Feature

Roof-Mounted Solar: ROI and Best Practices

By Rob Haddock and Mark Gies

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THE USE OF solar in building design is sharply on the rise. When considering adding rooftop solar, knowing what information is needed up front, planning the solar PV system design for optimal power production, and utilizing quality materials to secure the system for its lifetime are essential. But what information is needed to make an informed decision?

First, it's important to understand why mounting solar to a metal roof rather than alternative roof types can make the most sense.

Today's trends lean toward evaluating the long-term costs of owning and maintaining a roof. For owners and designers, environmental aspects of the industry—pre- and postconstruction—have become the primary focus in the life cycle of a roof's materials. Additionally, concerns over landfills becoming overburdened with former building components discarded due to shortsighted, budget-conscious building objectives are driving the focus on more sustainable roofing materials and their "cradle-to-grave" carbon footprint.

Metal roofing is known for its durability, environmental sustainability, variant styles, and versatility. The life-cycle costs and environmental appeal of metal offer several advantages over current life-cycle trends. As a result, metal is experiencing a surge in popularity for both commercial and residential applications because the maintenance requirements and life-cycle ownership costs are substantially lower than those of the alternatives.

SERVICE LIFE

In the commercial/industrial market sector, a field/lab study published by the Metal Construction Association indicates that the service life of (standing seam) coated steel is in the range of 70 years. Based upon empirical data, several domestic producers of 55% AlZn steel have recently raised no-cost warranted material performance up to 60 years, equaling the assumed building service life as described in LEED version 4. Additionally, because of the negligible maintenance afforded by properly installed metal roofs, owners are not faced with costly roof upkeep, patching, and repair.

With few exceptions, nonmetal commercial roofing systems generally expire after 15 to 20 years. They not only have more intensive maintenance requirements year over year, but also inevitable replacement. This results in an acute ("whole building") life-cycle cost disadvantage compared to standing seam metal roofing, which is documented to have a service life approaching 70 years and minimal maintenance requirements.

SUSTAINABILITY

The growing demand for durable and environmentally friendly construction materials with reduced maintenance and longer service lives often can lead commercial designers and owners to metal roofing. It is attractive, highly

Powerful Percentages

How does domestically produced hot-rolled structural steel stack up sustainability-wise?

- 93% recycled content
- 98% recycling rate
- 95% of US production is represented by facility-specific environmental product declarations (EPD)
- 75% is produced via electric arc furnace (scrap-based)

Modern Steel Construction (EAF statistics, May 2023)

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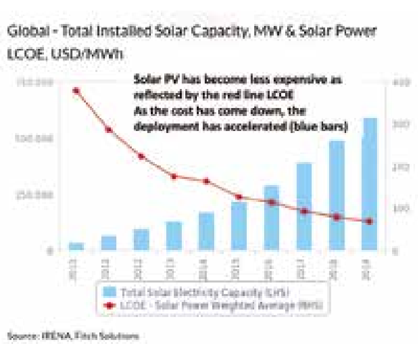
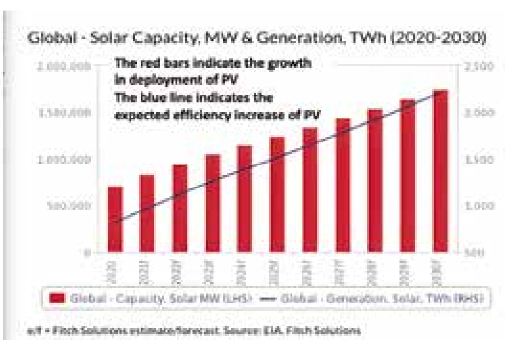




reflective, long-lasting, weather-resistant, and easy to maintain.

Metal roofing is a sustainable material because of its extended service life, low production consumption of natural resources, zero-petroleum byproducts, and recyclable economic prudence.

