrosion of the roof panels, components and sealants, and includes assessment of all integral ancillary components that impact the end of roof service life.

Background and Introduction

The desire to be able to accurately predict low-slope roof service life has been an important objective of the roofing industry for years. The benefits of achieving this objective include more accurate Life Cycle Cost (LCC) or whole building Life Cycle Assessment (LCA) analyses, as well as better preventive maintenance/repair cost estimating and scheduling. One method used previously to estimate roof service life relies on opinion surveys of roofing professionals [1, 2]. Another method uses tabulations of actual roof replacements at the end of their service lives [3]. J.L. Hoff has discussed the merits and limitations of these methods, as well as the use of manufacturers’ warranty service records [4] and warranty periods [5] to develop a meaningful number for roof service life of low-slope membrane roof coverings.

One of the shortcomings of using manufacturers’ warranty periods is that they can change as more experience is gained and actual field performance is documented. For example, Bethlehem Steel Corporation developed a highly corrosion-resistant 55% Al-Zn alloy-coated steel product in the 1960’s and began to market it in 1972 under the trade name of GALVALUME® sheet. Shortly thereafter, a 20-year warranty against through-penetration corrosion was offered, based on 9-year atmospheric corrosion data measured on pilot-line produced specimens [6]. As the product gained more widespread use through worldwide licensing agreements and additional corrosion data were developed [7-10], the warranty period was extended to 25 years. More recently, field inspections of 12 low-slope standing seam roofs in place in the U.S. for 30-36 years [11] have shown that the product continues to perform well in a wide range of environments, and that the current 25-year warranty period clearly underestimates the actual service life of a 55% Al-Zn alloy-coated steel standing seam roof.



The objective of this investigation was to *determine with reasonable certainty the service life that can be expected of a “like-in-kind” 55% Al-Zn alloy-coated steel SSR system when installed today in the Continental United States.* To arrive at such a determination, numerous elements require consideration. A “roof system” is comprised of many components, each having a different service life. Thus, in order to accurately assess the *system* service life, it is necessary to evaluate the service life of each individual component that comes to bear on the life of the roof system in total.

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In many cases, the expiry of a certain component may not constitute expiry of the roof system. If the component can be replaced or rehabilitated in a manner consistent with the design intent of the roof system (durability, reliability, maintenance freedom) for a reasonable cost without further detriment, then such replacement or rehabilitation should be considered “maintenance” or “capital renewal”, but should not be deemed to have defined the service life of the entire system. On the other hand, when service life of some vital component is at its end and it cannot be refurbished at reasonable cost, it defines end-of-life for the roof system. Discretion then needs to be exercised as to the meaning of the words “reasonable cost”, and the nature of the repair should not be such that it occurs so frequently that it becomes a maintenance nuisance in order to maintain roof system integrity.

Although first commercialized in 1972, the establishment of expected life for 55% Al-Zn alloy-coated steel, based on empirical data alone, is not possible due to the lack of data that would indicate end of service life. The logical approach then, is to locate roofs of significant age, analyze their “in service” condition and from that analysis, project future performance. Given the fact that some of these roofs are now past 30 years of age, there is a survey pool of sufficiently aged roofs available presenting opportunity to collect and assemble meaningful data for such evaluation and projections.

Given the above stated objective, a real challenge is to assess changes in technology and industry practice, and their effects on the expected service life of a roof as it would be constructed today. The goal is not only to project the service life of the roofs constructed over 30 years ago, but to use the pertinent data from those surveys as a tool to project the life of a similar roof constructed today using current technologies and best practices. While the key basic materials and systems have changed little, some of the related trade practices of 30 years ago have changed significantly. Simply stated, roofs are not built today in the manner in which they were commonly built then. Newer technologies, materials, components, details and practices have evolved over the last 30 years that have now become “best practice”, and are used regularly on premium metal roof systems being installed today.

“Current day best practice” is defined as the trade practice that would likely be demanded by a conscientious buyer, specifier or consultant in today’s marketplace to maximize, as nearly as possible, the total roof system life expectancy. In order to be considered “best practice”, the material/method must have ample commercial availability and be known and utilized regularly by scrutinizing trade practitioners. It need not necessarily be “state-of-art”, as this superlative sometimes carries economic consequence that is not commercially viable on a broad scale, and therefore not often practiced. In cases, however, when “state-of-art” is economically viable, it may be considered synonymous with “best practice”. In similar fashion, when “best practice” is of little economic premium, it is also “standard practice”.

In 2011, Haddock and Dutton developed general protocols for the inspection and analysis of a low slope 55% Al-Zn alloy-coated steel total standing seam roof system [12]. Those protocols are included and expounded herein. The Haddock/Dutton report however is for a single roof in Denver, Colorado. That project

piqued interest in exploring a broader sampling of roofs and in developing more comprehensive findings. Using the 2011 report as a basis for further research, three independent consulting firms with experience in the field were assembled for contribution to various aspects of this research project and report, including: the criteria of sample site selection, site inspection protocols, field data and sample collection, lab test protocols, evaluation of collected data, and analysis of findings and conclusions.

Basis for Site Selection, Inspection and Evaluation

It is appropriate that multiple sample sites be visited for data collection. Different climate regions with respect to heat and cold, UV and sunlight, relative humidity and pH of precipitation may have varying effects on degradation of metal roof system elements. The sites selected should be aged sufficiently to provide meaningful empirical data from which projections can be based. The original construction dates must be reliable. Preferably, the systems represented should still be commercially available and of style and art that are commonplace in today's market for low- slope, coated-steel commercial roofing systems; hence machine-folded, trapezoidal standing seam metal styles are preferred at slopes of $\leq 1:12$ (4.5°).

The elected sites must exhibit acceptable trade practice of the era when the roofs were constructed. The specimens should be installed in substantial compliance with manufacturer's standards and instructions and devoid of significant installation error. The base material must be 55% Al-Zn alloy-coated steel. This material is the standard practice and most common choice for today's low-slope, unpainted commercial metal roofing. It is known by many trade names throughout the world; principally GALVALUME® and Zincolume® in the US.

The research team selected 5 climate regions of various geographies in the Continental United States, exhibiting a spectrum of climates related to heat and humidity. They are designated, Hot-Dry, Hot-Humid, Cold-Dry, Cold-Humid, and Moderate-Acid, as seen in Figure 1. The precipitation acidity also varies considerably from one site to the next over this broad geography.

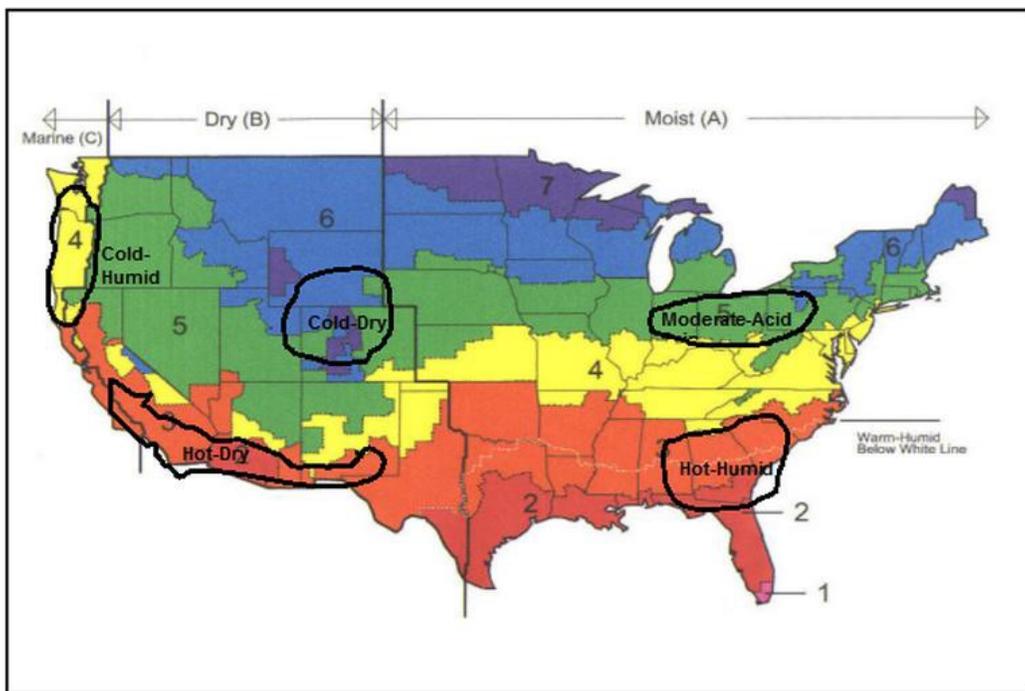


Figure 1. U.S. map showing general climate conditions of temperature and moisture.

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Because these roof types and sites are more easily identifiable by their original makers, members of the pre-engineered metal building community were contacted for possible candidate sites. The identification of probable survey sites thereupon became challenging. Because of multiple mergers, acquisitions and attrition within that industry, most constituents did not have records dating back 30 – plus years to identify these projects. Butler Manufacturing, a division of BlueScope Buildings North America, Inc., was the single exception, having ample records for sample identification and dating of origin nationwide. Because the researchers desired a broader sampling with respect to brand of manufacture, exhaustive efforts were made to identify and include other brands.

