PUBLIC REPORT

New York City Public Schools Solar PV Canopy + Rooftop Stormwater Management Feasibility Study

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EXECUTIVE SUMMARY

Statement of Problem

Rooftop ballasted solar PV panels and rooftop stormwater management practices (SMPs) such as green roofs represent competing claims on the limited roof space of new school capacity projects constructed by the New York City (City) School Construction Authority (SCA).

To date, SCA has been working towards maximizing rooftop solar PV generation in order to help capacity projects meet energy efficiency and GHG emission reduction mandates and support the City's goals for mitigating climate change. These include:

- A stated goal to install at least 100 MW of solar photovoltaic (PV) generation on municipal buildings by 2025, which is heavily reliant on school rooftops;
- Local Law 31/2016, which requires feasibility studies of renewable energy generation or net zero energy use for municipal buildings subject to low energy use intensity limits; and
- Local Law 94/2019, which requires new or rebuilt roofs to be covered by solar PV panels or vegetation (green roof systems).

The utilization of new school rooftops for energy generation using ballasted PV panels is already limited by obstructions such as stair and elevator bulkheads, rooftop mechanical rooms, and mechanical equipment including but not limited to air handling units (AHUs), chillers, heat pumps, exhaust fans, and emergency generators, some of which are installed on dunnage raised 5 feet above the roof surface in order to facilitate roof maintenance and replacement. These obstructions create shadows and often divide the unobstructed roof into small areas that are not suitable for ballasted PV panels.

Consolidating these obstructions at the north end of a building would create more space for ballasted PV panels, but elevator and stair placement is dictated by the locations of the lobby and double-loaded corridors on the floors below, while HVAC equipment placement is dictated by building HVAC zoning, the locations of restrooms on the floors below, and the need to minimize duct runs and elbows which can reduce equipment efficiency and increase duct noise.

At the same time, a number of recent and proposed policies are likely to significantly increase the prevalence, size, and complexity of stormwater management installations for SCA capacity projects and may require the dedication of more roof area to stormwater management. These include:

- Local Law 91/2020, which authorized the NYC Department of Environmental Preservation (DEP) to reduce the threshold area of developments in separate storm sewer system (MS4) areas that trigger stormwater pollution prevention requirements;
- DEP's Unified Stormwater Rule, which reduced the allowable maximum stormwater quantities and flow rates through new connections to City sewers, established new stormwater quality requirements, and mandated the use of green infrastructure where feasible; and
- Additional policy changes currently under discussion in the wake of recent flash floods, including adoption of the NYC Climate Resiliency Design Guidelines as a requirement for municipal construction projects.

Combined solar PV canopy and rooftop stormwater management installations may be the best way – and for some SCA capacity projects with limited at- or below-grade site availability for stormwater management, the only way – to cost-effectively reconcile these competing regulatory requirements.

The goal of this Research and Development Project (the "Project") is to establish the feasibility of a pilot project to demonstrate this strategy, with related tasks to include: estimates of potential energy and stormwater management benefits; analyses of regulatory, design, constructability, and cost implications; development of best practices and model standards; and preparation of schematic and design development drawings and specifications.

Research Objectives

Task 1: Research Review and Expansion

This task included literature review, consultation with SCA technical staff, and consultation with manufacturers and outside experts. It also included additional regulatory review and consultation with relevant City agencies, with particular consideration for the potential impacts of forthcoming DEP stormwater rules.

This task also included a review of relevant existing and planned SCA and DOE solar PV projects, rooftop stormwater management projects, and combined PV and stormwater management installations.

This research was distilled into a summary of best practices and design considerations for combined rooftop solar PV and stormwater management installations at SCA new construction projects. These include the following:

- Comparison of solar PV canopy system types and alternatives such as ballasted, direct mounted, and building integrated solar PV systems.
- Comparison of rooftop stormwater management system types such as blue roof, extensive green roof, intensive green roof, and hybrid systems.
- Overview of combined rooftop solar PV and stormwater management installations, and comparison to SCA and NYC Department of Education (DOE) solar PV installations and rooftop stormwater installations.
- Potential benefits of combined installations, such as blue/green roof installations, stormwater detention and retention, solar PV panel performance and yield, rooftop programming, rooftop shading, roof system durability and replacement, mechanical system operation and replacement.
- Technical design considerations for combined installations, such as regulatory, architectural, structural, mechanical, electrical, and plumbing issues, environmental impacts, and design coordination issues.
- Visual impact considerations for combined installations, such as integration into building design, visibility from street level, and Landmarks Preservation Commission approval.

- Construction and maintenance considerations for combined installations, such as phasing, green roof shade tolerance, and maintenance and replacement of PV panels, green or blue roof components, and mechanical equipment.

This task concluded with the development of a solar PV system and stormwater management system selection matrix to assist in SCA decision-making, including parameters for selecting suitable buildings for the application of combined installations.

Task 2: Case Study Analysis

EME applied the best practices developed in Task 1 to a case study selected by SCA in order to guide a code, zoning, and technical feasibility analysis. EME completed the following based on the selected case study:

- Zoning analysis and diagram demonstrating that the proposed installation follows the NYC zoning resolution, especially the height and setback requirements.
- Identification of site conditions that could impact the production and distribution of the solar PV canopy such as shading, mechanical equipment clearances, access to existing equipment and roof drains, and existing electrical infrastructure.
- Identification of site conditions that could impact the performance and longevity of the stormwater management system such as the existing roof slope, roof system composition and condition, and (for green roof systems) exposure to the sun, wind, reflected light, and heat and availability of temporary irrigation.
- Structural analysis of the existing roof to determine the optimal solar PV canopy design and optimal stormwater management system design, taking into account the additional load from stormwater management measures.
- Application of the selection matrix developed under Task 1 to determine the solar PV canopy system and rooftop stormwater management system to be studied.
- Estimated PV generation based on schematic layout using Helioscope; and estimated stormwater storage volume and flow reduction based on DEP formulas.
- Schematic plot plan including building location; front, side and rear yard dimensions; trees that could shade or fall on the PV system; and city infrastructure, utilities, or hazards.
- Schematic design drawings including existing equipment, clearances, obstructions, and maintenance and FDNY access requirements; solar PV canopy layout; stormwater management system layout; building elevations; and building sections.
- Cost estimates for solar PV canopy installation including generation equipment, electrical tie-ins, structural/mounting systems; cost estimates for stormwater management system installation including modifications to the roof structure, waterproofing, and drainage; and other cost implementation related costs.

Task 3: Schematic and Design Development

EME developed complete schematic and design development architectural, structural, PV/electrical, and details as required to illustrate the pilot project design concept. The technical package will include:

- Constructability and long-term maintenance impact analyses
- Zoning analysis and diagrams
- Demolition/dismantling and site preparation plans, if required

- Architectural roof plan with FDNY access, building elevations, building sections, and PV canopy and panel mounting details, and waterproofing details
- Structural calculations, plans, sections, and details encompassing static and dynamic load, lateral shear, seismic, and wind up-lift forces
- PV system specification, PV yield calculations, canopy and panel layout, conduit and equipment plan, three line diagram, and riser diagram
- Rooftop stormwater management system specification, stormwater calculations, system layout and details
- Preliminary phasing and staging plan
- Design development level cost estimates for all applicable trades.

Research Approach

EME reviewed and expanded on previous internal research by SCA into building code and solar PV zoning criteria; structural, architectural, and mechanical feasibility; manufacturer guidance; and design guidelines. EME reviewed materials provided by SCA and revisited its own previous work for SCA and DOE. Project case studies were identified from a variety of sources including SCA's portfolio, DOE and NYC Department of Environmental Protection (DEP) feasibility studies, manufacturer websites, and other online resources. Additionally, EME conducted a detailed review of existing studies relevant to rooftop stormwater management practices, combined green roof and PV canopy systems, and blue-green roof technology. This body of research and lessons-learned were used to inform the decision matrix and conceptual analysis and design which follows.

Summary of Findings

This report addresses the implementation of rooftop solar PV canopies and rooftop SMPs on new SCA capacity projects where these systems can be fully integrated into building design. The report does not directly address the incorporation of these systems into well-developed building designs, or the implementation of these systems on existing school buildings. However, some aspects of this report, including the comparison of SMP types and the discussion of green roof ballasted PV, may be useful for aiding in the consideration of such systems for existing buildings planned for roof replacement.

In general, decisions about PV canopies and rooftop SMPs must be made no later than the end of Schematic Design so that they can be fully incorporated into structural design, zoning and other approvals, and stormwater permitting. The most important decisions, in order of importance, are (1) extent and height of PV canopy, (2) method of PV canopy connection to building structure, and (3) extent and depth (weight) of rooftop SMP.

In general, this study found that there can be positive synergies between rooftop solar PV canopies and rooftop SMPs, particularly green or blue-green roofs. This study found that there are minimal negative interactions between these systems, although it does recommend against specific combinations of solar PV canopy and SMP types. There are also PV production and PV panel longevity benefits to canopies, which keep panels cooler by promoting air circulation below the panels.

