Feature

Forward-Thinking, Solar-Ready Commercial Roof Design

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RECENT ENERGY CONSERVATION code updates in various North American jurisdictions have introduced requirements for new and significantly altered roofs to be solar-ready. In Appendix CB, the 2021 *International Energy Conservation Code* (IECC)[1] defines the term "solar-ready" as having "a section or sections of the roof or building overhang designated and reserved for the future installation of a solar photovoltaic or solar thermal system." Currently, it is possible to approach the solar-ready requirement by denoting rooftop space for future PV panels on a roof plan, which is the minimum threshold for compliance. For example, the energy conservation code in Washington, DC[2] (where the authors reside), requires that the building design "show allocated space and pathways for future installation of on-site renewable energy systems…to cover no less than 25% of [the] horizontal projection of the gross roof area." This and similar code provisions do not require rooftop renewable energy systems (e.g., PV panels) to be installed when the base building construction is complete.

The building owner will typically engage a PV vendor (many of whom can provide a variety of helpful "turnkey" services) when they are ready to implement the PV system. However, engaging a PV specialist after the base building construction is complete may result in a disconnect in timelines and communication with the base building project team members. In the meantime, simply allocating a portion of the gross roof area during the initial building design—though a productive incremental step toward increasing on-site renewable energy on new buildings—does not account for the multidisciplinary base building design decisions that must often be considered and coordinated for a successful future installation of PV panels. A Canadian Roofing Contractors Association article titled "Photovoltaics in Roofing"[3] aptly notes, "If not carefully planned, not only can the hoped-for return on investment in solar quickly evaporate, it can result, instead, in significant financial loss and jeopardize the performance of the roof on which it was installed."

A proactive approach during initial roof and building design can contribute to a successful and predictable implementation of rooftop PV panels, maintaining the roofing assembly's performance and mitigating the potential for surprises, such as unexpected costs or constrained options to the building owner. These proceedings compile a set of forward-thinking, solar-ready roof considerations for low-slope membrane roofs (not including electrical design, which is outside the scope of this content) that go beyond roof area allocations and can guide design professionals and other project stakeholders, regardless of whether their jurisdiction regulates solar readiness. As a key member of multidisciplinary project teams for commercial, institutional, and multifamily base building designs, the building enclosure consultant is well-positioned to help keep these topics at the forefront of design/development teams' thought processes.

ROOFTOP PV BASICS

It is helpful for the base building design team and other project stakeholders to embark on a solar-ready building design with a baseline understanding of PV technology and strategies available to attach the rooftop PV system.

Solar panels consist of PV cells designed to generate electricity when exposed to radiant energy, such as sunlight. Sunlight (i.e., solar radiation) is absorbed by the semiconductors that make up PV cells, resulting in electrical charges within the cells that then generate electricity.[4] These PV cells are packaged together to create modules, which can be grouped into panels. The assembly of PV modules or panels with a support structure and other ancillary components (e.g., wiring, junction boxes, monitoring devices) is referred to as a PV array. PV arrays produce electrical power for the building, which can reduce the required demand for external energy from the local power grid.

PV arrays are typically supported by and attached to a framed structure referred to as a rack (**Fig. 1**). Attaching the rack to the building structure is a critical design decision that impacts various aspects of the roofing assembly. The most common attachment methods include ballast, dunnage/stanchion, mounts with through-fasteners, and hot-air-welded clips. Thin-film PV laminates, some of which can be adhered to thermoset, thermoplastic, or modified-bitumen membranes under the umbrella of the building-integrated PV philosophy, have not been part of the authors' projects in recent years and are therefore outside the scope of these proceedings.

In a ballasted assembly (**Fig. 2**), the PV rack is typically attached to plastic or metal trays that are loaded with concrete blocks, pavers, or other weights to secure the PV assembly and counteract wind uplift pressures. Typically, ballasted PV assemblies have a low profile, and the panels are close to the roof membrane. This approach avoids rack/mount penetrations through the roofing membrane, minimizing the opportunity for such penetrations that, if poorly flashed, can act as vulnerabilities for water leakage. Ballasted PV systems are also typically the most economical attachment method. However, ballasted systems have several disadvantages that must be considered. Since the PV panels are close to the roofing membrane and the ballast trays rest on the membrane, this approach can impede roof drainage and cause heat buildup between the PV panels and the membrane, which can negatively impact the PV panel and roofing performance.[5] Additionally, the PV assembly must be removed to access the roofing assembly for maintenance, repair, or replacement. Finally, the ballasted trays can shift in service, especially if adequate expansion/contraction measures are not designed into the system, potentially abrading or damaging the membrane.