The intent of the research team was to survey 3 sites in each climate region (totaling 15). After considerable delays and difficulty in identifying diversity in brand of roof manufacture, 14 final specimen sites were visited for inspection and sample and data collection over the course of approximately two years. While this falls just short of the 15-roof objective, it provides ample information for comprehensive analysis.

The site inspection protocols and methods for testing, evaluation, and future repair/rehabilitation costs are varied depending upon the component(s) involved. Those components have therefore been divided into 4 categories: Coated Steel Sheet; Sealants; Closures and Fasteners; and Ancillaries. Hence, each of these categories is segregated within this report with its own related 1) Inspection/Sampling/Test Procedures, 2) Observations and Results, and 3) Evaluation/Discussion. The protocols, logic and procedures that are common to all specimen sites are fully expounded within this Summary Report, and summary conclusions are likewise contained herein. Specific findings from each site surveyed are attached as Appendices and contain statistical and other information more specific to each sample site.

In summary, this report documents those efforts undertaken to determine with reasonable certainty the roof service life that can be expected of a “like-in-kind”, unpainted, low-slope 55% Al-Zn alloy-coated steel standing seam roof system when installed today using best practice within the Continental United States. In this analysis, a value for renewal costs in excess of 20% of the total roof system replacement cost was deemed to be excessive and would therefore constitute end of service life for the roof system.

Best Practices

For purposes of this study and report, the following shall be considered “best practice” of today:

Best Practices: Soil Stack and Other Round Penetrations

Best practice is to flash these type roof penetrations using a special pipe flashing having black EPDM top (state-of-the-art would be black silicone rather than EPDM) with flexible aluminum base, sealed to the roof with butyl copolymer tape, as shown in Figure 2. These products have been used now for more than 30 years and have also become the standard practice for this type roof. They are widely available from multiple sources and several brand names [13]. The expected performance life of such a flashing is 25 years or more, at which time they are easily replaced at an installed cost of less than \$150.

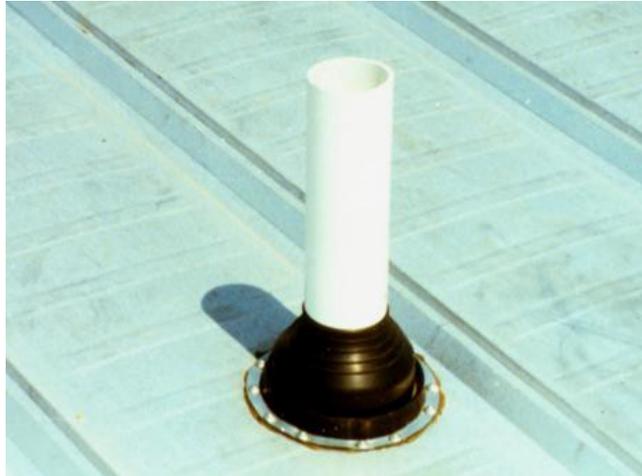


Figure 2 – Best-practice flashing of round roof penetration.

Best Practices: Condensate Drainage

Best practice today concerning condensate from A.C. condensing units or effluent from swamp coolers is that it is plumbed through the roof using a pipe flashing (as described above) into a plumbing drain, or alternatively direct it to the eave on the roof's topside using PVC piping and discharged to the ground avoiding any contact with coated steel roof components [13]. An example of this type of arrangement is shown in Figure 3.



Figure 3 – Best practice is to carry condensate to the eave or a vent pipe using PVC piping properly mounted to the roof panels to avoid premature corrosion of the 55% Al-Zn alloy coating of roof panels.

Best Practices: HVAC (Typical Load-Bearing and Non-Load-Bearing Roof Curbs)

Best practice today utilizes a welded, all-aluminum or stainless “floating” equipment curb similar to that pictured in Figure 4. The curb flanges are sealed with butyl polymer tape sandwiched between curb flange and the roof panel. Such an installation according to today’s best practice would have a service life of 65 years or more in most environments. In a mild corrosive environment such a curb may be expected to perform for 70 or 80 years – well beyond the service life of any HVAC unit, and likely beyond the service life of other, more crucial, roof system components. Such curbs are available from numerous sources within the metal roofing industry and can be replaced if necessary for \$1,500 - \$2,500 in today’s dollars (installed cost for the approximate size illustrated by Figure 4). Replacement during the service life of the roof system, however, would not be necessary.



Figure 4 – Best-practice floating equipment curbs.

Best practice today [13] for a frame-mounted HVAC unit is that the frame is mounted to the standing seams using non-penetrating seam clamps as shown in Figure 5. Care should be taken to evenly distribute collateral loads into the roof, and that point loads do not exceed 200 pounds per ASTM E1514. Any necessary ducting through the roof for units such as these is done with welded, all-aluminum or stainless “floating” equipment curbs similar to that pictured in Figure 4.

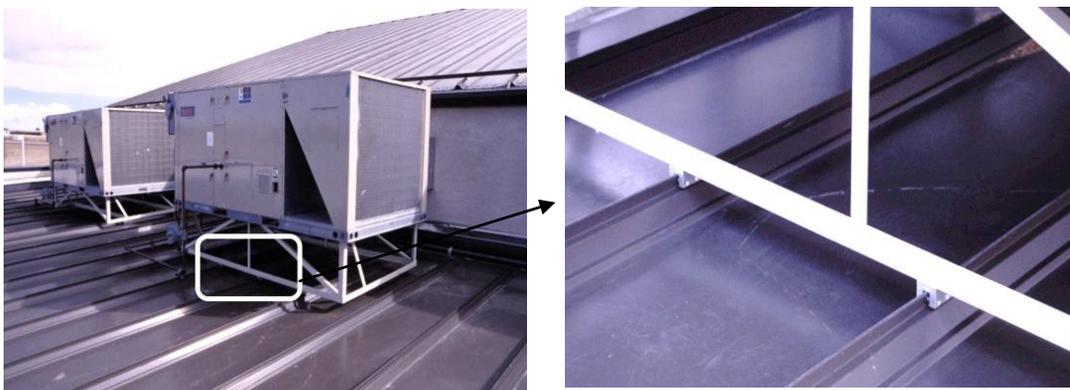


Figure 5 – Non-penetrating seam clamps used to frame-mount HVAC unit.

Best Practices: Mounting of Other Ancillaries

Best practice for the mounting of ancillaries that are not by function penetrating the roof membrane such as communications satellites, antennae, gas piping, condensate lines, lightning protection and the like is accomplished by means of non-penetrating aluminum seam clamps attached by pinching the seam with polished round point 300-series stainless steel fasteners as seen in Figure 6.

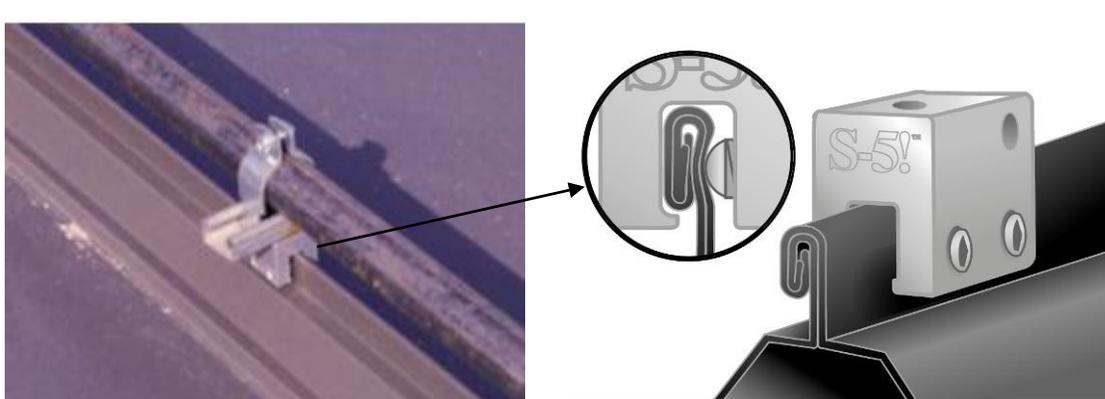


Figure 6 – Aluminum seam clamps used to mount a variety of ancillaries.

Such an installation is metallurgically compatible with 55% Al-Zn alloy coating and permits free drainage on the surface of the roof, avoiding any situation that would trap moisture, and thus lead to premature deterioration of the coating. These seam clamps are widely known and used within the industry. They have been commercially available at moderate cost since 1993. Such an interface would be expected to outlive the roof itself based on the exceptional corrosion resistance of the 300-series stainless steel and aluminum materials used in these clamps [14-16]. While gas piping and angle iron frame are beyond the scope of this report, prudence would suggest a rust-inhibitive paint coating to prevent formation and leaching of oxides onto the metal roofing.