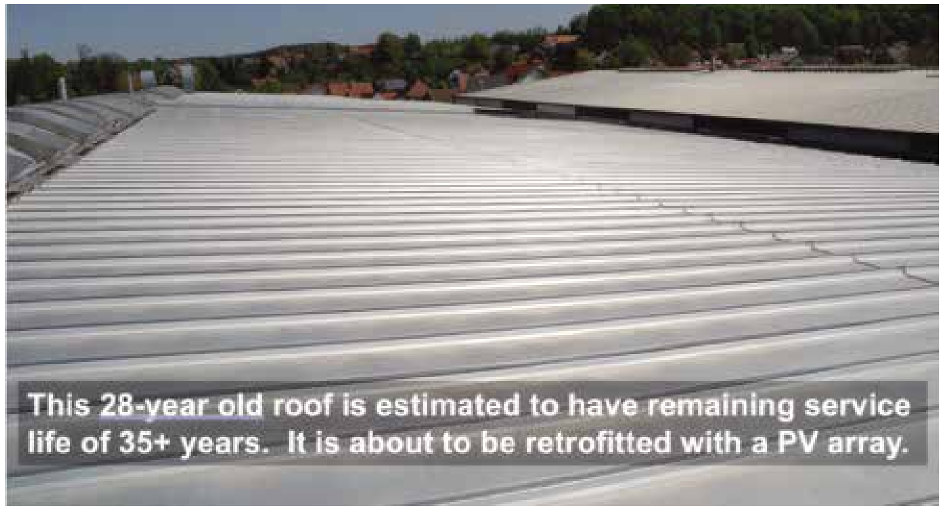
At nearly an 98% recycling rate, steel is one of the most-recycled construction materials available, second only to copper. This is important to building owners and designers conscious of both environmental and economic efficacies. Old metal roofs rarely end up in landfills, thus preserving landfill space and helping to protect the environment.

Metal roofing is also resistant to fire, weather, and climate conditions due to its sturdy and inert composition. It is noncombustible, adds no fuel, and will not ignite during a wildfire or lightning strike, which may help save on insurance premiums.

Metal is impervious to ultraviolet degradation. Premium factory finishes of polyvinylidene fluoride paint films offer up to 40-year warranties against excessive fade, chalk, and film integrity. Further, because metal panels have structural characteristics, they can be designed to resist virtually any wind speed, including a Category 5 hurricane.

THE METAL ROOF, A PERFECT PLATFORM FOR SOLAR PV

Today, building owners are adding grid-tied solar photovoltaic (PV) sources to augment the power required to run their facilities. The financial prospect of PV makes sense, turning cash positive in three to seven years and providing power for decades thereafter.


This 28-year old roof is estimated to have remaining service life of 35+ years. It is about to be retrofitted with a PV array.

With the increasing use of solar on commercial buildings, metal roofing has become a driver for roof type selection in many cases.

The service life of solar PV is between 28 and 37 years, with an average of 32.5 years, according to Wiser, Bolinger, and Seel. Most alternative roofing systems expire long before the life of the PV system. This leads to costly disassembly of the PV array, reroofing, and reassembly. A standing seam metal roof provides an ideal platform and is the only commercial roof type featuring a service life that exceeds the solar PV system.

It is also easier and less expensive to mount solar to a metal roof than any other roof type. In most cases, these cost savings are even sufficient to offset the premium initial cost of a standing seam roof. Solar PV can be mounted to the standing seams of the roof penetration-free, ballast-free, and with tested and engineered mechanical attachment methods.

With the cost of solar decreasing over the last decade, federal and local incentives, as well as public policy mandates driving the popularity of solar, the numbers improve every year. When solar PV is incorporated into building design, the standing seam roof makes sense from both a financial and ecological perspective.


With over 150,000 points of attachment, Apple HQ's Aluminum roof has an expected service life of 100 years with no penetration, no ballast and no warranty violation from the 7-MW PV array.

LIFETIME ROI

Once the decision is made to utilize solar, metal roofing is a driver for roof type selection because not only is a solar-and-metal roof system less expensive up front than other roof system combinations, but it also improves the real lifetime return on investment (ROI) of the system.

When computing ROI within the solar pro forma, inverter replacement is usually factored in at about year 15—but what about the cost of roof replacement? The solar array must be totally dismantled and then reinstalled on the replacement roof. Often, even the initial cost of the solar-and-metal roof is less than that of solar and other roof type alternatives. Factor in roof replacement, and the cost advantages become grossly magnified. Hence, the PV array and the roof should be regarded as a single asset.

A number of exorbitant expenses associated with completing a PV system/reroof include removing the solar modules, removing the mounting and racking system, decommissioning the system during the reroof, reroofing, reinstalling the PV system, recommissioning the system, the potential for damaged components during this process, and some new wiring and loss of power production during the project.