Rooftop Stormwater Management Practices

This report does not recommend specific changes to SCA specifications, details, or design requirements. However, it does recommend that the SCA evaluate the following recommendations through pilot projects to test initial costs, constructability, and impacts on rooftop temperatures, stormwater detention and retention volumes, plant health and longevity, and maintenance:

- Extensive green roofs with 6" substrates, 5%-10% organic matter, and a broad mix of vegetation including succulents and meadow species in order to maximize green roof benefits and longevity
- Built-in-place and hybrid modular systems instead of standard modular systems in order to promote horizontal root growth and water distribution
- Pre-grown vegetation in modular systems, or grown-in-place vegetation in built-in-place systems, instead of pre-grown mats or tiles which limit vegetation options
- Continued use of temporary irrigation systems, combined with the implementation of blue-green roofs and/or solar PV canopies to slow the drying out of green roof soils
- Experimentation with lightweight pavers embedded in green roof growth media in order to maximize green roof stormwater detention
- Experimentation with blue-green roofs that store and transport stormwater into green roof soils via capillary action using specialized wicks, fabrics, or microtubules

Rooftop Solar PV Systems

This report does not recommend specific changes to SCA specifications, details, or design requirements. However, it does recommend that the SCA evaluate the following recommendations through pilot projects to test initial costs, constructability, compatibility with rooftop SMPs and HVAC equipment, and impacts on solar PV energy production and maintenance:

Panel Type

For projects with no rooftop SMPs, bifacial solar panels are recommended. For projects with a green or blue-green roof system without occupant roof access, standard solid monofacial panels are recommended unless the canopy has no spacing between panels and is less than 9 feet above the roof surface. For projects with a green or blue-green roof below a canopy with no spacing between panels that is less than 9 feet above the roof surfaces, or projects with occupant roof access, semi-transparent monofacial panels are recommended.

Panel Orientation

In general, building alignment is recommended for rooftop PV canopies as it accommodates more panels than alignment with the solar azimuth (180° South). A 5°-10° tilt is recommended for most rooftop PV canopy applications. A shallower tilt is acceptable if needed to stay within zoning height limitations; conversely, where zoning height is not a limitation, a steeper tilt can maximize the PV generation of a monolithic array where the panels will not shade each other.

Canopy Arrays

Tilted monolithic arrays, consisting of a single unbroken array of panels on a tilted structure, are recommended to maximize coverage on bulkheads and smaller isolated roof areas with limited mechanical access requirements and no FDNY access requirements, and/or for buildings in R1-R5 zoning districts with lower height limitations for roof obstructions.

“Sawtooth” arrays, consisting of separated rows of tilted panels on a horizontal structure, are recommended for all other conditions, particularly if covering a green roof and/or occupied area where greater daylighting, sky exposure, and more evenly distributed stormwater irrigation are desired.

Tilted monolithic arrays are not recommended to cover large distances in the direction parallel to the tilt (the north-south direction), as this could result in a significant differential between the array’s high and low ends that could exceed height limitations. Tilted monolithic arrays are not recommended over green roofs unless they are at least 9 feet above the roof surface.

Canopy Supports

Concrete PV canopy posts are recommended for tilted monolithic arrays or low sawtooth arrays up to 6 ft in height if the building has a concrete structure (reinforced concrete deck), which allows for some structural and constructability efficiencies. Steel posts are recommended for all other conditions.

Canopy Anchors

Alignment of PV canopy posts with a building’s structural columns or beams is always preferable where feasible, and strongly recommended if the canopy coincides with a green, blue, or blue-green roof system. In general, buildings planned to incorporate PV canopies should use a regular structural grid without excessive spans in order to facilitate an efficient canopy design.

Alignment of PV canopy posts with rooftop mechanical dunnage posts is recommended as a cost-saving measure where feasible, particularly if posts coincide with structural columns or beams, as this will reduce the number of additional roof penetrations required to accommodate the canopy posts.

TECHNOLOGY DESCRIPTION AND APPLICATIONS

This study evaluates the feasibility of implementing three technologies at SCA capacity projects:

1. Solar PV canopies designed to maximize renewable energy yield
2. Rooftop stormwater management practices (SMPs) designed to meet USWR requirements
3. The combined installation of technologies 1 and 2

Consequently, this study investigates several specific products or combinations of products:

- Proprietary and custom-designed solar PV canopy systems
- Proprietary and custom-designed blue-green roof systems
- Proprietary PV support systems with green roof ballast
- Custom-designed PV solar canopy systems installed over blue-green roof systems

Rooftop PV Canopy Systems

Overview

The NYC School Construction Authority (SCA) builds more than 10 new schools or additions every year. Under Local Law 31 of 2016, these projects must be designed to achieve a source energy use intensity (EUI) of no more than 70 kBtu/sf/year. Starting in 2030, this target will be reduced to 38 kBtu/sf/year. Under Local Law 97 of 2019, the SCA is also charged with helping the City of New York to reduce the greenhouse gas (GHG) emissions from City government operations 50% by 2030. Most of these emissions come from energy use in City-owned buildings, including schools. As such, its is critical for SCA Capacity projects to maximize on-site renewable energy production where feasible.

Consolidating obstructions at a building's north end optimizes available rooftop space for ballasted PV. However, rooftop layout optimization for ballasted PV is often limited by elevator placement (dictated by locations of lobby and double-loaded corridor) and HVAC equipment placement (dictated by building HVAC zoning and the need to minimize duct runs and elbows). As a result, many projects are left with small, isolated areas that induce higher cost per Watt ($/W) or are technically unsuitable for PV, requiring the use of a green roof in order to comply with Local Law 94 of 2019.

PV canopies, particularly high canopies at least 9 feet above the finished roof surface (AFR), maximize PV coverage where rooftop layout optimization is not feasible. Additionally, PV canopy systems can be co-located with rooftop SMPs, which are discussed later in this report. The table below compares key characteristics of rooftop PV canopy systems and SCA standard ballasted PV systems.

	PV CANOPY	BALLASTED PV
Coverage	Up to 95% roof coverage	20-60% roof coverage
Limitations	Zoning variances may be required for height, coverage, or setbacks	None
Roof Penetrations	Required for canopy posts	None
Structural Impact	Point loads → larger building columns or beams and/or thicker slab	Distributed loads from ballast → thicker slab
PV Efficiency	Increased by air circulation below panels	Reduced by heat buildup below panels
PV Output	Up to 100% of annual building energy use	5% to 50% of annual building energy use

Current SCA Standards

Section 13602 of the SCA Standard Specification describes the current SCA design requirements for solar PV systems, including equipment modules and manufacturers which have been approved by the SCA. Section 13602 covers all PV system components as well as requirements for field quality control, procedural and safety measures, installation process, and commissioning.

SCA Design Requirements Section 8.0 – *Sustainability and Resiliency*, added in 2022, includes specific guidelines for typical solar PV installations at SCA schools. Per the DR, beginning in the Pre-Schematic phase, project teams shall assess the potential of renewable energy (e.g., solar PV) as part of the Integrative Design Process (IDP) outlined in the 2019 NYC Green Schools Guide. Conducting this process during the Pre-Schematic phase allows SCA design teams to:

- evaluate opportunities for building system synergy,
- satisfy the Onsite Energy Generating Building or Net Zero Building feasibility study requirements of Local Law 31 of 2016, and
- compare options for compliance with Local Law 94 of 2019.

DR 8.0 also covers applicable local laws and regulations, fire code requirements, energy code commissioning and building code progress inspection requirements, zoning requirements, historic building requirements, and permitting and approval procedures for rooftop solar installations. Finally, the Guidelines provide a description of general PV requirements including shading analysis, general design parameters, PV systems on bulkheads, structural analysis, and power distribution.

The NYC Climate Resiliency Design Guidelines (Guidelines) version 4.1, last updated in May 2022, include further recommendations applicable to SCA solar installations. The Guidelines recommend that a minimum of 50% of a project's site area be shaded, vegetated, and/or high solar reflectance surfaces. The Guidelines identify solar PV systems as a design strategy to help combat extreme heat risk by (a) shading the roof or site areas below them and (b) offsetting increased cooling energy requirements.

Rooftop Solar PV Canopy Options and Recommendations

It should be noted that PV parking canopies, which have standardized designs, cannot be mounted on buildings. PV parking canopies rely on structural foundations and wind and seismic loading conditions that are not applicable to building-mounted systems.

Thin-film PV panels mounted to resilient fabric canopies, such as those installed at the New York Botanical Garden, were briefly reviewed but ultimately rejected due to concerns about the durability and wind resistance of such systems when mounted at the top of an SCA building, and about the significantly lower electricity-generating efficiency of the PV panels.

Panel Type: Solid vs Semi-Transparent vs Bifacial

Several types of PV panels may be considered for SCA projects depending on factors including the presence of rooftop SMPs and occupant roof access. For projects with no rooftop SMPs, bifacial solar panels are recommended. Bifacial panels can capture sunlight from both sides of the panel, producing 10%-20% more power than monofacial panels. Bifacial panels are most effective when the mounting surface and surrounding environment has a high albedo, and thus would not be an optimal choice to install in combination with a green roof system.

For projects with a green or blue-green roof system without occupant roof access, standard solid monofacial panels are recommended unless the canopy has no spacing between panels and is less than 9 feet above the roof surface. For projects with a green or blue-green roof below a canopy with no spacing between panels that is less than 9 feet above the roof surfaces, or projects with occupant roof access, semi-transparent monofacial panels are recommended. Semi-transparent photovoltaic technologies provide less PV generation than standard monofacial panels or bifacial panels, but allow for some light penetration to the space below the panels.