1. Inspection, Sampling, Test Procedures

The procedures described in this report were used in the roof inspections that took place in 2012 and 2013 to evaluate and document the performance of 55% Al-Zn alloy-coated steel standing seam roofs (SSR) on 14 buildings in the United States. These building locations are shown in Figure 7 on a map of the U.S. that shows precipitation pH. This variable is a measure of the acidity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid, and higher values more alkaline. The local precipitation pH is a factor that will be shown to be of importance under Observations and Discussion. The building locations are also listed in Table I with accompanying information.

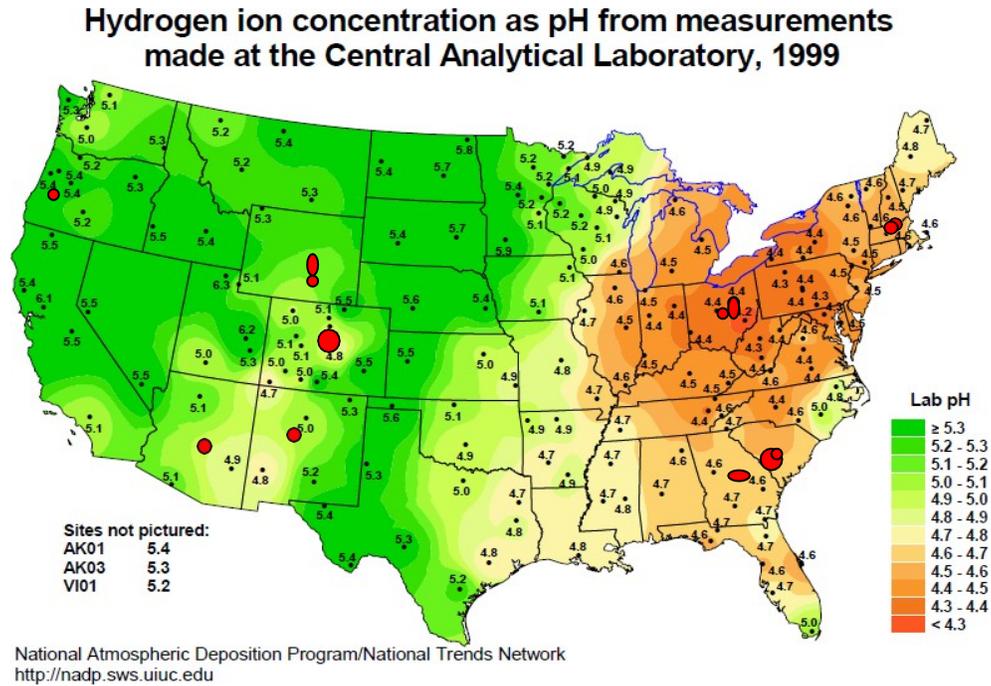


Figure 7. Locations of building inspection sites placed on a U.S. map showing precipitation pH levels [17].

Table I. Building Locations and Pertinent Statistical Information

Roof # and Location	Climate Region	Precipitation pH in 1999	Built	Age*	Slope
1- Denver, CO	Cold-Dry	5.00	1977	33	1/2 : 12
2- Riverton, WY	Cold-Dry	5.05	1980	31	1/2 : 12
3- Riverton, WY	Cold-Dry	5.05	1977	34	1/4 : 12
4- Ashland, OH	Moderate	4.36	1976	35	1/2 : 12
5- Ashland, OH	Moderate	4.36	1977	34	1/2 : 12
6- Ashland, OH	Moderate	4.36	1979	32	1/2 : 12
7- Athens, GA	Hot-Humid	4.64	1983	29	1/2 : 12
8- Irmo, SC	Hot-Humid	4.71	1992	20	1/4 : 12
9- Elloree, SC	Hot-Humid	4.71	1983	29	1/4 : 12
10- Phoenix, AZ	Hot-Dry	4.99	1989	23	1/4 : 12
11- Albuquerque, NM	Hot-Dry	5.05	1983	29	1 : 12
12- Westford, MA	Cold-Humid	4.47	1983	30	1/4 : 12
13- Westford, MA	Cold-Humid	4.47	1980	33	1/4 : 12
14- Eugene, OR	Cold-Humid	5.37	1981	31	1 : 12

* Age in years at time of inspection

1.a Inspection, Sampling, Test Procedures: Coated Steel Sheet

Collection of Coating Specimens for Laboratory Analysis

For most locations, the collection of coating specimens for laboratory analysis of corrosion will be done by finding a representative end lap for disassembly and removal of material. Where an end lap is not available, a ridge or roof penetration location can be selected for material sampling.

At the area of end lap disassembly, inspectors will cut a material specimen from the unexposed lower (down slope) panel that is covered by the upper panel. The specimen should be a minimum size of 27 cm (10.6”) wide x 7.5 cm (3.0”) long.

At an area immediately down-slope of the above end lap, inspectors will cut a specimen from the exposed panel area. The specimen should be a minimum size of 35 cm (13.8”) wide x 25 cm (9.8”) long. The photograph in Figure 8, depicting a laboratory mock-up of the standing seam end lap location, illustrates the relative locations for obtaining the unexposed and exposed samples. The sample locations are represented by the circular disks in Figure 8, although the actual samples taken from the roof are larger in size and rectangular in configuration.

Following the extraction of the specimen, field patching needs to be skillfully accomplished with new 55% Al-Zn alloy-coated material and sealed with butyl polymer tape. Figure 9 shows the specimen area from an actual site after the sample extractions and field patching of the area were accomplished.

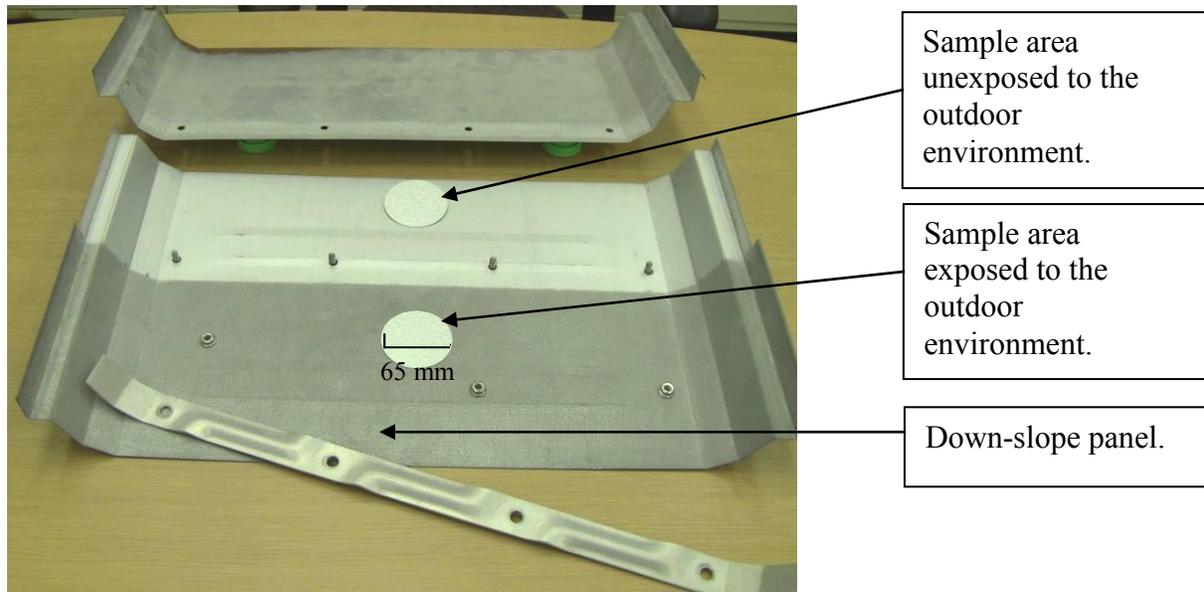


Figure 8. End lap location where two standing seam panels overlap and on which unexposed and exposed sample areas are represented.

For all samples, measurements of coating thicknesses should be made and recorded with a portable device, such as a magnetic induction or eddy current instrument. Similar measurements should also be made at random locations on other areas of the roof to establish an approximate range of coating thicknesses and to ensure the sample areas are representative of the roof. At least 5 other roof locations should be sampled, making 10 measurements at each location.

It is wise to label and photographically document the entire procedure to facilitate laboratory testing and detailed data analysis of samples.



Figure 9 – Completed patch after removal of exposed sample.

Inspectors should photo-document any unusual corrosive effects seen elsewhere on the roof and provide commentary, as well as photographing and providing commentary of sheared edges and radius bends of material.