With metal, roof replacement is avoided. The roof will perform long after the service life of the solar array has expired. When considering new construction, the standing seam metal roof actually lasts the lifetime of the first solar array as well as the second. In the case of solar retrofit, 30-year-old standing seam roofs that are properly designed, installed and maintained are still viable candidates for consideration.

For these and other reasons, metal has become a preferred roof type for the solar roof. The solar-and-metal roof can achieve significant improvements in the lifetime ROI and provides lower upfront costs than alternative roof system combinations. It is not only rational but vital to consider the roof and PV as a solitary asset, as the two are mutually dependent.

INVESTMENT TAX CREDITS AND OTHER INCENTIVES ON ROI

Since the introduction of the Inflation Reduction Act (IRA), the US solar market is now poised to reach the goal of 30% of US electricity generation by 2030. The legislation includes a 10-year extension of the solar Investment Tax Credits (ITC), additional incentives also known as adders, significant incentives to boost domestic manufacturing throughout the solar production supply chain, tax credits for energy storage, workforce development provisions, and additional policies that promote a clean energy economy. These policies are expected to accelerate growth, triggering an avalanche of solar development throughout the US.

WHY IS THIS IMPORTANT TO NEW SOLAR INSTALLATIONS?

Solar projects built through 2033 are eligible for the 30% ITC and can increase their tax credits significantly by qualifying for "adders." These include domestic content, energy communities, and low-income communities.

For the domestic content adder, if at least 40% of the products are made in the US, a project qualifies for 10% additional tax credits. For energy communities, installing solar in eligible areas, such as brownfields or closed coal mines, qualifies for another 10% tax credit. Installations in low-income areas receive an additional 10–20% tax credit.

In addition to ITCs, there is other federal money available, including the USDA's Rural Energy for America Program for designated rural areas. Some states, municipalities, and utilities are also offering loans, grants, and other incentives.

An important piece of the IRA is to grow US businesses, especially manufacturers, and the combination of the supply-side incentives and the ITC adder provides that opportunity to the solar industry in the US. Besides economic reasons, this is important because in the wake of the pandemic, US companies quickly realized the need to limit their reliance on foreign goods and services and increase domestic manufacturing to meet the demand. Ongoing supply chain issues also underscore the importance of domestic production.

An increase in domestic production of solar components should offset potential price increases, reduce shipping and import costs, and likely increase the level of support for solar PV and other renewables in the US.

HOW DO NATIONAL AND/OR LOCAL ENERGY POLICIES AND BUILDING/ ELECTRICAL CODES PLAY INTO THE USE OF SOLAR?

The role of codes and regulations is a double-edged sword. Some are very positive for solar, such as the residential solar mandates required for all new construction enacted in California a few years ago, while others may increase hurdles, making it more complex and difficult to install solar. As the use of solar increases, so do the number and revisions of codes, standards, and policies. This is inevitable and the right thing to do but may inadvertently increase the hurdles to deploying solar. Some energy conservation policies are focused on energy efficiency first, which may reduce the demand for solar.

That said, various municipalities and even entire states have enacted regulations, building codes, and public policy mandating the installation of solar PV or solar-ready design on new building construction. This is a major shift from the past, when there was no consideration for accommodating solar with new construction design, and solar was retroactively fitted to the roof in the best way possible. New mandates will result in the accelerated growth of rooftop solar, with the intent also to reduce costs and maximize the energy output of solar installations—leading to higher ROIs with fewer hurdles in deploying solar PV.

The key to complying with these mandates is in the upfront planning and design of new buildings with respect to factors not traditionally considered—factors focused on the anticipation of a solar installation on a new building.

For example, according to the solar-ready regulation St. Louis, Missouri, passed in December 2019, the area of a new commercial building's roof that is functional for solar must be at least 40% of the total roof area, often referred to as the "solar-ready zone." For new residential homes, the solar-ready zone must be at least 600 square feet and oriented between 110 and 270 degrees from true north to the southernmost point as possible—to produce more energy.

As more buildings are constructed with solar installed or solar-ready, the demand for better solutions will foster greater innovation of products and technology to allow a building, its roof, and its solar PV to work as a single system. This could be new products performing multiple functions, such as building-integrated PV, which has been around the industry for years but has also been relatively unsuccessful due to economic and technical difficulties.