Figure 1. *Example rooftop PV arrays on racks.*

In a dunnage approach (**Fig. 3**), the rack is mechanically attached to steel framing and localized posts (e.g., at the corner of each dunnage frame) that transfer the PV system's structural load to the building, often at underlying columns. Like dunnage (but with increased roofing penetration frequency), stanchions (**Fig. 4**) are composed of a series of repeating small-diameter posts that transfer the structural load to the roof deck or building structure. Both dunnage and stanchions elevate the PV panels above the roof surface. This allows for beneficial airflow under the panels and, depending on how tall the dunnage system is, allows for roof maintenance, repair, or replacement without disrupting the PV assembly. For both dunnage and stanchions, the posts are flashed with roofing membrane in a detail that, provided it follows the membrane manufacturer's instructions, is typically warrantable.

Another attachment option, for which commercially available options and partnerships with membrane manufacturers have increased in recent years, is PV roof mounts with through-fasteners (**Fig. 5**). These mounts generally consist of metal disks that attach to the roof deck and either rely on a gasket seal for water tightness or include an integral flange of exposed membrane roofing (e.g., polyvinyl chloride [PVC], thermoplastic polyolefin [TPO], modified bitumen) that is adhered or heat-welded to the roofing membrane. Manufacturers of through-fastened

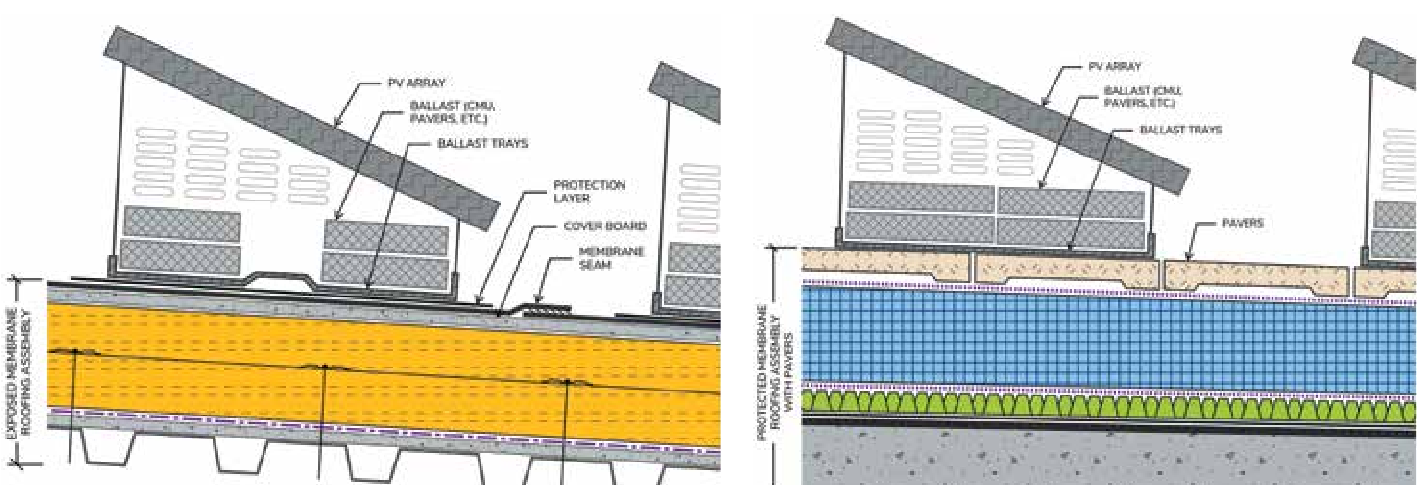

Figure 2. *Example representations of ballasted PV assemblies over exposed membrane (left) and protected membrane (right).*