Determining Corrosion Rate and Projected Panel Service Life

The samples taken from the roofs are to be evaluated by an independent laboratory (see Acknowledgments) for corrosion. A single specimen (denoted #1) will be cut from the unexposed sample from each site visited. Two specimens (denoted #2 and #3) will be cut from the exposed sample. Based on the corrosion measurements made on these specimens, the corrosion rate in $\text{g/m}^2/\text{yr}$ can be calculated by dividing the amount of corrosion loss on specimens 2 and 3, by the age of the roof, as shown in equation 1. Details of this analytical technique may be found elsewhere [12].

$$R = (S_1 - S_n)/t \quad (1)$$

where

R = rate of corrosion, $\text{g/m}^2/\text{yr}$

S_1 = total coating mass of unexposed specimen 1, g/m^2

S_n = total coating mass of exposed specimen n, g/m^2

n = 2 or 3

t = age of roof, years

This data will then be used to calculate a projected panel service life for a 55% Al-Zn alloy-coated steel SSR constructed today using best practices. The projected panel service life can be defined as the time required until total mass loss due to corrosion of the top coating surface has been achieved. Thus for a 55% Al-Zn alloy-coated steel SSR constructed today, it was assumed that a nominal coating mass of 165 g/m² (AZ55) would be used, as this is representative of most current unpainted 55% Al-Zn alloy-coated steel SSR systems. A “worst case scenario” is also assumed in that, according to ASTM A792/A792M -09a, “not less than 40% of the single-spot test limit will be found on either surface”. Further, assuming that 40% of the single-spot test limit of 150 g/m² is on the top surface of the roof panels where corrosion occurs, then the most conservative projected panel service life would be calculated from equation 2 as follows:

$$L_p = (C_t/R) \quad (2)$$

where

L_p = projected service life of roof panel, years

C_t = coating mass on top surface, g/m² (in this case, 40% of 150 equals 60 g/m²)

R = rate of corrosion, g/m²/yr

It should be noted that these calculations are based on a straight-line relationship between year zero and the corrosion mass loss measured at the year representing the age of the roof. As such, it is a conservative estimate since the corrosion rate of 55% Al-Zn alloy-coated steel sheet is known to decrease with time [18].

Other Observations and Reporting

Inspect the entire roof area visually, making photographic note of any unusual corrosive effects. Report the nature and effect of unusual corrosive effects, and the cause. If the cause is a normal phenomenon, then it may determine end of life of the coating. If the corrosive effect is the result of flagrant negligence or failure to observe best practice in installation, it shall be reported, but not considered as determining end-of-life of the metallic coating.

For panel edges and profile radius bends, representative areas will be photographed at close range to document the visual appearance at these areas. Any areas of corrosion will be noted, as well as any mechanically induced coating crazing due to roll forming or seaming.

1.b Inspection, Sampling, Test Procedures: Sealants

Collection of Sealant Samples for Laboratory Analysis

For most locations, the collection of sealant samples for laboratory analysis will be done by finding a representative end lap for disassembly and removal of material. Where an end lap is not available, a ridge, eave or roof penetration location can be selected for material sampling. After material removal, suitable replacement sealant will be applied to the area to maintain the waterproof seal.

Determining Material Properties of Sealant

The visual properties of the sealants will be noted and documented photographically upon sampling. In addition, material will be collected and stored in air-tight plastic bags for subsequent laboratory analysis. This analysis will consist of cohesive tensile strength according to ASTM C907 and cone penetration at 72 – 78 °F according to ASTM D217.

Conformity of Other Sealants to the Sample

During site inspections, sealants at eaves and ridges will also be examined by probing to ascertain that their general physical condition and aging is consistent with the sample area sealant. Document photographically and with commentary. Note any disparity between the visual observations of sealants at these locations and the sample area.

1.c Inspection, Sampling, Test Procedures: Closures and Fasteners

Ridge and eave closures will be examined for expected service life on each site. Ridge closures can normally be replaced if necessary. Eave closures cannot always be easily replaced, and therefore may constitute expiry of the roof system depending upon the eave detail and replacement practicality. Typically these components are not as directly exposed as the roof panels, but may be fabricated from different materials with different weathering characteristics.

Exposed fasteners would not constitute the expiry of the roof system, as they can be easily replaced, however their service life must be estimated and replacement costs factored if appropriate. Site inspections will include visual inspection, documentation of the condition of any exposed fasteners and rationale concerning remaining life and replacement costs when warranted.

1.d Inspection, Sampling, Test Procedures: Ancillaries

If a certain component is not actually part of the roof system, but an ancillary that is mounted on the roof system, the service life of the component itself need not be evaluated, but the actual interface should be evaluated. Examples include gas piping, conduit or a communications satellite that are mounted on the roof. These ancillaries are not integral to the roof and their condition and service life is not relevant to this report, however any mounting method for those components that interfaces with the roof is relevant and any detrimental effect of such methods and materials should be noted. For example, consider an HVAC unit mounted on a curb or frame that interfaces with the roof. The condition of the HVAC unit itself is not relevant to this report, but the condition of the curb or frame, and particularly its interface with or detriment to the roof should be evaluated as to service life (and replacement cost if appropriate) and noted within the site report. Another example is a PVC plumbing vent installed with a penetration flashing. The condition of the PVC pipe is not relevant. The flashing integrity and weather-tightness is relevant.

Perimeter flashings, gutter and gutter hangars are considered “ancillary” for purposes of this study. Often, they are a different material or may age differently than the roof material itself. They also would not constitute expiry of the entire roof system if their selective replacement is quite feasible and relatively inexpensive. They are to be inspected for condition and expected service life and replacement costs if appropriate.

Procedures for Component Rehabilitation/Replacement Costs

Given the stated objectives and repair parameters of this report, the ancillaries or components that reflect best practice of today and would be used in similar construction today but still require replacement within a 60-year time frame should be cost-factored within this study of the subject roof. Ancillaries or components that have or will expire that do not reflect best practice of today should only be factored to the extent that is reflective of today's best practice. Example 1: A galvanized roof curb on a subject roof has expired at the time of inspection. Given that .080" all-welded aluminum curbs are today's best practice, and have expected service life of 65+ years, the replacement of the subject roof curb should not be factored because today's best practice would use the appropriate curb material, not that of 30 years ago. Example 2: A galvanized pipe flashing for a soil stack is expired at the time of inspection. Given that EMDM rubber pipe flashings are currently best practice, and demonstrate a 25-year service life, replacement of this ancillary component should be factored in year 25 and again at year 50.

Costs for rehabilitation or replacement should be consistent with respect to best practices of today, and if multiple replacements are required during the 60-year term, they should be calculated accordingly using today's dollar values. All these replacement costs for all components not punctuating "end of roof service life" should be aggregated for a given site. Replacement costs shall be calculated in similar fashion to the 33-year old roof in Denver [12], including both labor and material using fair value in today's market. If and when these aggregated costs exceed 20% of today's costs for total roof replacement, the roof shall be deemed to be at end of life.

2. OBSERVATIONS AND RESULTS

2.a Observations and Results: Coated Steel Sheet

The coating masses measured for each of the three specimens from each location and the corresponding calculated corrosion rates (from equation 1) and projected panel service lives (from equation 2) for each roof are shown in Table II.

Table II. Total Coating Masses, Corrosion Rates and Projected Panel Service Lives

Roof # and Location	Climate Region	Coating Mass of Unweathered Spec. 1, g/m ²	Coating Mass of Weathered Spec. 2 & 3, g/m ²	Calculated Corrosion Rates, R, g/m ² /yr	Projected Panel Service Life, years
1-Denver, CO	Cold-Dry	200	188 189	0.36 0.33	167 182
2-Riverton, WY	Cold-Dry	190	178 179	0.39 0.35	154 171
3-Riverton, WY	Cold-Dry	203	193 189	0.29 0.41	207 146
4-Ashland, OH	Moderate	182	159 159	0.66 0.66	91 91
5-Ashland, OH	Moderate	200	182 176	0.53 0.71	113 85
6-Ashland, OH	Moderate	198	171 166	0.84 1.00	71 60
7-Athens, GA	Hot-Humid	198	181 179	0.59 0.66	102 91
8-Irmo, SC	Hot-Humid	181	168 167	0.65 0.70	92 86
9-Elloree, SC	Hot-Humid	180	166 169	0.48 0.38	125 158
10-Phoenix, AZ	Hot-Dry	204	194 197	0.43 0.30	140 200
11-Albuquerque, NM	Hot-Dry	200	n/a 191	n/a 0.31	n/a 194
12-Westford, MA	Cold-Humid	192	178 177	0.47 0.50	128 120
13-Westford, MA	Cold-Humid	213	189 188	0.73 0.76	82 79
14-Eugene, OR	Cold-Humid	185	180 180	0.16 0.16	375 375

As an example, using the corrosion rates shown in Table II (as calculated from equation 1), and the “worst case scenario” assumptions of coating mass distribution noted above, the projected panel service life for a newly constructed 55% Al-Zn alloy-coated steel SSR system in Athens, GA can be calculated by using equation 2 as follows:

$$L_p = (C_t/R) \quad (2)$$

$$= 60/0.59$$

$$= 102 \text{ years, based on specimen 2,}$$

or $= 60/0.66$

$$= 91 \text{ years, based on specimen 3.}$$

These values for projected 55% Al-Zn alloy-coated steel panel service life are in good agreement with other studies that used 10 x 15 cm atmospheric exposure panels to measure corrosion mass loss in a wide range of environments [7, 19, 20].

Roof Panel Edges and Bend Performance:

Edges and bends typically exhibit the first signs of corrosion as they are areas where a raw steel edge is exposed or where there may be a condition of tensile strain on the panel profile bend radius. Our inspections revealed excellent-to-very good performance in these two areas. The close-up photograph in Figure 10 shows a representative condition of a sheared, panel lap edge on the roof in Athens, GA. The sheared edge is free of red rust, indicating excellent long-term edge protection after 29 years. This performance is consistent with prior work [21] that reported only superficial stain and no rust deposits on exposure panels after 30 years of exposure in rural, industrial and moderate marine environments.