DESIGNING A SOLAR-READY ROOF AND THE EFFECTS OF ORIENTATION ON THE SYSTEM'S OUTPUT

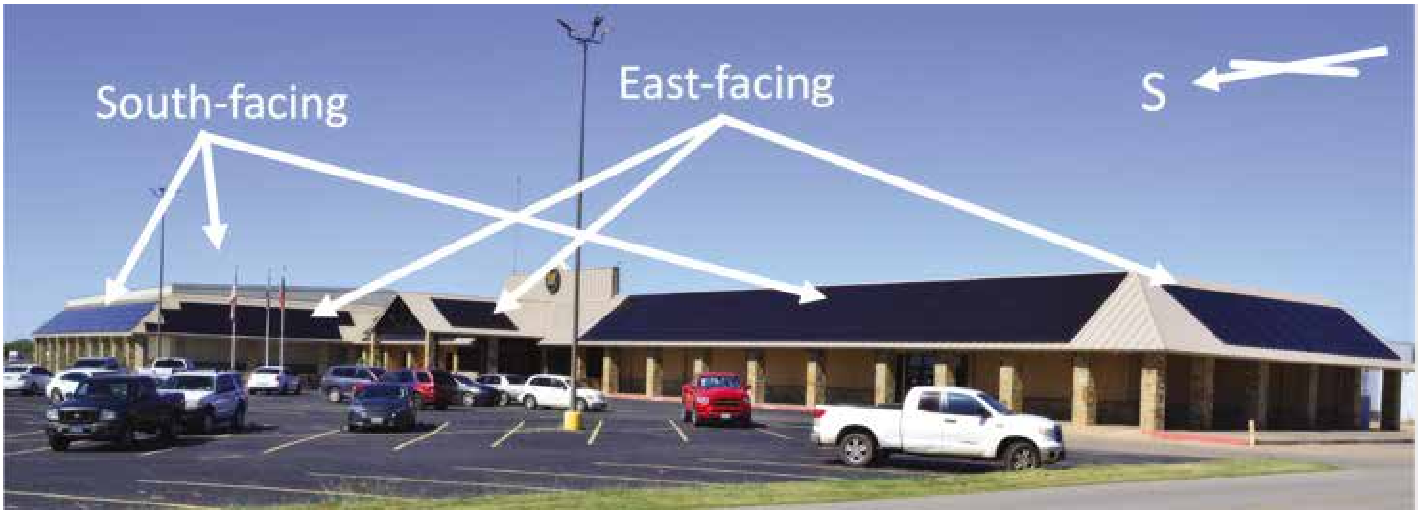
Whether mandated or not, it is a good idea to plan for a solar-ready roof during the design stages, as up-front planning can minimize cost and increase feasibility. Planning for a solar installation in the future ensures informed decision-making with regard to the timing of the installation and ensures optimal power production.

Mounting rooftop PV should always be consistent with the design principles of the host roof and vary according to the specific roof type. Further, a PV array on a rooftop is exposed to the environmental forces of wind, snow, rain, hail, and even earthquakes. These forces can be complex, making secure attachments of PV crucial. PV arrays improperly designed and installed can become airborne during a wind event and pose a serious threat of personal injury or property damage. Therefore, skilled design, engineering, and production of these components are required. All these criteria point directly to metal. So, a working knowledge of metallurgy, sealant chemistries, metal roof types, and other variables is also critical to a long-lasting solar-and-metal-roof combined asset.

When planning the location of the rooftop solar array, the orientation of the building should be considered to maximize the solar gain (increase in solar absorption of the area due to the natural direct exposure to the sun) and power production of the system. When a steep-slope roof (a slope approaching latitude) is involved, a south-facing roof surface is the optimal location for the array. Southwest and southeast orientation can also be good options affecting power production minimally. As the module orientation moves away from a south-facing orientation, the solar gain and total energy produced on any given day are reduced. Orientation is not as critical for low-slope roofs (roofs 5% or lower).

Today, solar modules are normally installed planar to the roof surface on steep roofs and planar or very slightly tilted on low-slope applications. Aggressive tilting of modules is seldom done primarily due to economic considerations (adversely affecting the ROI payback period) but also due to adverse wind effects on roof systems and structures.