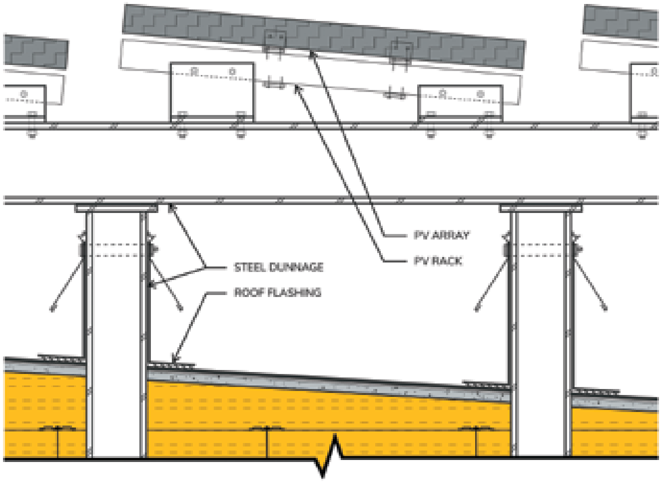

Figure 3. *Example representation of dunnage PV assembly.*

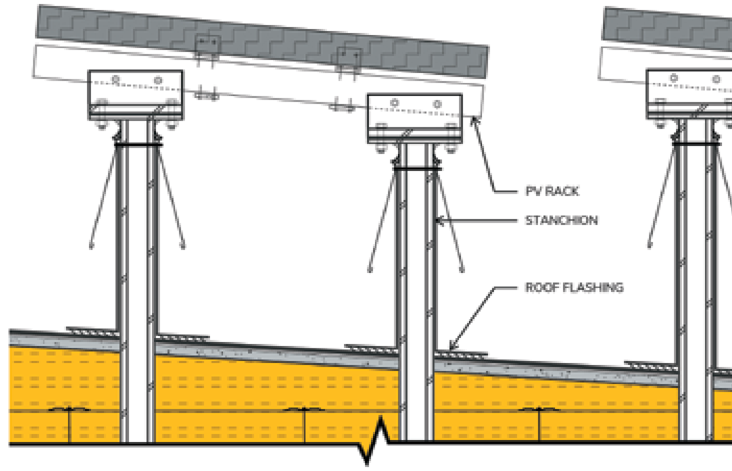

Figure 4. *Example representation of stanchion PV assembly.*

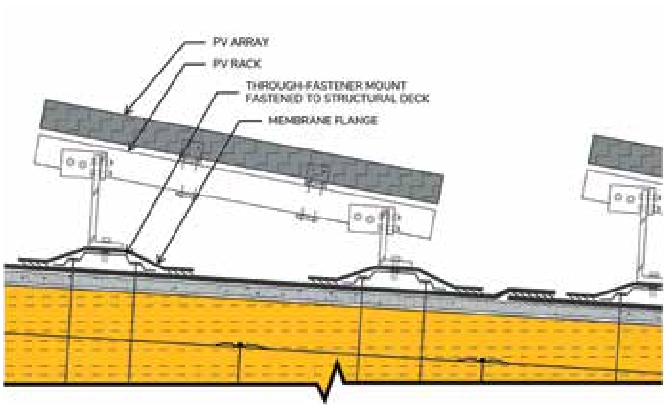

Figure 5. *Example representation of through-fastened PV assembly.*

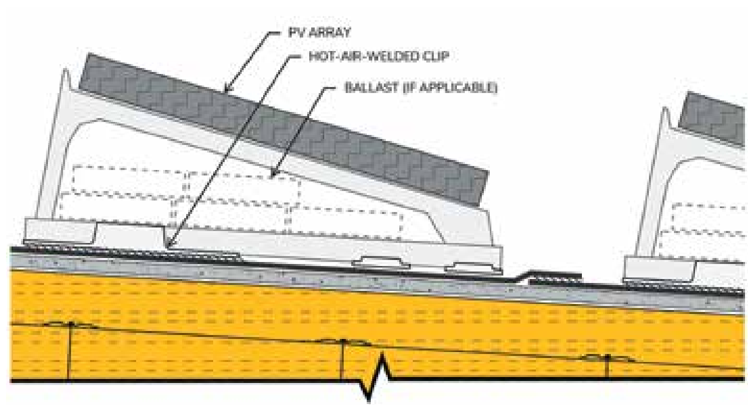

Figure 6. *Example representation of hot-air-welded PV clip assembly.*

mounts typically have slope limitations (e.g., 2:12 maximum or 1:12 at areas of high snow load). This approach is generally more economical than dunnage/stanchions but requires numerous penetrations through the roofing membrane and may have limited structural capacity relative to other attachment methods. Unless each mount is raised onto a curb, the systems may present an increased vulnerability to water leakage versus the dunnage/stanchion approach. The membrane penetration points have varying sealing features, depending on the specific product, and their low position puts them in the roof's drainage path. This approach also has similar drawbacks to ballasted systems associated with the PV panel's low-profile above the roof surface.

For PVC roofing assemblies, hot-air-welded clips (**Fig. 6**) are another newer attachment option. These clips are proprietary (and consequently offered by limited manufacturers), and they avoid rack/mount penetrations through the roofing membrane by using the roofing assembly to resist wind uplift pressures rather than attaching directly to the roof deck or building structure.