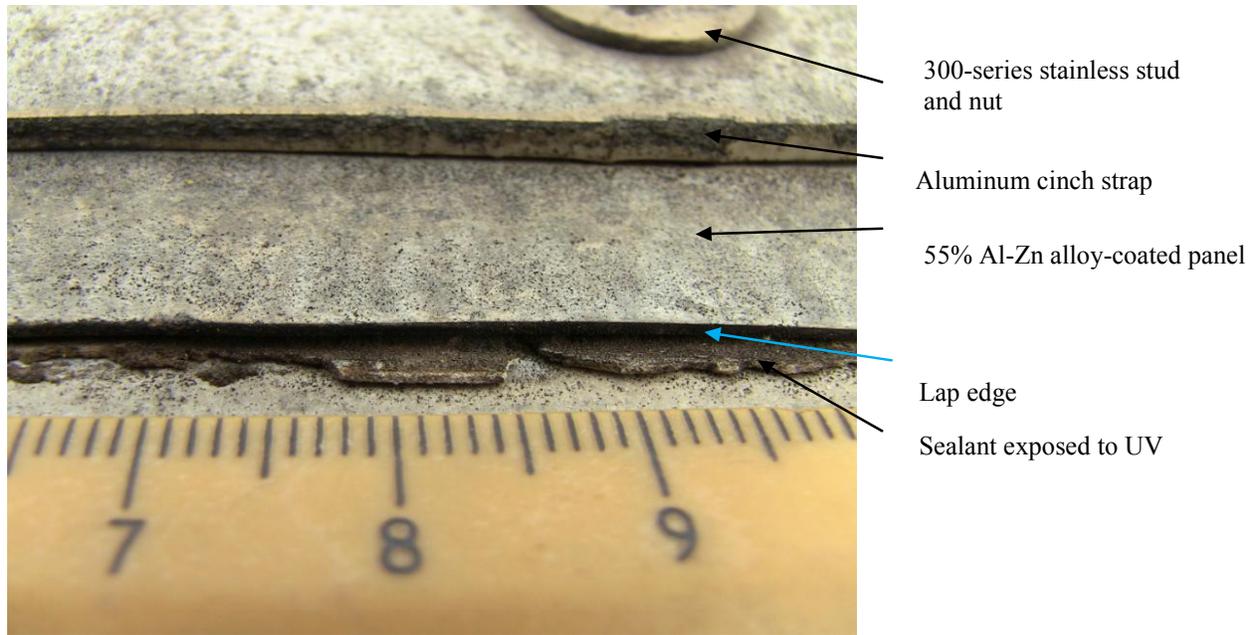


Figure 10 – Sheared, lap edge of 55% Al-Zn alloy-coated SSR panel showing negligible corrosion after 29 years on a roof in Athens, GA.

Panel profile radii may undergo a degree of tensile strain if the panel is not properly roll formed. Severely formed radii can exhibit heavy crazing of the metallic coating which can lead to significant corrosion in aggressive environments. Currently, however, steel manufacturers, working with roof panel manufacturers and trade organizations, have developed roll forming “best practice” guidelines that virtually eliminate such occurrences.

The photograph in Figure 11 shows a representative condition of the major rib profile radius of the SSR panel. Only minor crazing and light superficial staining is observable. The performance along the top radius of the standing seam is also excellent, as shown in a representative seam in Figure 12.

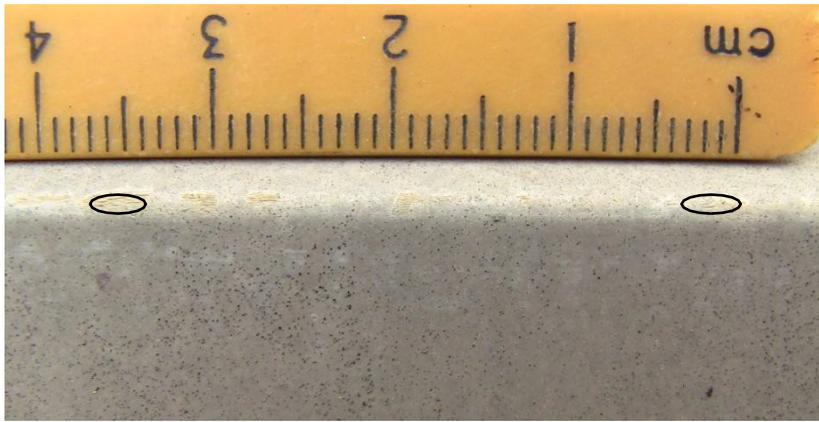


Figure 11 – Light crazing and superficial staining along a major rib profile radius after 29 years’ exposure on a roof in Athens, GA.



Figure 12 – Excellent performance (only brownish dirt pick-up) along the top radius of a standing seam on a 29-year old roof in Athens, GA.

2.b Observations and Results: Sealants

The butyl sealants used in the construction of these roofs were observed to be consistently tacky to the touch with good elastic webbing characteristics and adhesion to adjacent surfaces. A representative example of this performance is seen in Figure 13 which shows the disassembly of a 33-year old endlap.



Figure 13 - Excellent elasticity demonstrated by the butyl sealant on the Denver roof after 33 years.

Table III. Properties of Butyl Sealants Obtained from Roofs of Various Ages

Roof # and Location	Age, years	Cohesive Tensile Strength, psi	Cone Penetration at 72 to 78F, mm
A-Methuen, MA	5	19.0	93
B-Hampstead, NH	11	20.6	92
C-North Andover, MA	16	29.6	87
D-Haverhill, MA	26	17.4	140*
E-Westford, MA	30	21.0	98*
F-Westford, MA	33	28.0	86
G-Haverhill, MA	35	25.5	110*
1-Denver, CO	33	33.0	90
10-Phoenix, AZ	23	23.0	80
11-Albuquerque, NM	29	34.0	63
Fresh, unweathered	0	22.9	85

*De-polymerization noted in sample

The butyl sealants at ridge and eave closures exhibited excellent elasticity and webbing characteristics. Figures 14 and 15 show the condition of the butyl sealant when the eave closure and ridge closure were probed with a knife edge. At fillets exposed to U.V. from the sun, the sealant was dry and chalky, forming somewhat of a barrier to further penetration of the elements into the lap. However, when the outer-most exposed material was removed, the sealant beneath and beyond exhibited the same tackiness, feel and elasticity as the endlap sealant sample area.



Figure 14 – Eave closure probed with knife edge (left) produced a sample of the butyl sealant that exhibited



significant elasticity after 33 years in Denver (right)

Figure 15 – Sealant between metal panel and metal ridge closure was also very elastic after 31 years in Wyoming.

2.c Observations and Results: Closures and Fasteners

Although some of these materials were somewhat less durable than the panel material, they are used in areas where they are at least partially sheltered from U.V. and the most severe atmospheric weathering. The possible exception to this was when closures were used at the gutter line to seal between roof panel and back leg of gutter profile. In that location, closures are exposed to increased U.V. and although none had expired at the time of inspection, some (non-metal) closures showed some early stages of degradation on older specimen roofs. In such cases, the closure is not an eave closure, but a gutter closure, and not vital to building envelope integrity

and replacement of those components is easily accomplished in conjunction with gutter replacement. Costs are included within each site report (appendix). Typical eave and ridge closures are shown in Figures 16 and 17, respectively.



Figure 16 – Typical eave closure.



Figure 17 – Typical ridge closure.

Screw fastener types and materials encountered included Series 300 stainless steel, Series 400 stainless steel, carbon steel with Series 300 stainless steel cap, and carbon steel with (unidentified) plating or coating, examples of which are shown in Figure 18. In all cases, the Series 300 materials showed no sign of corrosion, nor adverse effect on adjacent 55% Al-Zn alloy-coated sheet panels. In all cases, the 400 Series and plated carbon steel materials did show signs of corrosion to varying degrees and would require replacement at some point prior to expiry of panels and sealants. There was no evident adverse effect on adjacent 55% Al-Zn alloy-coated sheet panels. Such replacement is economically feasible and the costs are computed within each site report (appendix).



(a) 300 series SS at 31 years



(b) 400 series SS at 31 years



(c) 300 series SS cap screws at 31 years



(d) Plated carbon steel at 31 years

Figure 18 – Typical fastener appearance of various materials

Sealing washers were in all cases black EPDM. Vacuum seal testing revealed positive seals in all cases and only minor degradation was observed at the outermost exposed surfaces, even on the oldest specimens. Miscellaneous fasteners included cinch straps typically used at eaves or endlaps. These aluminum components (alloy unknown) showed no signs of requiring replacement within the life of the system (Fig. 18a and 18b). The same is true of 300 series stainless cinch straps as in Fig 18d (upper). Galvanized cinch straps consistently exhibited excessive corrosion (Fig. 18c and 18d) Galvanized cinch strap components are no longer used within the industry and do not reflect today's best practice.