Tilted systems are still sometimes used in very northern geographies or on roofs that are not oriented to the south. It is a delicate balance



between increased cost and increased power production.

When designing a project, structural analysis should always include the potential added collateral load, as solar modules add approximately 2½ pounds per square foot. A rail-mounted system adds 3 pounds or more per square foot. A rail-less system is lighter weight because it eliminates the need for 85% of the collateral load of rails.

Another design consideration is an unobstructed roof area(s), free of shading issues. Building components, such as plumbing stacks, skylights, chimneys, and adjacent walls and roofs, can create shadows on the solar system; therefore, the system should be designed to avoid obstacles and eliminate shadows. Consideration should also be given to any future buildings or trees planted near the building that could cast a shadow on the system.

After the building design is finalized, there should be a specific area called out as the solar zone for the PV system. This is the predetermined maximum roof area usable and best suited for solar mounting considering roof orientation, free space availability, and the building's consumption. Other issues that affect the size of the solar zone include building and fire codes, roof access paths for maintenance, the balance of system components, and the size of the array.

TYPES OF SOLAR MOUNTING SYSTEMS ON METAL ROOFS AND BEST PRACTICES

Solar modules are secured to metal roofs by several methods, generally falling into two categories: either flush mounted to achieve maximum module density or tilted to achieve optimal sun angle. Both methods result in different energy outputs from a given module or number of modules. These options may have differing roof inter-row spacing, structural engineering factors, and serious cost implications, so initial cost and ROI should be analyzed individually when considering and comparing the two options.

In years past, when PV modules were at their highest cost per watt and lower efficiencies, tilted systems were the norm to achieve optimal sun angle and were also demonstrably financially prudent. Solar array design was driven primarily by the high cost of the PV module, hence achieving optimal sun angle using tilted mounting systems was worth the added costs. Within the last decade, PV costs per watt have fallen from dollars-to-dimes/watt, so the gain in power production from optimal sun angle seldom offsets the added costs of tilting. Trends now favor lower-cost, flush-mounted systems that facilitate higher power density (watts per square foot) with less-severe wind effects and other structural considerations.

The next consideration concerns further details of the actual flush-mounting method.

RAIL MOUNTED

As demonstrated in **Fig. 1**, a typical rail-mounted system utilizes aluminum or light-gauge coated steel rails mounted above the seams or ribs of a metal roof.

This method normally orients the rails traversing the seams or ribs of the south-facing metal roof. Most module producers specify the "grabs" (hold-down clamps) for the module to engage the module along the long dimension, resulting in modules with "portrait" orientation to the roof slope. In high-wind areas, additional rails are sometimes necessary to provide another module attachment point (**Fig. 2**). Continuous rail allows neighboring modules to be within an inch or less of each other, which may maximize power density.

The offset above the base roof surface (usually 7 to 9 inches) allows easy access during installation and extra space for microinverters, optimizers, and rapid-shutdown equipment.

In climates prone to snow accumulation, the forces acting on the surface of the module create an eccentric loading (or moment arm) at the rails' attachment points, increasing the forces applied to the attachment components. This effect is increased by higher offset dimensions (height above the roof), snow load, and roof slope. These variables must be considered in the design of the system. The disadvantages of this configuration

Figure 1. *Flush Rail Mounting; Use of rails on the metal roof is redundant and adds unnecessary collateral load.*

include structural design complications, the resulting additional material and labor costs (over rail-less mounting), higher collateral loads, and the (perceived or real) negative aesthetics of a system raised above the roof.

Another version of a flush-rail PV mounting system is a flush "short-rail" (aka mini-rail or micro-rail), where short sections of rail are mounted on metal roof ribs as needed, to mount solar modules. These short-rails are installed parallel or perpendicular to ribs, depending on module orientation, and are sheet-only attachments when used on face-fastened roofs. While a short rail may save material costs and lessen collateral loads compared with continuous rails, the method of attachment should be carefully scrutinized.

Many products simply use one or two sheet metal screws on the top of the roof panels' ribs. This method puts the fastening in direct withdrawal and yields very low pull-out values in light-gauge sheet metal. In contrast, fastening to the side of the rib wall puts the fastening in shear rather than direct withdrawal and is generally preferred (**Fig. 3**).