PV panel types, from left to right: solid monofacial, semi-transparent monofacial, and bi-facial (credits, from left to right: EME Group, www.onyxsolar.com, www.solarsena.com)

Panel Orientation: Alignment and Tilt Angle

In general, building alignment is recommended for rooftop PV canopies as it accommodates more panels than alignment with the solar azimuth (180° South). A 5° tilt is recommended for most rooftop PV canopy applications. A shallower tilt is acceptable if needed to stay within zoning height limitations;

conversely, where zoning height is not a limitation, a steeper tilt can maximize the PV generation of a monolithic array where the panels will not shade each other.

Building-aligned "sawtooth" PV canopy with 5° tilt angle at Apex Place, Queens (credit: FXCollaborative)

Zoning: Canopy Height and Coverage

While maximum PV coverage of the building rooftop is desired in order to maximize PV production, all NYC zoning districts limit obstructions greater than 4 ft above the finished roof surface – which would include almost any rooftop solar PV canopy – to 25% of the roof lot coverage area (i.e., 25% of the roof area that is not occupied by recreational uses such as play roofs). This limitation does not affect ballasted PV systems, which are generally less than 2 ft above the roof surface.

When NYC's "Zone Green" zoning text amendments were passed in 2012 to facilitate building energy improvements including the installation of solar PV panels on more rooftops, this coverage limitation was imposed because it would maximize PV rooftop coverage below typical roof parapet heights, and therefore below (a) increased wind uplift forces and (b) sightlines from street level. Since 2012, as rooftop solar PV canopies have become more prevalent and the need for increased PV generation has become more urgent, the Urban Green Council and other primary supporters of the original Zone Green have acknowledged that the 25% coverage limit should be a priority for future amendments.

Two PV array types at different heights: Canopy (rear) and Tilt Rack (foreground)
(credit: Brooklyn SolarWorks)

Zoning coverage limitations aside, rooftop solar PV canopy heights can be correlated to zoning height allowances and the desired rooftop coverage area as follows:

- Up to 6 ft (permitted in all zoning districts): Coverage can extend over main roof areas not required for FDNY or mechanical access, bulkheads, restroom exhaust fans, vents, smoke hatches, and split system HVAC components
- Up to 15 ft (permitted over main roofs in R6-10 districts and manufacturing and commercial districts except C3 and C4-1): Coverage can extend over all main roof areas including mechanical and FDNY access (except at parapets) plus all systems covered up to 6 ft
- Greater than 15 ft (requires zoning variance unless below): Coverage can extend over all main roof areas, FDNY access at parapets, bulkheads (where array is up to 6 ft above bulkhead roof), AHUs with side intake and exhaust, kitchen and lab upblast exhaust fans, boiler flues, and all systems covered up to 15 ft
- Coverage at any height should not extend over chillers or AHUs with vertical intake and exhaust

Canopy Arrays: Tilted Monolithic vs Horizontal with Separated Tilted Rows ("Sawtooth")

Tilted monolithic arrays are recommended to maximize coverage on bulkheads and smaller isolated roof areas with limited mechanical access requirements and no FDNY access requirements, and/or for buildings in R1-R5 zoning districts with lower height limitations for roof obstructions.

Sawtooth arrays are recommended for all other conditions, particularly if covering a green roof and/or occupied area where greater daylighting, sky exposure, and more evenly distributed stormwater irrigation are desired.

Tilted monolithic arrays are not recommended to cover large distances in the direction parallel to the tilt (the north-south direction), as this could result in a significant differential between the array's high and low ends that could exceed height limitations. Tilted monolithic arrays are not recommended over green roofs unless they are at least 9 feet above the roof surface.

Sawtooth type canopy at PS in Manhattan, Battery Park City, Manhattan (credit: EME Group)

Canopy Supports: Concrete vs Steel Posts

Concrete PV canopy posts are recommended for tilted monolithic arrays or low sawtooth arrays up to 6 ft in height if the building has a concrete structure (reinforced concrete deck), which allows for some structural and constructability efficiencies. Steel posts are recommended for all other conditions.

Concrete posts (left, credit: www. pvsolarfirst.com) and steel posts (right, credit: FXCollaborative)

Canopy Supports: Rooftop Playground Enclosures

The steel structures that support the enclosures surrounding rooftop playgrounds should be considered for PV canopies, particularly for south-facing play roofs with few adjacent windows that would be shaded by the panels. These structures support vertical netting or fencing (the enclosure “walls”) as well as horizontal netting or fencing (the enclosure “ceiling”) and are typically constructed of large columns and beams that can accommodate the additional structural loads of PV panels.

Rooftop playground enclosure and proposed PV canopy (not implemented) at a PS in Brooklyn (credit: EME Group)

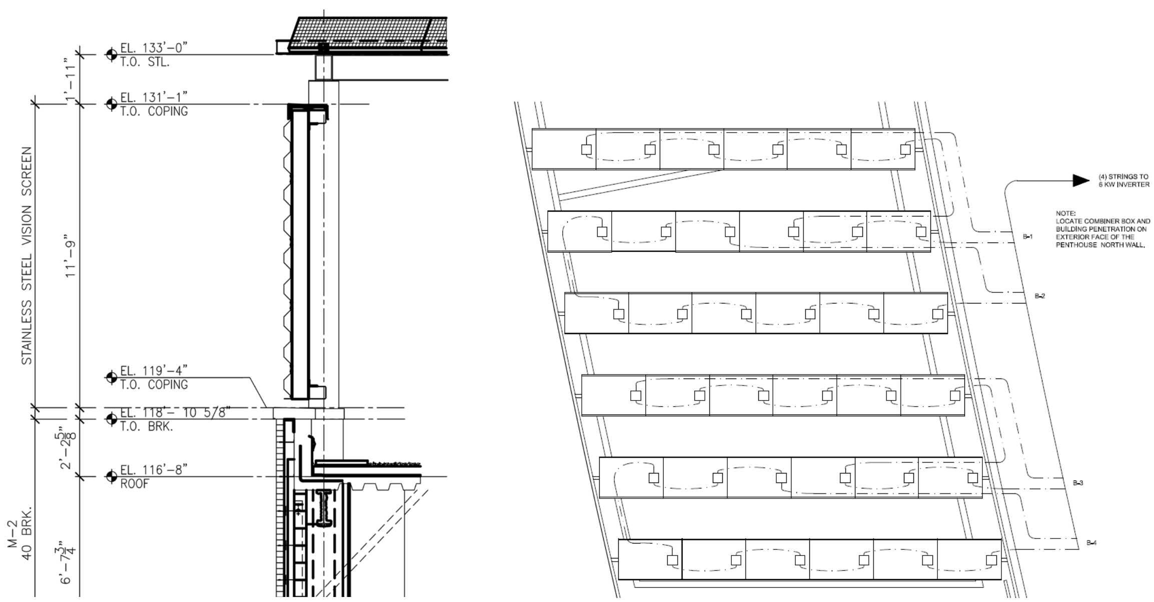
Widely spaced and/or semi-transparent panels with zero or minimal tilt are recommended for such canopies in order to provide direct sunlight to the play roof and/or adjacent windows that would otherwise be fully shaded. Panel support rails should be directly attached to the play roof enclosure structure or, if necessary, to interstitial beams. The horizontal enclosure netting or fencing across the top of the enclosure should be designed to allow for temporary removal in order to allow access to the PV panels from below for maintenance or replacement.

Canopy Anchors: Structural Columns vs Roof Slab vs Mechanical Dunnage

Rooftop PV canopies must be direct attached to a building in order to resist wind and seismic loads. Depending on the canopy size and location, the canopy structure can be attached directly to:

- Building structural columns and/or beams
- Roof deck (i.e., not aligned with building structural columns and/or beams)
- Columns or beams behind rooftop bulkhead walls
- Rooftop mechanical dunnage posts

PV canopies should not be attached to parapets. Anchoring of canopies using ballast (such as steel planters or concrete blocks) is prohibited as such objects are inherently temporary and could be removed in the future.



Canopy at a PS in Manhattan, featuring posts aligned with the building's structural columns

Alignment of PV canopy posts with a building's structural columns or beams is always preferable where feasible, and strongly recommended if the canopy coincides with a green, blue, or blue-green roof system. In general, buildings planned to incorporate PV canopies should use a regular structural grid without excessive spans in order to facilitate an efficient canopy design.

Alignment of PV canopy posts with rooftop mechanical dunnage posts is recommended as a cost-saving measure where feasible, particularly if posts coincide with structural columns or beams, as this will reduce the number of additional roof penetrations required to accommodate the canopy posts.

Attachment of PV canopies to the structural columns or beams behind rooftop bulkhead walls is another way to reduce the number of additional roof penetrations required to accommodate the canopy posts.

Direct attachments of PV canopy elements to building structural elements must incorporate a structural thermal break and air sealing according to NYC Energy Conservation Code (ECC) requirements. Such penetrations are subject to ECC visual inspection requirements for air sealing and insulation.

Rooftop PV canopy design, base building structural design, and rooftop mechanical dunnage design should be coordinated as early as possible in the design process in order to maximize structural efficiency and minimize penetrations of the building's continuous air sealing and insulation layers.