2.d Observations and Results: Ancillaries

Round penetrations were primarily exhaust flues from space heating equipment within, or soil stacks related to plumbing mechanicals. In many cases, these flashings had been replaced with more appropriate flexible rubber flashings that currently reflect best practice. In other cases they had been coated and refurbished with liquid-applied coatings and external sealants. When these treatments had been executed there were often detrimental effects to adjacent roof panels. Best practice today utilizes methods shown in Figure 2, and these practices have been well-known and utilized in the trade for about 25 years. Several examples of improper (but typical to the era) round penetration flashings



Figure 19 – Two examples of flashing round penetrations

Mounting of air conditioning equipment and swamp coolers also reflected the common practices of the day 30+ years ago. Drainage of the effluent (copper-ion containing condensate) resulting from normal operation of condensing units was typically drained directly onto the roof surface, causing extensive corrosive effect to the exposed roof panels, as shown in Figures 20 and 21(right). These detrimental effects are well known by the trade today as is the solution prescribed earlier in this report under Best Practices.



Figure 20 – Accelerated corrosion of 55% Al/Zn sheet due to improper drainage of copper ion-containing HVAC condensate.

A variety of load-bearing and non-load bearing curb and flashing types were found still in place for the mounting of rooftop HVAC equipment, many exhibiting the common practices of the 1980's. In many cases these curb types were galvanized materials that have been treated with various topical sealants and coatings to restore weather integrity and prevent corrosion. Often units were mounted onto wood blocking which is corrosive to the roof material. Typical examples of poor HVAC mounting are shown in Figure 21. Best practices currently obviate the use of such materials.



Figure 21 – Typical examples of poor HVAC mounting

Gutters found at all sites were original material and were generally broken shapes of pre-painted G-90 steel, a typical example of which is shown in figure 22.



Figure 22 – Typical gutter manufactured from pre-painted galvanized G-90 steel.



Figure 23 – Gutter hanger performance of galvanized G-90 steel after 32 years in Ohio.

In most cases, gutters will have to be replaced prior to end-of-life for the roof system. Remaining life and replacement costs of gutters are included in individual site reports. Gutters can be rather easily and economically replaced when necessary, and in no case would they effect end of life of the system.

3. Evaluation / Discussion

3.a Evaluation and Discussion: Coated Steel Sheet

In analyzing the corrosion results, many climate characteristics, such as temperature, humidity, amount of rainfall, etc., were reviewed. The single key variable that correlated strongly with the amount of corrosion measured on the 55% Al-Zn alloy-coated steel panels was the acidity of the precipitation where the buildings were located. This precipitation acidity, or pH, has been measured across the U.S. for decades by the National Atmospheric Deposition Program [17]. The precipitation pH values measured in 1999 are shown on the map in Figure 7, together with the building inspection locations. The 1999 data were selected since this year represents the approximate mid-point in age for many of the buildings.

Using the calculated corrosion rates from Table II, the projected 55% Al-Zn alloy-coated steel panel service life is plotted in Figure 24 as a function of the precipitation pH associated with each building's location. It should be remembered here that the definition for panel service life was stated as the time required for total coating mass loss to occur due to corrosion of the top coating surface. Thus, it is a conservative definition because it does not include the additional years required, after the coating has been totally consumed, for the exposed steel substrate to corrode to a significant loss of thickness that would define a more accurate end of roof service life.

As seen in Figure 24, there is a very good correlation between the precipitation pH and the projected 55% Al-Zn alloy-coated steel panel service life, a finding which helps to explain the wide range of service life values calculated from the corrosion rates determined in this study. That is, the wide range in precipitation pH for the different building locations accounts for the wide range of projected service life values and is consistent with the expectation that more aggressive environments (lower pH) are more corrosive to materials of construction exposed to those atmospheric conditions.

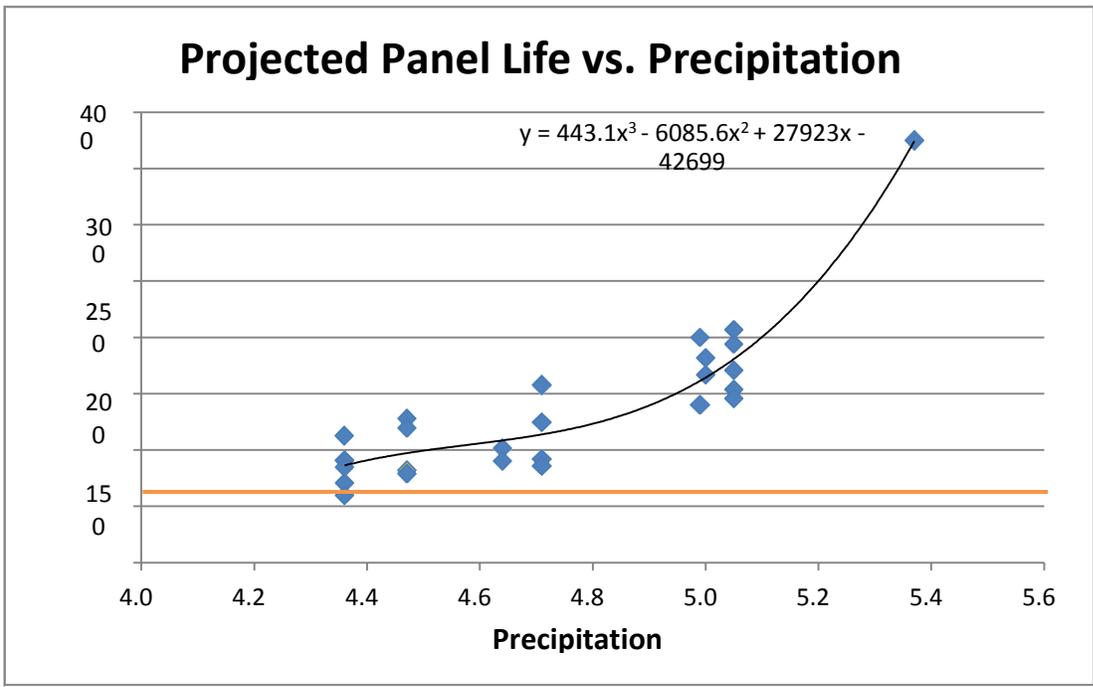


Figure 24 – Strong correlation between projected service life for 55%Al-Zn alloy-coated steel SSR panels and precipitation pH.

The reference line at 60 years in Figure 24 is significant in that it represents an “assumed building service life” as described in LEED, version 4 [22]. Thus the data from this project support the proposition that a 55% Al-Zn alloy-coated steel SSR system, installed today on new or retrofit low-slope roof systems in a wide range of environments, would not require replacement during the building’s entire service life, a significant advantage compared to other roof systems that require one or more full replacements within this 60-year period. Periodic roof inspections and maintenance associated with roof ancillaries are advised, to minimize any detrimental effects to the roof system and maximize roof system life.

While this level of projected service life is impressive, it is still a conservative projection. First, the analysis does not take into account the decrease in corrosion rate over time of the 55% Al-Zn alloy coating as clearly reported in the literature [18]. Second, for buildings constructed today using best practice, even longer service life can be expected than that reported here, as explained below.

This improved performance is due to the significant improvement in climate experienced in the U.S. over the last 30 years due to industry’s compliance with government regulatory air quality requirements. The data shown in Figure 25 are an example of the improvement in precipitation pH that has resulted from these efforts. In this figure, the change in precipitation pH is plotted vs. time for a site located in Ohio near three of the building locations in this study. The pH has improved from a value of about 4.4 in 1999 to a value of 4.8 in 2010. Thus if the current-day pH values are used in the service life equation shown in Figure 24, the projected panel service life can be calculated for a building that would be constructed today using best practices. Thus, in the case of this location in Ohio, the projected panel service life, calculated from the equation in Figure 24, improves from a value of about 90 years (pH of 4.4) to a value of about 122 years (pH of 4.8). That is to say, the 55%Al-Zn alloy-coated steel panel service lives reported in this study, while significant in their own right, represent conservative estimates of the service lives to be expected on buildings erected today with this material.