STRUCTURAL CONSIDERATIONS

Considering future PV installation during the base building structural design is essential to a holistic rooftop solar design. The building's structural system is interdependent with the attachments discussed in the previous section and may unexpectedly restrict the ability to install future PV panels if not sufficiently considered. The following sections discuss select base building structural considerations that the project's structural engineer can oversee.

Dead and Live Loads

Section 1606.4 of the 2021 *International Building Code* (IBC)[6] requires that the weight of the PV array and its support system or ballast is included as a dead load when designing the roof structure. The design of the roof structure is, therefore, interdependent with the type of the future PV assembly. Ballasted systems, relative to other attachment systems, more uniformly distribute their dead load across the roof deck, while stanchion systems impose concentrated point loads on the building's structure at each post. Steel dunnage systems, which typically impose greater concentrated dead loads than stanchions, consequently require particular coordination with the base building structure. Design professionals should consult with the building owner and structural engineer regarding what type of support system they envision for the future and plan accordingly by designing the base building structure with adequate reserve capacity for PV dead loads that can be reasonably anticipated. If dunnage systems are anticipated, the base building design may go so far as to identify specific future dunnage layouts and structural capacity at the associated future post locations.

Additionally, section 1607.14.4.1.1 of the 2021 IBC requires that the roof be designed for live loads both *with* and *without* the PV panels, so the base building structural engineer should capture future PV-related live loads for the area planned for future PV.

Deflections and Ponding

If the future PV will be a ballasted system, section 1607.14.4.5 of the 2021 IBC requires that the roof structure be designed and analyzed for deflections per section 1604.3.6 and ponding per chapters 7 and 8 of ASCE 7.[7] The authors have investigated outcomes where the addition of a ballasted PV assembly resulted in ponding at areas of localized deflection in the roof structure (**Fig. 7**) and in the displacement of the roofing base flashing at the perimeter of the roof, resulting in water leakage to the interior.

Wind, Snow, and Seismic Loads

Sections 3111.1.1 and 1607.14.4.2 of the 2021 IBC[6] also require that rooftop-mounted PV systems be designed for wind loads in accordance with section 1609, which references chapters 26 to 30 of ASCE 7,[7] and that snowdrift loads created by PV panels (if applicable) be included as dead load.

Besides the IBC, other industry codes and standards, such as those published by the ASCE (which the IBC references) and the Structural Engineers Association of California (SEAOC), include requirements or guidelines for the structural design of rooftop PV. The 2016 edition of ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures,* added new provisions for determining wind loads on PV panels. ASCE 7-16 also states that solar panels should be considered as roof projections that may cause windward drifts on the roof around them, and it includes provisions for how to calculate the snowdrift geometry and loading.[7] Therefore, the base building design should assume a conservative weight for the solar-ready portion of the roof and/or perform a proof-of-concept analysis for the snowdrift of the future PV assembly. As always, project teams must utilize the latest applicable versions of codes and standards since their evolutions are likely to affect solar-ready building designs. For example, ASCE 7-22 includes increased structural design loads (e.g., snow loads and rain intensities) relative to earlier versions.

Where applicable, seismic loads must be considered as they relate to the PV array and the associated load path to the building structure. Three reports SEAOC has published provide structural seismic requirements for rooftop PV (PV-1),[8] include requirements and recommendations for wind design for solar arrays (PV-2),[9] and address key issues for evaluating the capacity of the building roof structures to support gravity loads imposed by PV arrays (PV-3).[10] Even where these provisions are not triggered by a project's governing codes, they can be helpful tools for design teams performing due diligence or proof-of-concept exercises to prepare a current base building for future rooftop PV.

Figure 7. *Localized deflection and ponding under ballasted PV assembly.*

FIRE-RELATED/COMBUSTIBILITY CONSIDERATIONS

Sections 1505.1 and 1505.9 of the 2021 IBC include requirements for fire classification of the roofing and PV assemblies based on the building construction type and reference additional requirements in the *International Fire Code* (IFC)[11] and standards by the National Fire Protection Association. When preparing a new building design that anticipates future rooftop PV, these provisions are worthy of an upfront understanding, particularly those related to firefighter access.