Alternatives to Solar PV Canopies

Solar PV canopies are not the only way to increase the PV generation potential of SCA buildings. Building-integrated photovoltaics (BIPV) may be used in addition to or instead of canopies. Options for BIPV include vertical rainscreen systems for exterior walls, semi-transparent PV-embedded glazing for windows, and the integration of tilted or horizontal, solid or semi-transparent PV panels into canopies over building entrances or awnings over windows. Research into these technologies was beyond the scope of this study.

PV pavers are a relatively new technology that integrates PV cells into structural pavers with an impact-resistant, slip-resistant surface. These pavers are designed to be installed over a leveled concrete foundation or compressed pea gravel bedding, making them unsuitable for incorporation into SCA roof systems. Unlike other forms of BIPV, PV pavers would also reduce the area available for rooftop SMPs.

Proprietary Products and Case Studies

Brooklyn SolarWorks

Brooklyn SolarWorks (BSW) specializes in lightweight PV canopies designed primarily for brownstones and other relatively small buildings with heights of 3 to 5 stories and roof widths of 18' to 24', although their proprietary canopy systems can be installed with larger spans on larger roofs.

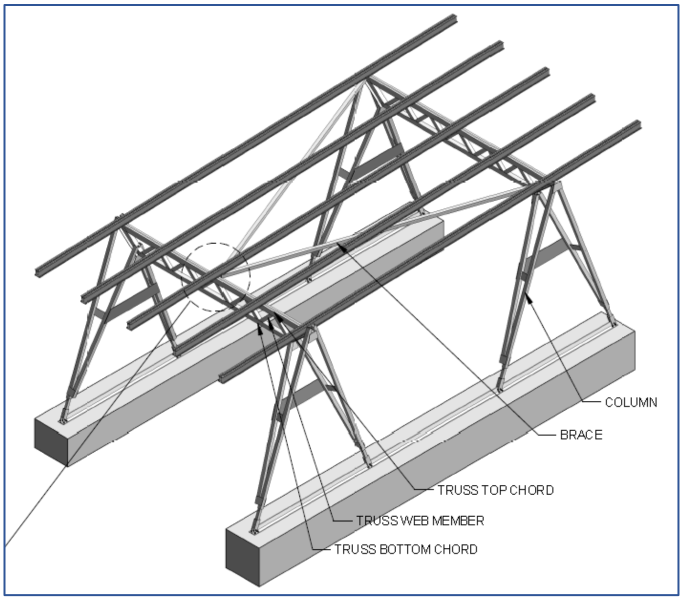
BSW produces, designs, and installs variations on two proprietary systems that maximize structural efficiency. Both systems carry monolithic tilted arrays (panels arranged in a continuous surface) rather than separated rows of tilted panels (a "sawtooth" pattern). Both systems use commonly available aluminum pipes or square tubes, flanges, and stainless steel bolts. Both systems use extruded PV panel support rails provided by BSW (a proprietary design) or by the solar PV panel manufacturer.

The BSW Tilt Rack raises the panels 1 foot above the roof surface at the low end and up to 6 feet at the high end, with a panel tilt of 7, 15, 18, or 30 degrees. There are 4 components to the aluminum structure of the Tilt Rack: vertical posts of varying height; tilted beams connecting the posts; diagonal braces connecting the posts and beams; and PV panel support rails, connected to and perpendicular to the beams. Posts are attached to the roof by pipe flanges or aluminum T-rails. The posts, beams, and braces are constructed from aluminum pipes. Connections are bolted.

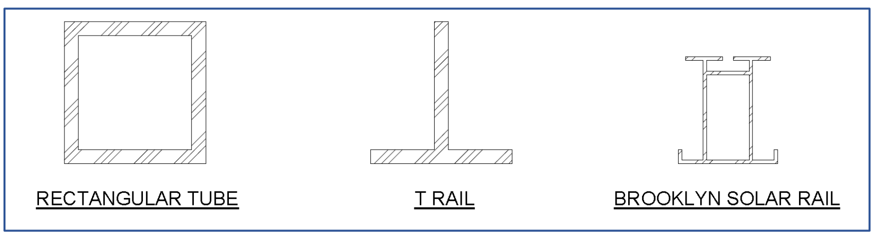
The BSW Canopy raises the panels 9 feet above the roof surface in order to accommodate FDNY access. There are 4 components to the aluminum structure of the Canopy: flat truss beams (generally, simple "Warren" trusses); doubled A-frame posts, braced with aluminum plates, at each end of each truss, connected to the top and bottom chords of the truss ends; PV panel support rails, connected to and perpendicular to the trusses; and diagonal braces connecting the trusses to one another in the horizontal plane. Posts are attached to the roof by common aluminum T-rails (if connected to the roof beams) or by OMG PowerGrip anchor plates (if connected to the roof deck).

The BSW Canopy comes in 3 configurations: with a tilt of 0 degrees; with a tilt of 5 degrees along the truss; or (as illustrated in the diagram and photo below) with a tilt of 5 degrees along the rails. Trusses may span 12' to 33'. Rails may span 10' to 15' between trusses. Truss depths and aluminum thicknesses vary depending on the span. The posts, truss beams, and braces are constructed from welded square aluminum tubes or pipes. Connections are bolted.

Brooklyn SolarWorks Canopy (rear) and Tilt Rack (foreground) PV Arrays



BSW Canopy Diagram (credit: PZSE Structural Engineers)



BSW Canopy System Components (credit: PZSE Structural Engineers)

OMG PowerGrip Anchor Plate with Threaded Fasteners (credit: OMG website)

According to BSW, the Canopy system is rated for winds up to 200 mph in some configurations. The primary limitation on Canopy applications is the roof size and structure. On roofs up to 24’ wide (typical brownstone width), the Canopy supports can be located on or near the roof beam ends, near the beam connections to the loadbearing walls. On roofs greater than 30’ wide, the Canopy supports create point loads that could require roof reinforcement if located midspan of the roof beams.

By contrast, the BSW Tilt Rack system is supported by a larger number of posts, each supporting less weight, and therefore creates smaller point loads. However, the size and placement of Tilt Rack installations, which are much less expensive, is limited by the 6’ maximum height.

BSW encourages its customers to use bi-facial solar panels with its Canopy systems if installed over high-reflectivity roof surfaces in order to maximize PV energy yield.

The BSW Canopy system has not been installed at any schools. A 36-panel BSW Canopy with a customized structure has been installed at the Brooklyn Public Library’s new Greenpoint Library and Environmental Education Center, which opened in 2020.

Brooklyn SolarWorks Case Study: Greenpoint Library, Brooklyn

Brooklyn SolarWorks for Brooklyn Public Library, 2020

(credit: Michael Moran/OTTO via ArchDaily)

Building Type: Library

PV Support: BSW Canopy; bottom of panels approximately 4 ft above roof surface

PV Panels: (36) panels (landscape arrangement) / 5° tilt / 0 separation / 170° azimuth

PV Generation: 13 kW / 16,800 kWh/yr (estimated)

Design Limitations: Top end of canopy limited by zoning to 6’ above bulkhead roof surface. Bottom end of canopy limited by zoning to 15’ above main roof surface.