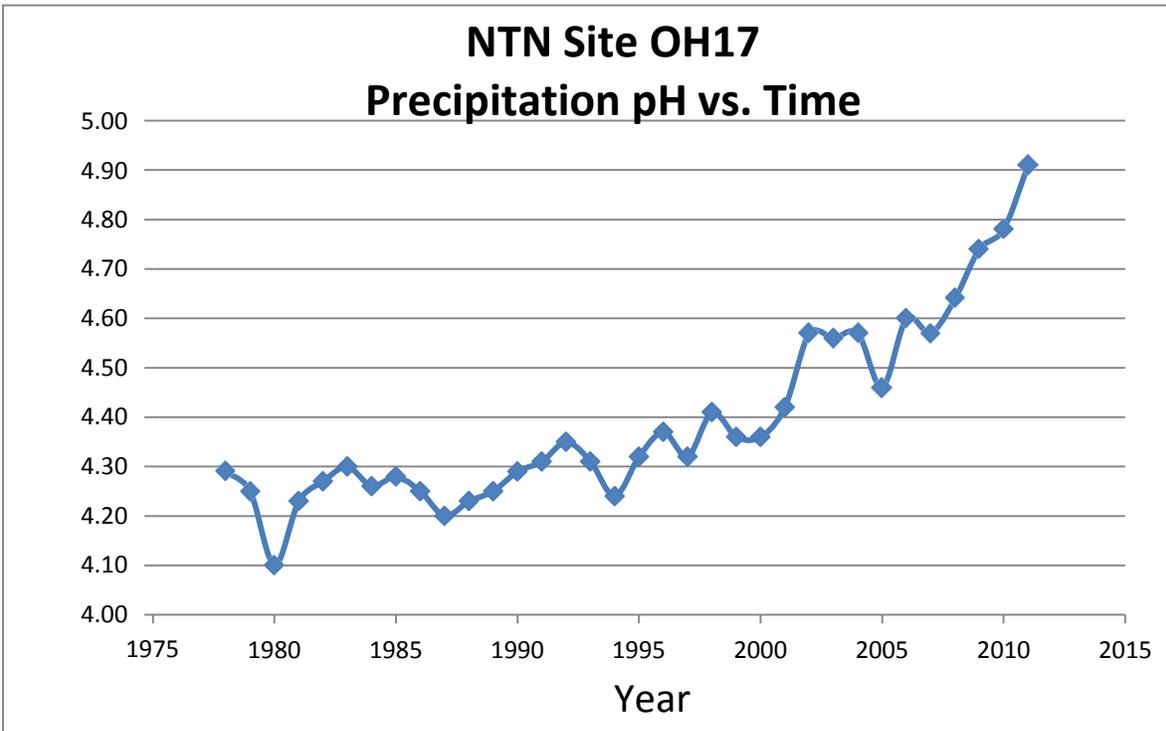


Figure 25 – Improvement in precipitation pH over the last 30 years near one of the building sites in Ohio [17].

3.b Evaluation and Discussion: Sealant

Qualitatively, sealant samples exhibited good adhesion to the substrate, plus good overall flexibility and elongation. This performance, as shown in Figure 12, was typical of the roofs evaluated in this study.

From a quantitative perspective, long-term ageing characteristics of butyl-based sealants are not well documented. Thus, sealant samples were analyzed to determine if there was any loss of physical properties resulting from the ageing of the sealant material on the roofs. Various sealant failure mechanisms were considered and sealant failure was then defined as follows: loss of adhesion to the metal surface; hardening of the sealant; or loss of significant flexibility and/or elongation (webbing); in other words, an inability to maintain a weather tight joint.

Cohesive tensile strength and cone penetration values were chosen as the physical properties that were most relevant and measureable, given the quantity of sealant that was able to be removed from each roof. If this had been a controlled experiment initiated at the times the roofs were installed, it would then have been a simple procedure to measure the change in these properties over time, compared to the properties exhibited by the original materials. However, as the original sealant material was not available for analysis, fresh, unweathered sealant material was used to provide an approximation of the properties of the original material. The results discussed below demonstrate that even samples that had been in service for up to 35 years did not have a significant loss in these physical properties.

Cohesive tensile strength can be thought of as a measure of the ability of a sealant to maintain internal integrity and resist shearing in order to effectively seal the joint. The cohesive tensile strength of the butyl sealant samples obtained in this study is plotted as a function of the age of the roof in Figure 26. The inadequate performance value was assumed to be at $\frac{1}{4}$ of the minimum specification limit of 17 psi, or at 4.25 psi, and is plotted as such. At this low level of cohesive tensile strength, it was speculated that the sealant would have undergone significant decomposition, or de-polymerization, with the result being that the sealant would behave more like a low-viscosity liquid that would easily flow out of the joint, thus rendering the joint unacceptable.

The plot in Figure 26 shows that, even for those sealant samples exhibiting some degree of de-polymerization, the cohesive tensile strength continues to maintain consistent levels above the minimum specification and well above the inadequate performance level. Based on the data in Figure 26, there is no evidence of deterioration of this property through 35 years of service on these roofs

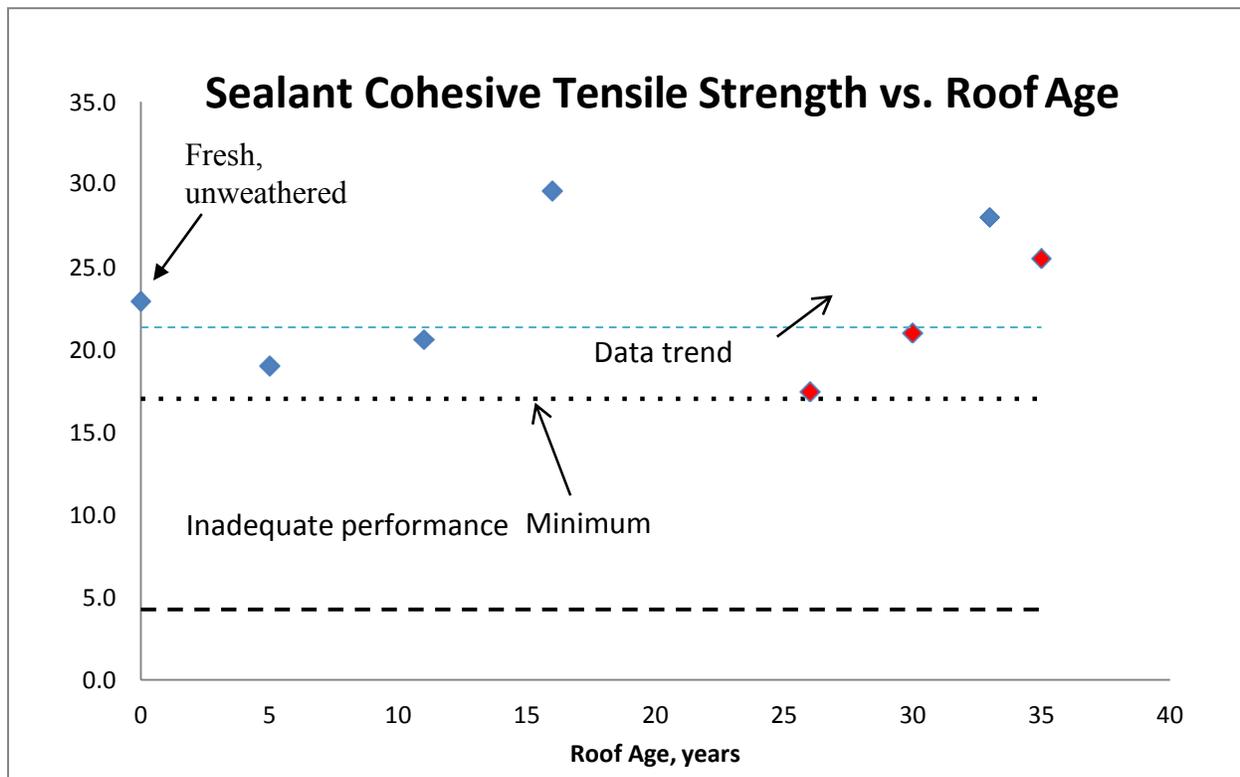


Figure 26 – Cohesive tensile strength of butyl sealant vs. roof age. Sealant samples from New England roofs. Red symbols indicate samples exhibited some degree of de-polymerization

The cone penetration data are plotted vs. roof age in Figure 27. Higher cone penetration values indicate the sealant exhibits an increased tendency to flow. The maximum specification at 120 is a value selected for qualifying butyl sealants for initial use. All but one of the data points are under this maximum value. The sealant samples from the 26-, 30- and 35-year roofs, noted with red symbols, showed evidence in laboratory analysis of some degree of de-polymerization. This condition was noted in the cone penetration testing done at 120F in which the materials exhibited a level of softness that prevented valid test results from being obtained. Notwithstanding these laboratory observations, the behavior of these sealants in the actual roof systems was judged to be entirely adequate and without issue, providing a weather tight seal.

The cone penetration data trend line in Figure 27 shows a slight upward trend toward the maximum specification line and would mathematically intersect that line at approximately 57 years. However, the amount of scatter in this limited data set is significant (correlation coefficient less than 0.20), so it is unwise to draw a firm conclusion from such an intersection. However, it is also unclear whether a cone penetration value of 120 is indicative of inadequate performance. What is clear, is that the 26-, 30- and 35-year roofs in New England continue to perform well, and that the roofs in AZ, NM and CO exhibit excellent cone penetration values, and field performance, after up to 33 years (Table III). Thus, the likelihood of butyl sealants achieving a failure mode prior to about 60 years of service is deemed to be nil.

It is also worth noting that the authors have witnessed instances (outside the scope of this investigation) where butyl sealants have degraded and failed significantly short of these numbers. Caution is therefore advised. These compounds are all proprietary in their exact composition and are not all “created equal”. The roofs that are still in service after 30 or more years are utilizing sealants sourced from highly reputable manufacturers with time-proven formulae.