Access Pathways for Firefighters

Section 1205.3 of the 2021 IFC[11] requires pathways to support firefighters accessing roofs with PV arrays. These requirements vary between Group R-3 buildings (mainly smaller residential buildings) and all other buildings (which include commercial construction). For commercial roofs, the code prescribes the following minimum pathway widths and spacing based on the location and application:

- Minimum 6 ft (1.8 m) wide perimeter pathway around the edges of the roof (exception: where either axis of the building is 250 ft [76 m] or less, the width may be reduced to 4 ft).
- Minimum 4 ft (1.2 m) wide interior pathways at minimum 150 ft (46 m) intervals, in a straight line to roof standpipes or ventilation hatches, around roof access hatches, and (minimum one) pathway to the parapet or roof edge.
- Minimum 4 ft wide pathways bordering all sides of non-gravity-operated smoke/heat vents.
- Minimum 4 ft wide pathways on minimum one side of gravity-operated dropout smoke/heat vents.
- Between array sections: minimum 8 ft (2.4 m) wide pathway or minimum 4 ft wide pathway bordering 4 ft by 8 ft venting cutouts every 20 ft (6 m) on alternating sides of the pathway.

The geometry of the roof and the layout of rooftop mechanical equipment and roof hatches can significantly impact and, in some cases, limit the layout of future rooftop PV, especially with consideration of the aforementioned access requirements. Accordingly, when determining the portion of the roof that will be allocated for future PV panels, it is prudent to conduct a proof-of-concept layout process that maps out these pathways, especially if the building owner is relying on the PV assembly to provide a minimum power output that is based on a panel layout that consumes the allocated square footage.

MECHANICAL, ELECTRICAL, AND PLUMBING CONSIDERATIONS

Electrical Pathways/Penetrations

The future rooftop PV system will require electrical conduits to route through the building and penetrate the roof, and some solar-ready roof designs generically require providing conduits with the base building project for the future PV. Deferring the identification of conduit pathways and penetration points/methods to the future can lead to limited choices and possibly compromised decisions and performance problems. Therefore, it is good practice to incorporate these features, with some specificity, in the base building design. Regarding conduit runs in the building, allocate and label space within ceiling cavities, vertical chases, or other suitable pathways. Do not route electrical conduits through the roofing insulation above the structural roof deck; the authors have investigated existing buildings where this approach was used, resulting in a concealed safety hazard for future roofing contractors (**Fig. 8**). Moreover, the National Roofing Contractors Association (NRCA) also recommends against this practice, adding that conduits should not be routed through flutes in steel decks or directly mounted to wood decks.

Regarding electrical penetrations through the roofing assembly, collecting and routing electrical conduits through enclosures (either field-fabricated sheet metal using NRCA details or prefabricated using commercially available products [**Fig. 9**]) near or within the future PV area is a prudent feature to incorporate in the base design. The availability of these predetermined and reliable penetration points can help future electrical contractors and roofing contractors avoid the temptation to use less-reliable penetration techniques such as pitch pockets, whose sky-facing sealant tends to deteriorate in service and cause water leakage vulnerabilities far faster than the surrounding roofing membrane.