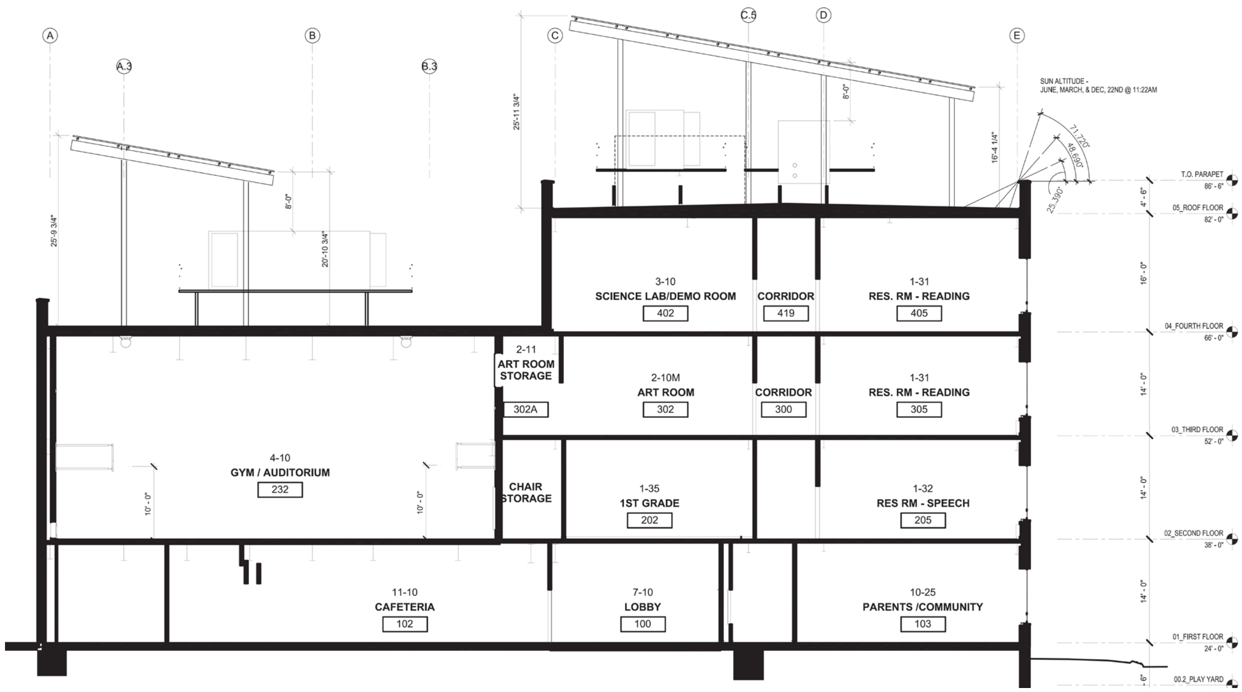
Lessons Learned

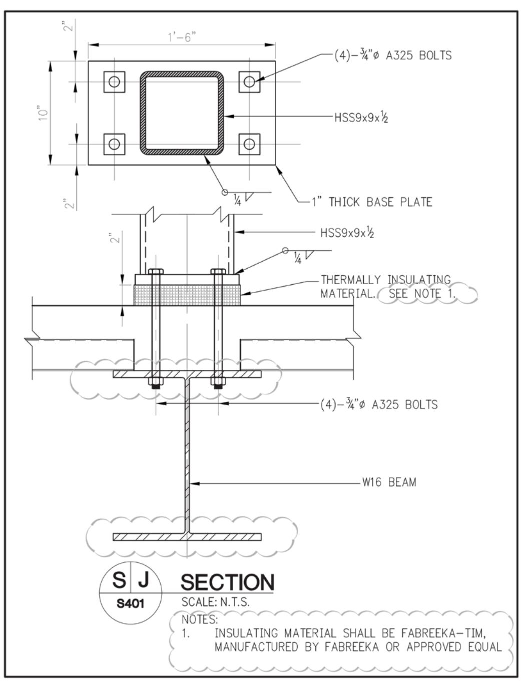
- The tight confines of the available roof area required offset of canopy posts from truss ends. Custom BSW Canopy system design was supported by the project’s structural engineer.
- Canopy visibility from street reinforces the building’s environmental education mission.
- Bi-facial panels cover rooftop mechanical equipment (air source heat pumps).

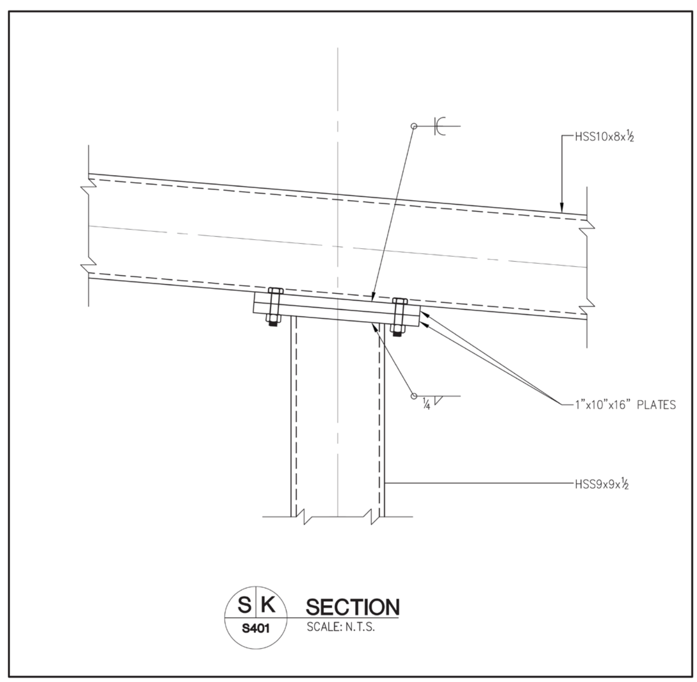
Custom Designs and Case Studies

Canopy at a PS in Queens

FXCollaborative for SCA LL31 Feasibility Study, 2018 (Unbuilt)

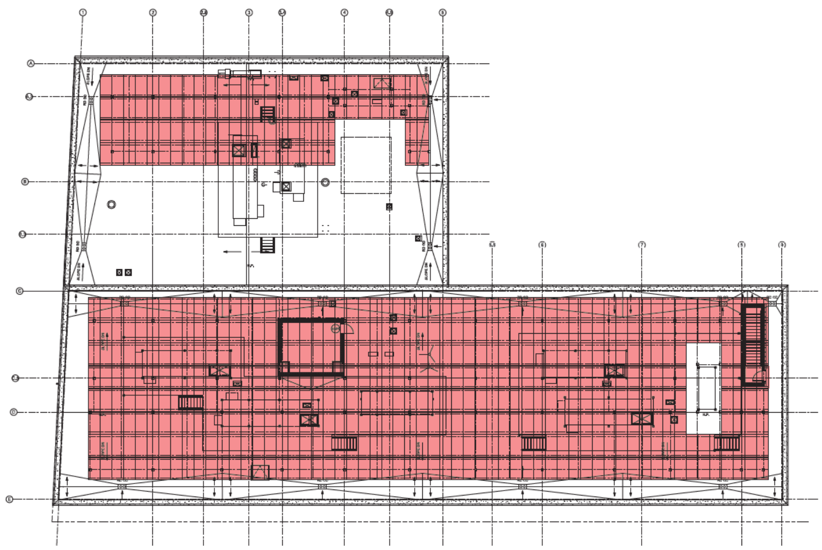






PV canopy section and connection details (credit: FXCollaborative)

PV canopy plan for a PS in Queens without canopy (credit: FXCollaborative)



PV canopy plan for a PS in Queens without canopy (credit: FXCollaborative)

Building Type: School

PV Support: Custom monolithic tilted canopy spanning rooftop AHUs; standard PV rails on grid of HSS 10x8x3/8 beams on HSS 9x9x1/2 posts on 1” plates bolted to W16 building structural beams through structural thermal break material

PV Panels: (552) panels (landscape arrangement) / 10° tilt / no separation / 152.62° azimuth

PV Generation: 253 kW / 322,911 kWh/yr (estimated)

Design Limitations: PV panels are omitted over equipment that requires open sky, such as the emergency generator and chiller. The analysis did not address zoning limitations, lateral loads on the canopy, or impacts to the building structure supporting the canopy.

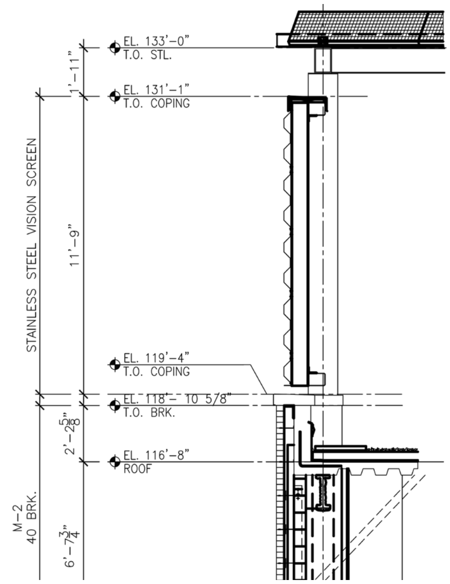
Cost (Estimated): $3.32/W for entire PV system + $6.48/W for steel structure

Lessons Learned

- Most PV canopy posts are connected to the building’s structural beams, but some are supported by the roof slab alone. Implementation would likely require increased roof slab thickness and reinforcement, and deeper roof beams.
- A complete analysis of wind and seismic loads would likely result in much larger canopy beams and columns than illustrated, particularly at the upper roof, as well as the addition of diagonal bracing to accommodate the significant lateral forces on a canopy over 25 ft in height, which would be reflected in higher material and labor costs for the steel structure.

Canopy at a PS in Manhattan, Battery Park City, Manhattan

Dattner Architects and Ysrael A. Seinuk PC for SCA, 2010



Building Type: School

PV Support: Custom canopy; HSS4x2x3/15 panel supports on HSS6x4 purlins on HSS12x6 beams on W12x35 girders supported by HSS14x14 posts on steel plates connected to roof deck immediately above building's structural columns; bottom of panels approximately 2 ft above roof surface at bulkhead (photo above at left), 16 ft at screened mechanical equipment enclosure (drawing above at right), and 34 ft at classroom terrace.

PV Panels: (126) standard 315W panels and (36) 186W custom semi-transparent panels (landscape arrangement) / 15° tilt / 3.3 ft separation / 180° azimuth

PV Generation: 39.7 kW / 52,800 kWh/yr (standard panels, estimated) and 6.7 kW / 8,900 kWh/yr (semi-transparent panels, estimated)

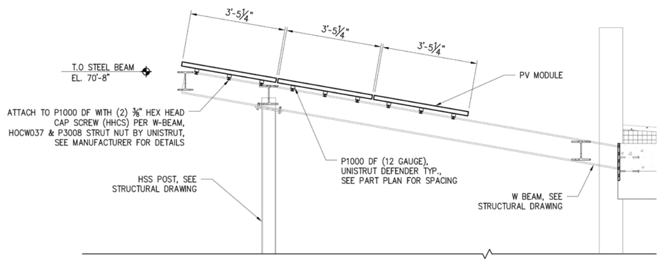
Design Limitations: Tops of panels are just below the 135 ft maximum building height per zoning (BPC A1 District). Semi-transparent panels are located high above an outdoor terrace which has southern and western exposure.