RAIL-LESS MOUNTED (DIRECT-ATTACHED)

Solar modules may also mount directly to the seams of a standing seam metal roof or to the ribs of a face-fastened metal roof, eliminating the rail and related components entirely. Instead, the seams or ribs inherent to the metal roof serve as the mounting rails. The modules are installed in landscape orientation **(Fig. 4** and **5)**, still enabling recommended anchorage at the long side.

This method is like the flush-rail mounted system; however, it is lower in profile (usually 4 to 5¾ inches above the plane of the roof). This mounting method provides a more uniform load distribution to the roof and/or roof structure with as little as 15% of the weight (collateral load) of rails. Cost savings can be dramatic, especially in regions experiencing high-wind exposure, as in such cases the third rail is also obviated.

Another advantage of this method is that the roof is replete with ribs or seams, so there is increased module placement flexibility. Any loss (if it occurs) of power and energy density should be balanced against the rail material and labor cost savings in the financial analysis.

CONCLUSION

With increasing popularity, the metal roof is the ideal host for mounting solar PV due to its extended service life. Alternative roofing types will likely expire years before the life of the PV system, leading to erosion of the aforementioned ROI model.

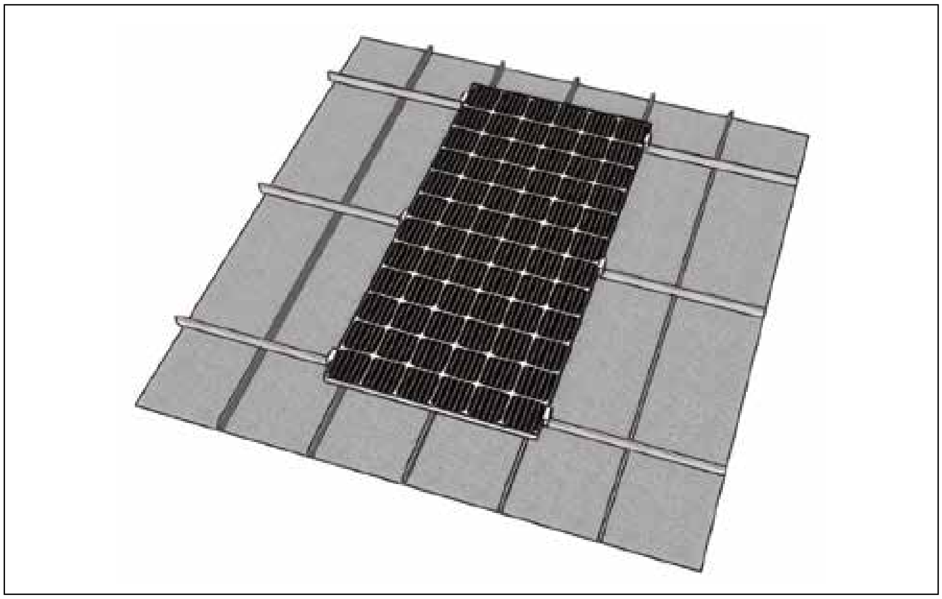


Figure 2. *Flush Rail Mounted Portrait with 3 attachment points per side.*

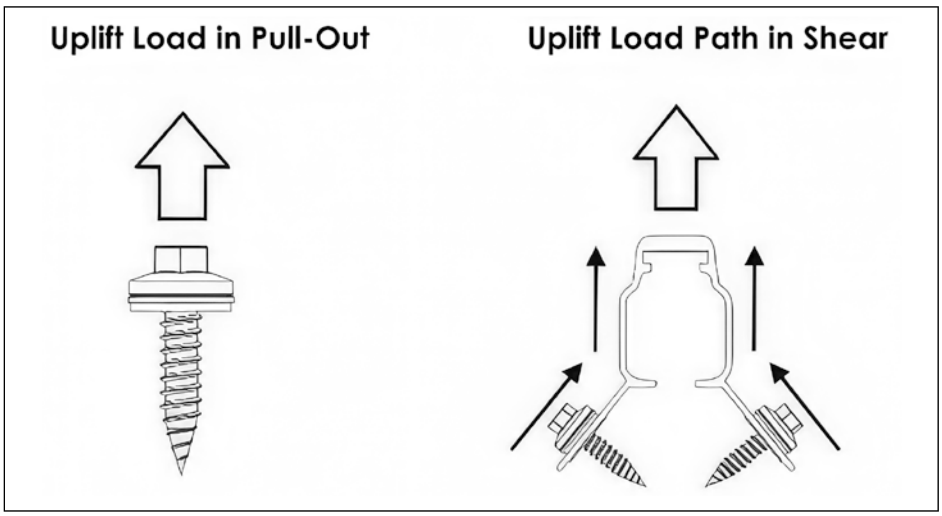


Figure 3. *Wind Uplift Load Reactions with fastener in pull-out and shear.*

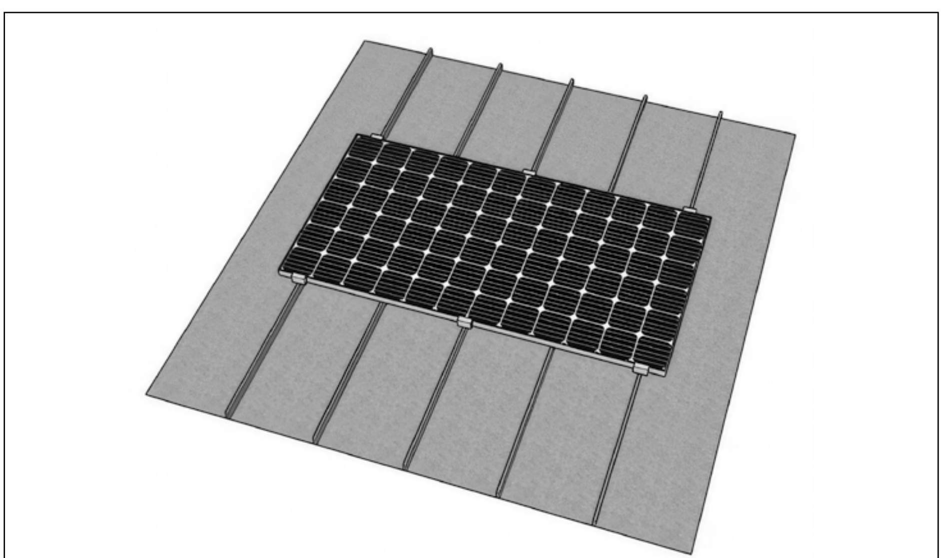


Figure 4. *Flush Rail-less Mounted Landscape with 3 attachment points per side.*

Figure 5. *Flush Rail-less Mount.*