Figure 8. *Electrical conduit on roof deck within roofing assembly.*

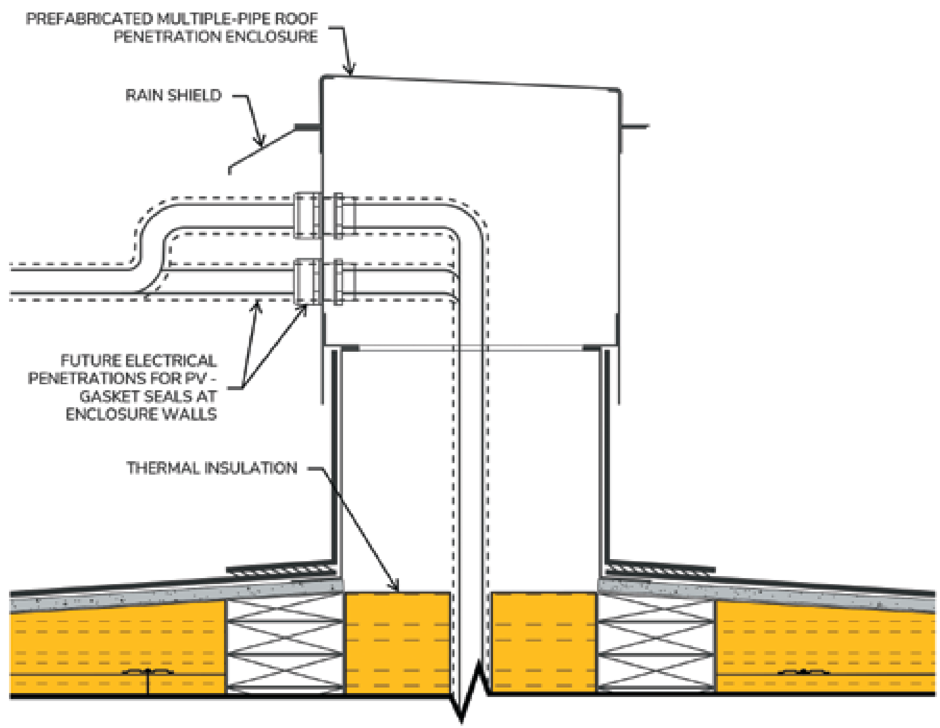

Figure 9. *Example prefabricated enclosure for multiple-pipe/electrical conduit penetrations.*

Mechanical and Plumbing Equipment Layout

As described earlier, although the detailed layout of the future PV panels will likely not be included in the base building design, it is prudent to consider how the layout of the rooftop mechanical equipment may impact the available space for future PV. First, design teams should carefully consider whether mechanical equipment belongs on the rooftop in the first place or is better suited within a protected enclosure such as a penthouse, which is more conducive to a safe and recurring preventive maintenance program and less likely to be a source of water leakage through the roof. Design teams should endeavor to consolidate rooftop mechanical equipment, in part to minimize the number of access pathways required between and around each unit, which can reduce the overall square footage of usable area for PV panels. Additionally, consider how large equipment (e.g., chillers or air-handling units) or mechanical penthouses or screen walls will cast shadows and position the PV area accordingly, since shading or otherwise obstructing only a small section of a PV module or panel can reduce its output.[12]

Roof Drainage Systems

The drainage strategy for the roof should be coordinated with the anticipated PV assembly support system and the locations of the solar-ready areas. The building code requires provisions for both primary and secondary (i.e., overflow) drainage on all roof areas. Roof drainage systems may include internal roof drains, through-wall scuppers, and/or gutters—all of which require access to inspect, maintain, and repair. It is prudent to avoid installing PV arrays over roof drains or blocking scuppers, especially with low-profile attachment systems (e.g., ballast, roof mounts, and clips) where routine maintenance is not possible without temporarily relocating the PV arrays to access the drainage system, which would be costly and impractical.

ROOFING DESIGN CONSIDERATIONS

Single Ply Roofing Industry (SPRI) aptly characterizes the importance of roofing performance, even on roofs with PV: "The roof's function is, first and foremost, to protect the building contents and its people from the elements."[13] This section discusses several factors directly related to designing the base building roofing assembly in the context of its future use under the PV assembly.

Alignment of Service Life

According to the NRCA, the service life of a typical PV assembly is approximately 25 years, and the service life of the average low-slope commercial roof is 17.4 years.[12] With that said, depending on the type/configuration of the assembly, membrane type, quality of installation, and degree of preventive maintenance, some roofing assemblies can functionally remain in service for 25 or more years. Endeavoring for the base building roof to last as long as possible is critical for establishing reasonable alignment with the service life of the future PV. Once the base building roof is installed below an allocated solar-ready area, the clock begins ticking toward misalignment of service lives until the PV is eventually installed. Misalignment (particularly if the PV implementation does not occur for several years) can result in a future scenario where costly removal and reinstallation of the PV assembly (especially for low-profile attachment systems) is required to accommodate the first roof replacement in the building's life cycle.

Accordingly, enhancing the roofing assembly in the base building design to prioritize the length of its service life should be a design priority. Some fundamental strategies in this regard include the following:

- Configuring the roof as a protected membrane assembly, where the membrane (e.g., a reinforced, monolithic fluid-applied waterproofing with a track record in this application) is protected with overburden such as drainage composite, rigid and moisture-tolerant insulation, and a wearing surface. This approach typically lends itself more readily to roofs with a structural concrete deck than with a wood-framed plywood deck.
- For single-ply roofs, specifying the thickest membrane in the manufacturer's standard offerings (e.g., 80 mil polyvinyl chloride or thermoplastic polyolefin instead of 60 mil).
- Specifying a cover board below the roofing membrane for improved puncture resistance and load distribution (e.g., distributing the load from ballast trays in a manner that helps avoid localized insulation compression below the membrane and consequent localized ponding).
- Specifying higher-compressive-strength insulation (e.g., 25 psi instead of 20 psi).
- Including robust flashing detailing at all penetrations (e.g., avoiding pitch pockets, specifying prefabricated flashing boots, and specifying counterflashings at all penetrations to shield the underlying base flashing).
- If considering a ballasted system for the future PV, fully adhering the cover board instead of mechanically attaching it since the shifting of the ballast can cause the roofing membrane to abrade against the fastener plates for the cover board.