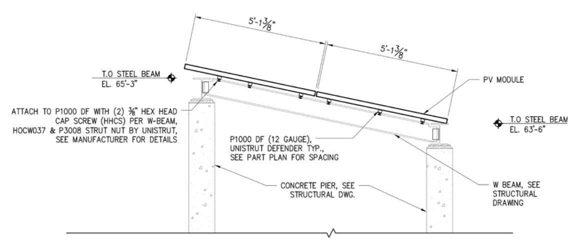
Lessons Learned

- Canopy structure appears to be massively overbuilt for wind loads.
- Most panels are shaded until mid-day by tower on adjacent property to the south.

Canopy at a PS in Queens

EME Group for SCA, Under Construction





Building Type: School

PV Support 1 (above left): Custom canopy; Unistrut P1000 rails on W10x39 beams supported at one end by W8x40 girder on HSS8x6x3/8 posts bolted to roof deck and at other end by steel plate embedded in bulkhead roof slab; bottom of lowest panels 14.5 ft above roof surface.

PV Panels 1: (27) commercial 475W panels (landscape) / 10° tilt / no separation / 132° azimuth

PV Support 2 (above right): Custom canopy; on Unistrut P1000 rails on W8x40 beams on W10x39 girders supported by 12”x12” reinforced concrete piers tied into roof deck; bottom of lowest panels 8.5 ft above roof surface (not within FDNY landing or access areas).

PV Panels 2: (20) commercial 475W panels (portrait) / 10° tilt / no separation / 132° azimuth

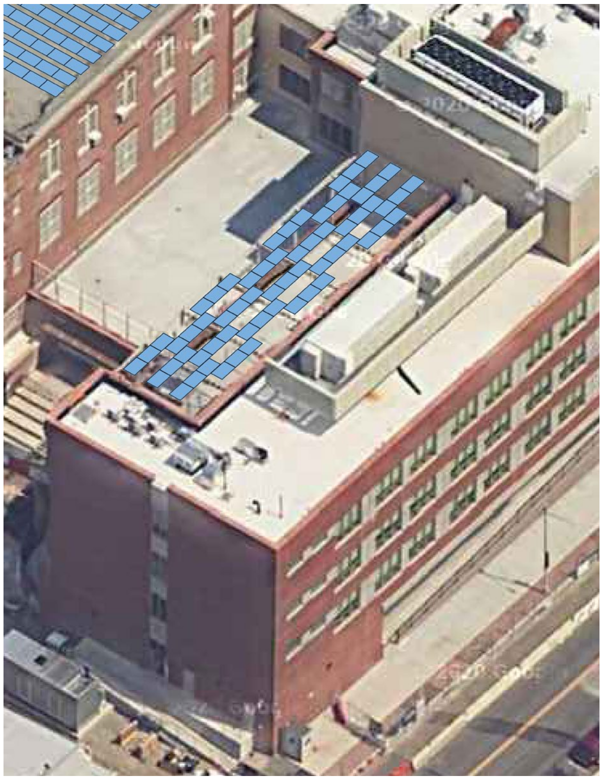
PV Generation: 22.3 kW / 29,500 kWh/yr (estimated)

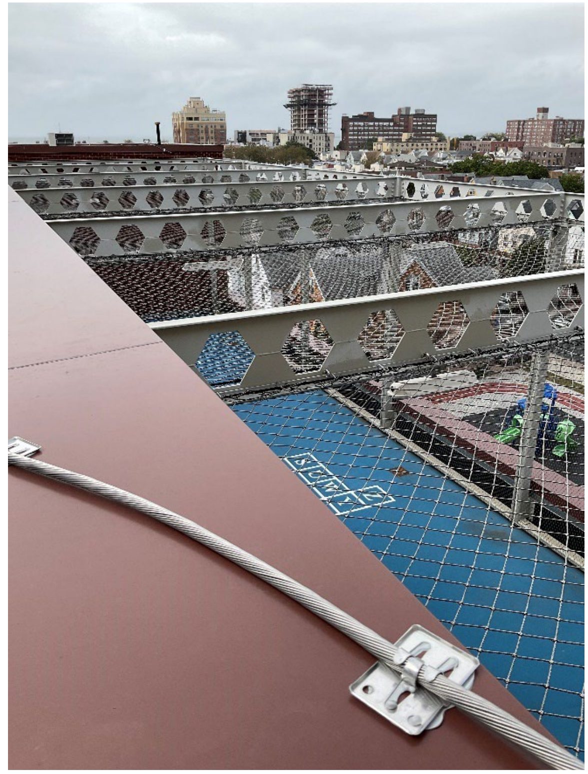
Design Limitations: Canopies were required to raise panels above shadows of bulkhead (Support 1) and HVAC equipment or parapet (Support 2) in areas that otherwise would have been required to have green roofs in order to comply with LL94. The top of PV Support 1 is over 16 ft above roof surface but the 69.5 ft high building already required a zoning height variance from the District R5D limit of 40 ft.

Lessons Learned

- Three different PV systems (steel post canopy, concrete pier canopy, and ballasted) necessitated by LL94 compliance and poorly optimized rooftop bulkhead and equipment layouts.
- Contractor proposed utility-scale bi-facial Q Cells Q.Peak Duo XL-G10.3 475W panels (87.2”x39.4”) with 21.4% efficiency instead of standard residential SunPower X22 360W panels (61.3”x41.2”) with 22.2% due to availability, necessitating a change in canopy design.

Canopy at a PS in Brooklyn
EME Group for DOE DSF (Unbuilt)





Building Type: School

PV Support: Custom canopy on structure of existing rooftop playground enclosure; PV panel support rails attached to existing CB18x22 girders supported by HSS8x8x1/2 posts; bottom of panels approximately 20 feet above play roof surface

PV Panels: (63) 370W panels in groups of 3 (portrait checkerboard arrangement) / 0° tilt / no separation (within groups of 3) / 128° azimuth

PV Generation: 327 kW / 98,300 kWh/yr (estimated)

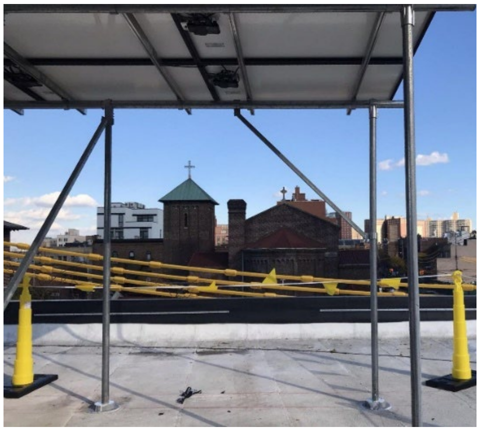
Design Limitations: Zoning would have allowed panels to be mounted up to 6 feet above the play roof enclosure. Primary limitation was structural due to capacity of existing beams. Structural limits required large openings between groups of panels, which also provided sunlight for the play roof.

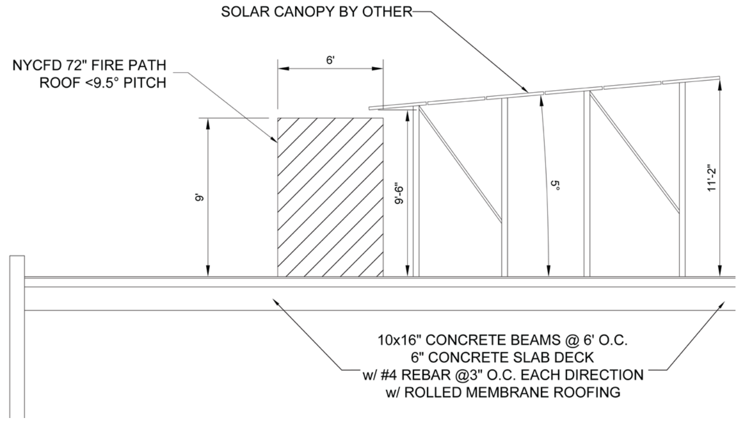
Lessons Learned

- Not selected for the school due to shading of play roof which was not preferred for this particular site, as it was already partially shaded by adjacent rooftop equipment for much of the day.
- Would have required existing play roof enclosure cable netting (attached to bottom chord of existing castellated beams) to be replaced with removable or hinged panels in order to provide maintenance access to PV panels from below.

Canopy at Coney Island Library, Brooklyn

ARC Design for DCAS and Brooklyn Public Library, 2021





(credit: DCAS)

Building Type: Library

PV Support: Custom canopy added to existing building; square steel tube beams and braces supported by steel pipes, connected to concrete deck; bottom of panels 9.5 ft above roof surface

PV Panels: (60) panels (landscape arrangement) / 5° tilt / 0 separation / 261° azimuth

PV Generation: 21 kW / 26,000 kWh/yr (estimated)

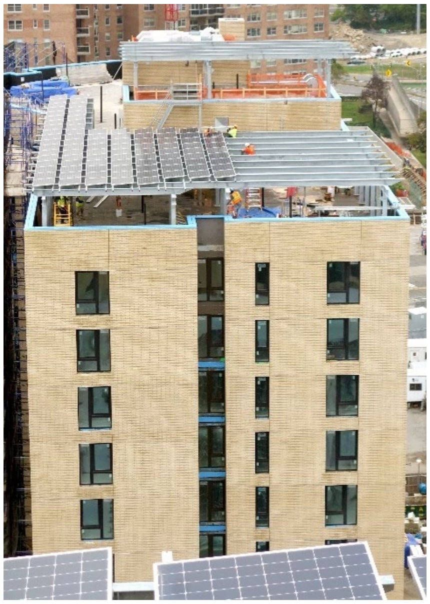
Design Limitations: Required zoning height variance, as top end of canopy was limited by R5 District zoning to 6’ above roof surface (building already exceeded maximum zoning height). Canopy edges were held back from all roof edges (even where not required by zoning or FDNY) to reduce wind loads.