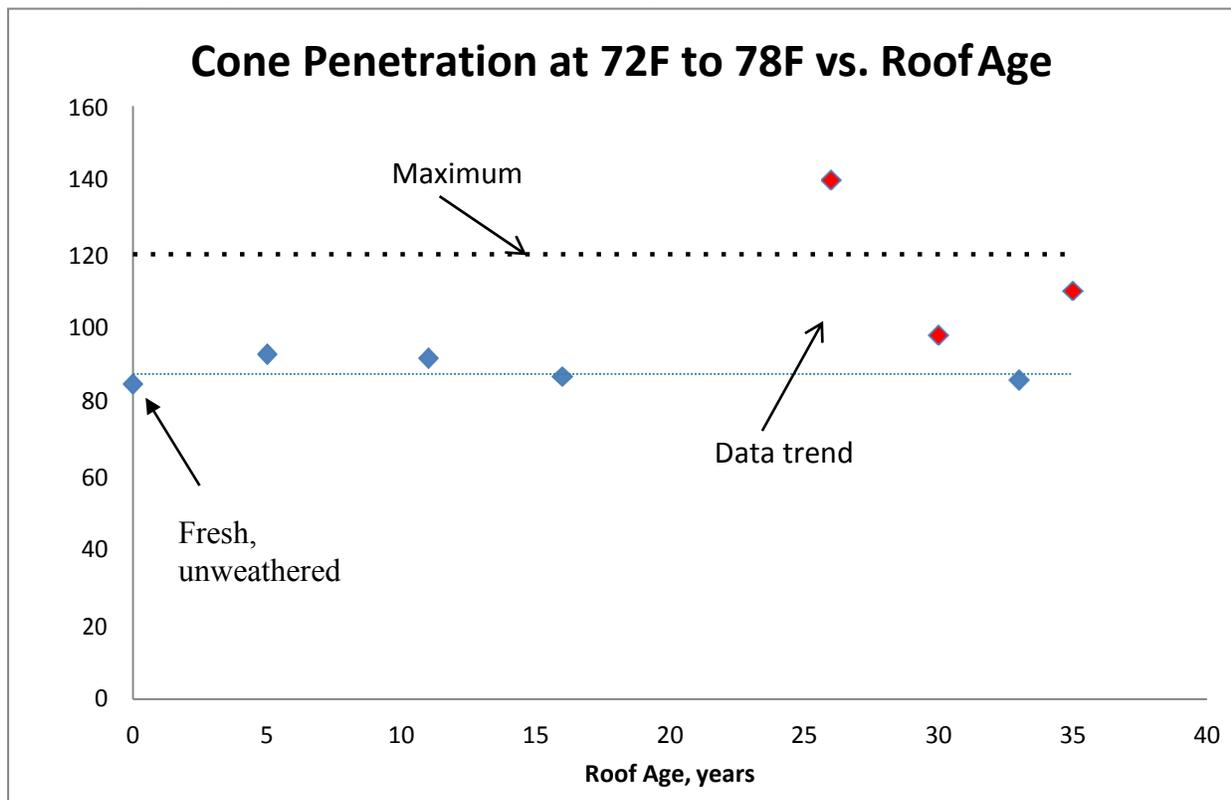


Figure 27 – Cone penetration values of butyl sealant vs. roof age. Sealant samples from New England roofs. Red symbols indicate samples exhibited some degree of de-polymerization.

3.c Evaluation and Discussion: Closures and Fasteners

In no cases were ridge or eave closures found to be in need of replacement short of a 60-year life. Series 300 stainless fasteners show no signs of corrosion and have had no adverse effects on 55% Al-Zn alloy-coated steel roof panels. They will outlive all other vital components. Plated steel fasteners consistently show corrosive effects and require replacement short of end of life for roof system. Series 400 stainless fasteners show significant signs of corrosion and will require replacement. Neither will cause end-of life for a roof system as they can be easily and economically replaced. Those costs have been tabulated on individual reports (see appendices).

3.b Evaluation and Discussion: Ancillaries

There are alternatives to replacement of roof components. For instance, gutter brackets could be cleaned and treated with rust inhibitive coatings rather than being replaced. The same may be said of the eave gutter. Given costs to do this and expected service life after such rehabilitation, such alternatives are not considered economically justified. From a practical perspective, however, a building owner may elect to repair at lower cost, albeit this may not be the most ideal solution in the long range.

It is noteworthy that the design of a particular gutter and eave detail is such that the closures and sealants to the roof system occur at the gutter line. This means that gutter replacement of necessity also includes replacement of those components, even though their life may not have expired.

In addition to the above, pipe flashings would need to be replaced at 25-year intervals. The cost to do so is generally below \$150/each depending upon size and material (EPDM vs Silicone). Thus the cost will depend on the number, size and type of such pipe flashings on the roof.

These costs represent all major roof system-related refurbishments of roof components and adjunct or ancillary components directly integrated into the roof system that would be required over a 60-year time frame for a new roof installed today using best practices as currently known within the industry.

A summary of these costs, as a percentage of the cost for an entire roof replacement, is shown in Table IV for the 14 buildings represented in this study. For all roof systems, located in a wide range of climate regions, the total cost for renewal is well below the 20% of replacement value stipulated in the inspection protocol as signifying end of service life. Specifics of these costs are detailed in the individual site reports appended to this report. It is worth noting that gutter and downspout replacement costs represent from 1/3 to 2/3 of the total renewal costs. In no case were the 55% Al-Zn alloy-coated panels considered at risk for renewal before the 60-year time frame.

Table IV. Renewal Cost Summary

Roof # and Location	Climate Region	Age, years*	Total Cost of Renewal, %
1- Denver, CO	Cold-Dry	33	9.6
2- Riverton, WY	Cold-Dry	31	15.4
3- Riverton, WY	Cold-Dry	34	12.3
4- Ashland, OH	Moderate	35	5.1
5- Ashland, OH	Moderate	34	6.5
6- Ashland, OH	Moderate	32	5.2
7- Athens, GA	Hot-Humid	29	6.1
8- Irmo, SC	Hot-Humid	20	8.4
9- Elloree, SC	Hot-Humid	29	10.3
10- Phoenix, AZ	Hot-Dry	23	4.7
11- Albuquerque, NM	Hot-Dry	29	10.0
12- Westford, MA	Cold-Humid	30	8.4
13- Westford, MA	Cold-Humid	33	5.3
14- Eugene, OR	Cold-Humid	31	14.3

* Age in years at time of inspection

Conclusions

Based upon the field inspections of 14 low-slope, unpainted 55% Al-Zn alloy-coated steel standing seam roofs with up to 35 years of service across the United States, the following conclusions can be drawn concerning roof system service life:

- Butyl sealant life will be the deciding factor in establishing end-of-life for these roof systems. Butyl sealant has shown no significant deterioration in cohesive tensile strength or cone penetration values after up to 35 years of performance at laps and joints. Even in cases where some degree of de-polymerization was noted on some 26- to 35-year-old roofs, actual sealant performance was judged to be entirely adequate and without issue. Accordingly, sealant service life is conservatively projected at 60 years.
- 55% Al-Zn alloy-coated steel panels have weathered uniformly with corrosion rates that conservatively project flat panel service lives ranging from 60 to 375 years for an AZ55 coating, depending on the local precipitation pH. In all but the worst case (site #6), coating life is 79 years or more. For sheared edges and panel profile bends, the absence of significant red rust after up to 35 years indicates exceptional corrosion resistance in areas susceptible to exhibiting the first signs of corrosion.
- On many of the sites, ancillary roof components have begun to rust and exhibit inferior service lives that could negatively impact the service life of panels with which they are in contact. Thus, these components will require remediation. In most cases these corrosive components are not consistent with current best practice.
- The cost of projected remediation or replacement of these ancillary components was shown to represent significantly less than 20% of a total roof replacement cost, the value deemed to be excessive and, by which, would have constituted end of service life for the roof system. Therefore, ancillary service lives do not dictate roof service life, which is more directly a function of the butyl sealant at laps and joints.
- The 300 series stainless steel fasteners, cinch plates and other related hardware are ageing well, showing little signs of corrosion and no adverse effects on the 55% Al-Zn alloy coating. These metal components are expected to have a life consistent with or exceeding that of the metal panels. The same is true of integral aluminum components and ancillaries. Hence, these materials demonstrated excellent compatibility with 55% Al-Zn alloy-coated sheet. The 400 series stainless steel fasteners are showing varying degrees of corrosion, depending upon site location (atmospheric corrosivity), and will require replacement prior to end of roof service life.
- The expected service life of a similar roof constructed today in a wide range of environments using best practices can be expected to be in excess of 60 years, a value that equals the assumed building service life as described in LEED, version 4. This estimate is based upon the projected sealant service life, which has been conservatively projected due to a lack of measurable ageing and degradation of sealant.
- Although a 55% Al-Zn alloy-coated SSR system is relatively maintenance-free, a roof inspection program should be conducted on a regular basis to detect and eliminate problems before they lead to localized, premature corrosion that could decrease the service lives reported in this study. On sites where deciduous leaves, pine straw, dirt and other fallout accumulate, periodic cleaning, at least bi- annually, is prudent. In wet climates, where roofs are prone to algae growth, cleaning at even 5-year intervals will help maximize the service life of the roof.

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