Roofing Assembly Warranty

In addition to pre-PV-install inspections and other solar-related prerequisites, roofing manufacturers generally have requirements related to the composition of the roofing assembly. Base building design professionals should consult the basis-of-design roofing manufacturers to understand how the installation of future PV panels may impact the roofing warranty and what provisions are necessary to maintain the warranty at that time. For example, some manufacturers have specific guidance regarding membrane attachment and other roofing design enhancements described in the previous section. Additionally, some roofing manufacturers have limitations on the roofing attachment options that they allow under their warranty, which may inform the structural design of the base building.

Insurance Requirements

FM Global, a commercial property insurance company, requires adherence to specific standards for roofing materials and installation procedures on FM-insured buildings. FM Global has published these requirements via Property Loss Prevention Data Sheets. FM Global Data Sheet 1-15, "Roof-Mounted Solar Photovoltaic Panels,"[14] incorporates requirements related to fire and natural hazards for the design, installation, and maintenance of all roof-mounted PV panels, and this standard was updated in January 2023. FM Global mandates provisions that affect the base building design, including prohibiting multi-ply roofing assemblies (e.g., modified bitumen) under PV panels, requiring specific design parameters such as factors of safety (which can affect structural load reactions to the base building structure), and requiring additional ballast (where ballast is applicable) at specific portions of the PV array. If a building is insured by FM Global, then it is critical for the base building design team to coordinate with FM Global Approvals staff and the pertinent data sheets to ensure the design complies with all FM Global requirements and will be able to comply with any future requirements during the PV installation.

Roof Maintenance

SPRI recommends that PV array racks be installed with enough clearance above the roof membrane for maintenance/servicing, limiting PV arrays over field seams and penetrations so that they are accessible, and protecting high-traffic areas with walkway pads.[13] Similarly, the NRCA recommends rack-mounted PV systems on support stands (e.g., stanchions) or on curbs with a minimum clearance of 30 in (760 mm) from walls, curbs, or adjacent racks and enough room underneath to facilitate preventive maintenance, repairs, or replacement.[12] In section 9.7 of the *NRCA Roofing Manual: Membrane Roof Systems – 2023,*[15] the NRCA provides guidelines for clearance above the roof surface for equipment support stands based on the width of the equipment.

BUILDING USAGE AND MAINTENANCE CONSIDERATIONS

Though it should, roofing design does not always consider how the building will actually be used and maintained, including maintenance of rooftop equipment and maintenance of the facade. To help base building design teams avoid imposing future unnecessary constraints on the building owner, this section highlights considerations related to fall protection required for future work on low-slope roofs and considerations related to future facade access.

Rooftop Fall Protection Requirements

The U.S. Occupational Safety and Health Administration (OSHA) sets and enforces standards to ensure safe and healthy working conditions for workers. OSHA's general industry standard (§1910.28)[16] includes regulations, which were updated in 2017, for work on low-slope roofs of existing buildings. The standard essentially prescribes that employers of those working on low-slope roofs are responsible for providing their employees with an approved fall protection system where fall hazards are present. Key aspects of OSHA 1910.28's provisions for work on low-slope roofs include the following:

- If a worker is less than 6 ft from the roof edge, they must be protected by a fall protection system such as a guardrail or personal fall arrest/restraint system.
- If a worker is more than 6 ft (1.8 m) and less than 15 ft (4.5 m) from the roof edge, either they need a fall protection system

(as described above) or the employer may implement a designated area (e.g., warning line system) if the work is both infrequent and temporary.
- If a worker is more than 15 ft from the roof edge, then, at a minimum, the employer must implement and enforce a work rule prohibiting employees from going within 15 ft of the roof edge without some form of fall protection.

Additionally, sections 1015.6 and 1015.7 of the 2021 IBC require guardrails whenever components that require service (e.g., rooftop mechanical equipment and PV panels) or roof hatches are located within 10 ft (3 m) of a roof edge, with the exception that guardrails are not required if personal fall arrest anchorage connector devices are present to protect workers in the defined edge zone.

A fall arrest/restraint system typically consists of a body harness, lanyard, and anchorage to the building. In conjunction with designating solar-ready roof areas and with consideration of complying with the aforementioned standards/code provisions, it is prudent for design professionals to incorporate guardrails, fall protection unit anchors, or travel arrest/restraint systems in the base building design to facilitate safe access of roof areas for future workers, including PV technicians.