Lessons Learned

- Low building height and location away from roof edges allowed for use of an extremely lightweight structure due to reduced wind loads. Structural analysis was not provided.
- Although high enough, canopy only slightly overlaps with FDNY access routes. Diagonal braces prevent clear passage through some parts of the canopy structure.
- Canopy is tilted in east-west direction for rain shedding. Tilting in the longer north-south direction would have maximized PV production but would have increased canopy height.
- Canopy was paired with 12kW rooftop battery as part of DCAS energy resiliency program.

Canopy at Apex Place, Forest Hills, Queens

FXCollaborative, Curtis + Ginsberg and Bright Power for Apex Place Associates, 2022



(credit: FXCollaborative)

Building Type: Multifamily residential

PV Support: Custom canopy; PV panel support rails on W12x14 purlins with tapered ends on W12x26 beams, with doubled L4x4x3/8 steel angle 45° diagonal braces, supported by HSS 6x6x5/16 columns on 3/4" steel base plate bolted to concrete deck. A separate canopy covers the boiler room bulkhead. Bottom of lowest beam approximately 10 ft above main roof or bulkhead roof surface.

PV Panels: Building A (362) panels, Building B (400) panels, Building C (298) panels (landscape arrangement) / 5° tilt / 0.75 ft separation / 155° azimuth

PV Generation: 381.6 kW / 475,000 kWh/yr (estimated)

Design Limitations: No height limit for canopy. Tapered canopy edges extend over parapets for aesthetic purposes. FDNY perimeter access rules do not apply as building is more than 100' high, but access is required around rooftop bulkheads and equipment.

Lessons Learned

- Concrete deck was thickened by 4" with additional reinforcement to support canopy posts, which were not aligned with the building structure. This change was not included in the cost estimate.
- Extensive studies determined the optimal panel tilt angle, separation, and orientation (building aligned vs. azimuth aligned) for maximum PV yield.
- Canopy was treated as a design element, not strictly functional, and therefore may be overbuilt.

Rooftop Stormwater Management Practices (SMPs)

Overview

Green roofs are systems consisting of vegetation, growing media (i.e. soil), filtration media, and drainage media, and can be applied to flat or minimally sloped roofs. For stormwater management, green roofs can provide multiple functions including:

- Retention, via the uptake and release of water by plants (evapotranspiration)
- Detention, via the temporary storage and slow release of water by the growing media and drainage media
- Filtration, via the movement of water through the growing media and geotextile layers

In addition to stormwater management, green roofs can provide benefits including but not limited to:

- Reduced temperature flux
- Reduced heat island effect (green roofs are considered “cool” roofs)
- Cooler microclimate, which can improve the performance of rooftop mechanical equipment
- Increased thermal resistance, which can reduce the building’s cooling and heating loads
- Added UV and wearing protection for the roofing membrane
- Filtration of air and stormwater pollutants
- Amenity for rooftop occupancy
- Support for local biodiversity
- (Limited) agricultural use
- Educational value

Blue roofs are flat roofs with the ability to temporarily store stormwater and slowly drain through check-dams, modular structures or “cells” with voids, and/or restricted-flow roof drains. The water may be stored above all roof layers or below a raised walking surface such as pavers on pedestals. The water must be released within a limited period of time (typically 24 hours or less) in order to prevent the potential hazards of standing water, including leaks, structural impacts, obstruction of roof accessibility and maintenance, and growth of mold, microbes, and mosquito larvae.

Blue roofs do not provide filtration, thermal resistance, biodiversity support, or many of the other benefits of green roofs. If constructed with a high-albedo surface, they can reduce heat island effect, but this is a function of the surface and not the blue roof per se. Evaporation of the stored water can provide a cooler microclimate, but this is limited due to the temporary nature of the storage.

Green/Blue roofs are green roofs installed atop a water detention layer with restricted-flow roof drains. The water detention layer may be a granulated material such as gravel, a porous material such as rock wool, or, most typically, modular structures or “cells” with voids. The green roof growth media is typically separated from the detention layer with a geotextile layer and air gap to prevent long-term soil saturation that could lead to rotting of the plants, while roots may grow through the geotextile to reach the detention layer. Blue-green roofs may be designed with wicks, capillaries, or other components to allow the stored water to passively irrigate the green roof vegetation from below.

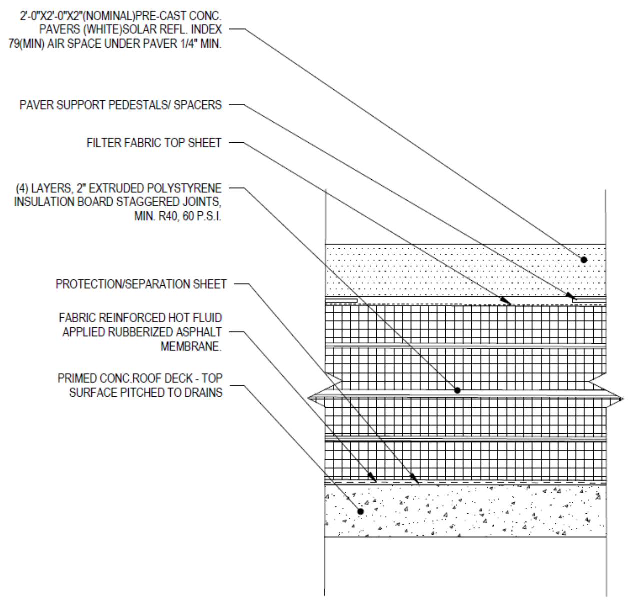
Current SCA Standards

The current SCA standard roof consists of the following layers and minimum thicknesses, sitting atop the structural roof slab and lightweight screed concrete slope:

1. Roof Membrane*, rubberized asphalt, 215 mils (about 0.25”)
2. Protection Sheet*, rubberized asphalt, 50 mils (about 0.05”)
3. Root Barrier (may be combined with Protection Sheet), polyethylene/polypropylene, 10-20 mils (about 0.02”)
4. Drainage Mat*, molded plastic with geotextile facing, 0.25”-0.50”
5. Insulation*, extruded polystyrene (XPS), 8”

6a. Roof Pavers, precast concrete, 4.25-4.75” total (0.25” air space plus two layers 2.0”-2.25” pavers on rigid plastic setting blocks) OR

6b. Cementitious-Topped Roof Insulation, tongue-and-groove latex-modified concrete bonded to top layer of insulation, 1” in addition to insulation thickness



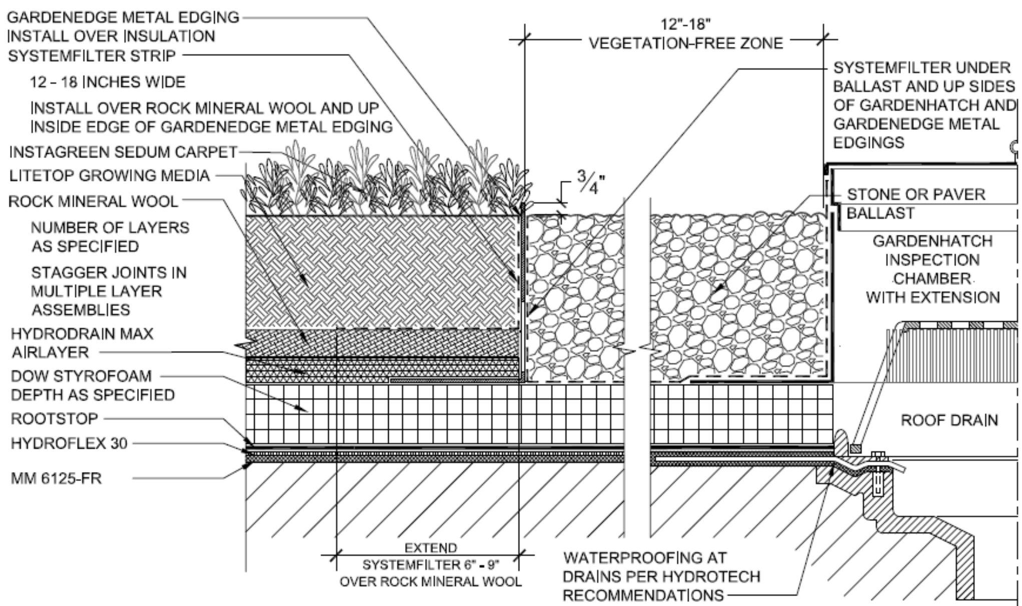
SCA Standard Roof Illustration

The SCA specification for exposed roof pavers calls for an initial SRI of at least 82. (Pavers located under mechanical equipment are permitted to have a lower SRI.) The SCA specification for cementitious-topped roof insulation calls for an integral coating with an initial SRI of at least 82 or a field-applied coating with an SR of at least 0.7. Both roof surface types comply with the NYC Cool Roofs Law.

The SCA originally intended to use cementitious-topped roof insulation only for roofs with ballasted PV panels, as the panels and their ballast provided additional ballast. However, the SCA has determined that the tongue-and-groove construction of the cementitious-topped roof insulation provides sufficient resistance to wind uplift without any additional ballast, and is considering more widespread use of this roof surface due to its simplicity and lighter weight.