Designers and owners should know about roofing alternatives and their service lives to bring added value to their customers. When it comes to attaching solar modules to metal rooftops, using conventional rails has been the traditional method. Yet, familiar concepts don't necessarily deliver the best outcomes. By installing solar on metal roofs with lower material, labor, and shipping costs, the rail-less attachment solution is proving to be a green innovation in both the solar and roofing industries. Solar engineering procurement construction companies are often underinformed on all these subjects.

Recyclable metal roofs have a demonstrated service life several times that of any other roof type and are never destined for a landfill. Therefore, solar metal roof attachments enable installation on most aged roofs without a roof replacement. Production of rail-less systems saves an estimated 90% of the energy used to produce rail mountings and 85% of carbon emissions in transportation, hence a much lower carbon footprint.

Because of significant cost savings, time savings, ease of installation and flexibility of module layouts, simplified and low-cost logistics, and a greater return on investment, rail-less mounting on metal roofs is gaining traction—fast. As more industry professionals experience these benefits firsthand, these innovations will continue to be a go-to solution for metal rooftop solar mounting.

ABOUT THE AUTHORS

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Rob Haddock *is a metal roofing expert who has worked in the industry for 5 decades—first as a laborer, then as a contractor, forensic analyst, technical author, innovator, and founder of S-5! He is a member of NRCA, ASHRAE, the American Society of Civil Engineers, the Construction Specifiers Institute, IIBEC, and ASTM. He is also a lifetime honorary member of the Metal Building Contractors and Erectors Association and the Metal Construction Association. Haddock innovated the concept of seam clamps for standing-seam roof profiles. He has served as faculty for the Roofing Industry Educational Institute, RCI, and the University of Wisconsin. He is a recipient of numerous awards, including the RCI Richard M. Horowitz Award and was a charter inductee to the Metal Construction Hall of Fame.*

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