Facade Access

Similar to planning for future roof access, it is prudent to consider how the facade of the building will be accessed for future inspections, maintenance, and repairs. While shorter buildings may be serviced via mobile elevated work platforms (e.g., scissor lift or boom lift) or scaffolding, taller buildings in dense urban areas may require facade access from the roof. Workers descending the face of the building, either via a hung platform (e.g., suspended scaffolds) or rope descent, would require personal lifelines and anchor points, and other equipment that is worthy of coordinating with the solar-ready roof area to minimize the chances of conflict with future PV panels. For example, suspended scaffolds (i.e., swing stages) need unobstructed rooftop edge space to erect the suspension system (e.g., beams and counterweights). Also, the suspension system requires independent anchorage (i.e., tiebacks) and a pathway for the tieback cables to attach to a suitable independent anchor. Design professionals should consider conceptualizing and/or overlaying these pathways on an anticipated PV panel layout to avoid future facade access limitations for the building owner.

OTHER RESOURCES

As rooftop PV has become more common in recent decades, various agencies and industry associations have published helpful resources for building owners and design professionals. For example, the National Renewable Energy Laboratory, affiliated with the Department of Energy, has several guides that enumerate high-level considerations, discuss policy updates, and provide cost-benefit analyses for building owners. Building owners and design professionals may benefit from these resources in addition to those listed at the end of this paper.

CONCLUSION

When tasked with solar-ready low-slope commercial, institutional, or multifamily building designs, project teams (aided by the guidance of the building enclosure consultant) can contribute to a successful future PV and roofing system by considering the following forward-thinking steps:

- Work with the project's structural engineer of record and other team members (including PV specialists) to conceptualize the future PV support system and its various loads so they can design the base building structure with adequate reserve capacity that meets the code and avoids performance issues.
- Identify mandatory access/maintenance pathways to prepare for future compliance with fire codes, coordinate with rooftop equipment and roofing maintenance needs, and inform the solar-ready area designated in the base building design. Also, consider how the roof and facade will be accessed, in conjunction with considering how the PV array will be accessed, when laying out solar-ready roof areas.
- Design the roofing and rooftop MEP systems in the base building with the future PV system in mind rather than entirely deferring PV-related considerations such that they are not able to be coordinated with base building decisions.
- Specify a durable roofing assembly with enhancements that will prolong the roof's performance and service life (ideally meeting or exceeding the service life of the PV array) and meet roofing manufacturers' PV-related warranty requirements.

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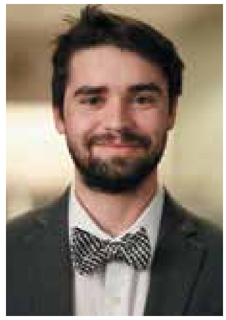
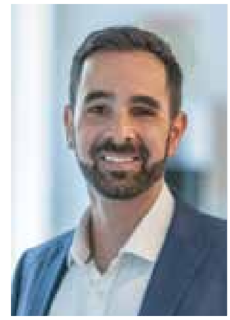
Samantha Corbel *is an engineer for the Loan Programs Office at the Department of Energy. She previously worked as a building enclosure consultant for Simpson Gumpertz & Heger (SGH) Inc.'s Building Technology group. Sam is experienced with new design, construction administration, rehabilitation, and investigation projects for owners, architects, and clients in the DC, Maryland, and Virginia areas. She has investigated roof leakage related to PV panels and consulted with architects regarding Net Zero and on-site renewable energy goals.*



JACOB RINGER, EIT

Jacob Ringer *joined Simpson Gumpertz & Heger (SGH) Inc.'s technical staff in the Washington, DC, office in 2022. He is experienced with enclosure consulting for a variety of project types including commissioning, rehabilitation, and investigation, as well as with dispute resolution and building science.*



JOHN KARRAS, PE

John Karras *is a principal in Simpson Gumpertz & Heger (SGH) Inc.'s Building Technology group. He has over 20 years of building enclosure consulting and construction management experience on commercial, institutional, government, and multifamily buildings. He serves architect, building owner, and contractor clients while designing, investigating, and rehabilitating building enclosure systems on a variety of building types. His responsibilities include design consultation, preparation of design documents, field investigation, and construction administration related to building enclosure systems such as below-grade waterproofing, roofing, exterior wall claddings and weather barriers, and fenestration/glazing systems.*

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