The current SCA standard green roof includes the following layers above the insulation:

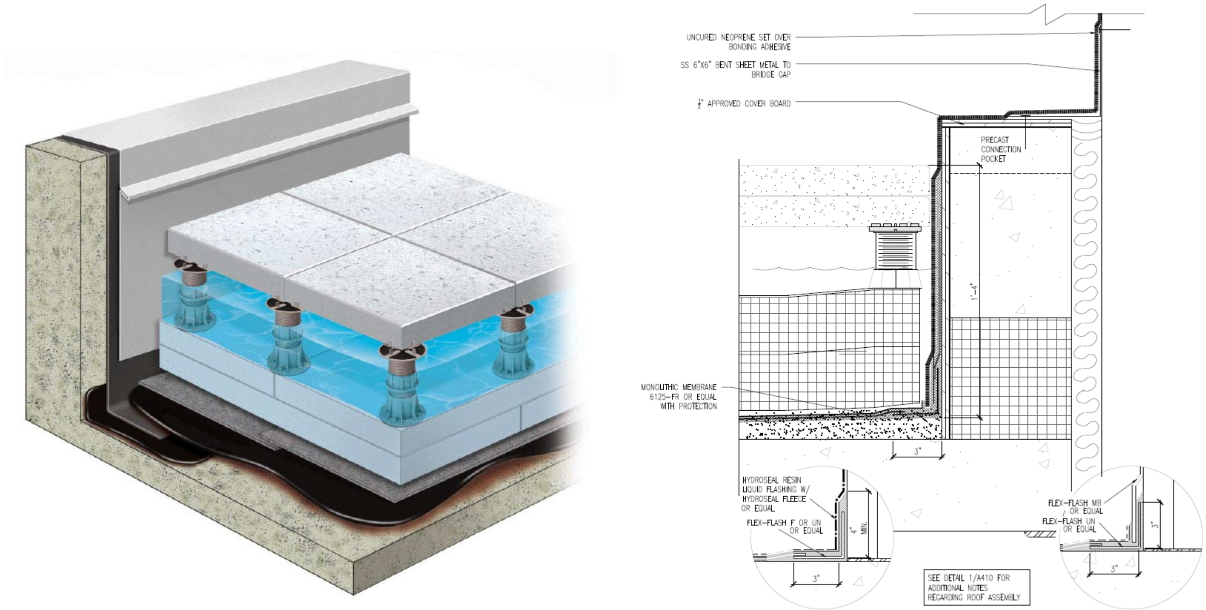
6. Air Layer Composite (if required by roofing manufacturer), polyethylene, about 0.125”
7. Drainage and Water Retention Mat, rigid molded plastic with geotextile facing, 0.25”-2.00” (available up to 10”; typically 0.5”)
8. Filter Fabric, polyethylene/polypropylene, 50 mils (about 0.05”)
9. Growing Substrate, compacted mineral aggregates (volcanic pumice, expanded shale, expanded clay, sand) and organic material, 4” minimum (may vary due to slope)
10. Vegetation, typically a mix of Sedum (aka Stonecrop) species delivered as a pre-grown mat, 1” (thickness may be incorporated into growing substrate)



SCA Standard Green Roof Illustration (PS in Brooklyn)

The current SCA standard blue roof includes the following layers above the insulation:

6. Air/Water Detention Space with Adjustable Roof Paver Pedestals, 3” min. (typically 1”-2” average water depth + 1”-4” air space; varies due to slope)
7. Roof Pavers, precast concrete, 4-4.5” total (two layers 2.0”-2.25” pavers)



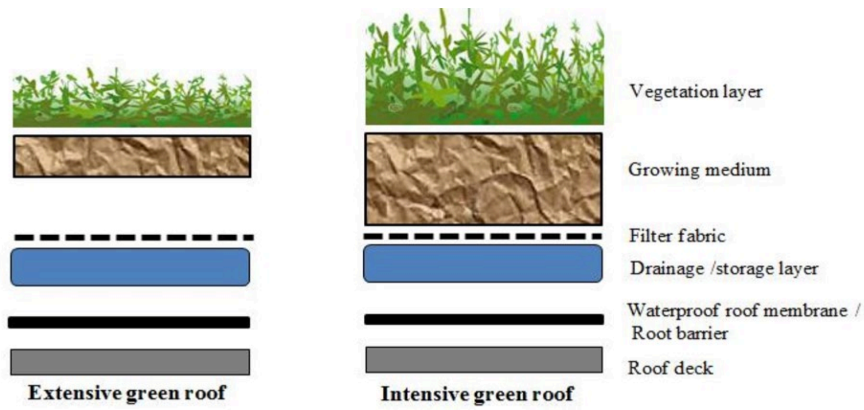
SCA Standard Blue Roof Illustration

Summary of Standard SCA Roof Types

	SCA Standard	SCA Green	SCA Blue
Total Thickness	10”-14”	14”-16”	16”-18”
Thickness Above Insulation	1”-5”	5”-7”	7”-9”
Total Weight (Dry)	30 psf	10-25 psf	30 psf
Total Weight (Wet)	30 psf	20-45 psf	35-45 psf

Rooftop SMP Options and Recommendations

Green Roofs: Extensive vs Intensive



Illustrations of Extensive (left) and Intensive (right) Green Roofs (credit: www.semanticscholar.org)

The current SCA standard is an extensive green roof with 4” of compacted substrate. Typical extensive green roofs are 4”-6” deep, although systems as shallow as 2” and as deep as 8” are possible.

Intensive green roofs are thicker, with a typical growing substrate of 12” or more. Advantages include:

- more water detention
- more thermal mass
- reduced vulnerability to freezing
- ability to support a much wider variety of vegetation including woody plants, which provide:
    - more water retention via sequestration and transpiration
    - more microclimate cooling
    - more biodiversity
    - more carbon sequestration

Disadvantages of intensive green roofs include:

- generally must be built-in-place systems
- increased irrigation requirements
- more intensive plant maintenance
- reduced access and visibility in heavily vegetated areas
- increased vulnerability to high winds
- much greater weight

For SCA projects, this study recommends extensive green roofs. Test cases for this study will assume the use of an extensive green roof.

Green Roofs: Growing Substrate and Vegetation

Illustrations of 4" Substrate with Sedum (left) and 6" Substrate with Mixed Grasses (right)
(credit: www.liveroof .com)

The current SCA standard is 4" of compacted substrate with minimal organic matter (0%-5% by dry weight) i.e. mulch mixed with loam, compost, or biochar. This can support low-growing drought-resistant plants and succulents such as Sedum (aka Stonecrop) and mosses, which sequester relatively large amounts of water but release it only at night, reducing their potential for transpiration.

The current NYC Department of Parks and Recreation (DPR) standard is soil with 20% organic material, weighing between 25-60 lbs/cf. According to DPR, sedum is inexpensive, low-maintenance, and can be walked on, whereas native species such as grasses, herbs, and small perennials produce less dust and have increased microclimate cooling impacts.

A substrate thickness of 6" with more organic matter (5%-15%) was considered as a potential alternative for this study. Advantages include:

- recommended by the USWR
- more water detention
- more microclimate cooling
- ability to support a wider variety of vegetation including some meadow species such as grasses and small perennials, which release water throughout the day and night and provide:
  - slightly more water retention via transpiration
  - slightly more microclimate cooling
  - slightly more biodiversity
  - slightly more carbon sequestration
- less dust, which impacts solar PV panel productivity

Disadvantages of a 6" extensive green roof with more organic matter include:

- slightly reduced access and visibility in heavily vegetated areas
- more soil shrinkage due to increased organic matter
- more variability in plant biomass production due to increased organic matter
- greater weight, depending on the soil mixture used

For SCA projects, this study recommends experimentation with 6” substrates with 5%-10% organic matter and a broad mix of vegetation including succulents and meadow species. Test cases for this study will assume the use of a 6” substrate with 5% organic matter and a broad mix of vegetation.

Green Roofs: Modular vs Built-in-Place Systems

Illustrations of Modular (left) and Built-in-Place (right) Green Roof Systems
(credit: www.wallbarn.com, Kansas State University Architecture, Planning, and Design)

The current SCA standard is modular trays, although built-in-place green roofs are also used. Advantages of modular green roofs include:

- ease of installation
- ease of removal for access to roofing materials below or installation of new equipment
- may offer pre-grown vegetation which requires less initial maintenance

Disadvantages of modular green roofs include:

- reduced water retention due to limited horizontal flow
- reduced plant health due to limited horizontal root growth
- design limitations of a modular layout
- substrate thickness limited to 8” maximum
- higher lifecycle costs due to plastic trays
- higher material cost

Like modular systems, built-in-place systems can be procured from a single source to ensure ideal performance and compatibility of materials. However, built-in-place systems can be built to any depth. Advantages include:

- increased water retention and detention
- improved long-term plant health due to horizontal root growth and migration of water, nutrients, and beneficial organisms
- elimination of modular design limitations, which should allow for greater overall roof coverage
- lower material cost

Disadvantages of built-in-place green roof systems include:

- need for a crane to lift bulk materials to the roof (although modular green roofs may also use cranes to lift pallets of modules)
- difficulty of removal, which requires the careful use of hand tools
- may require more initial maintenance for successful plant establishment

Hybrid modular systems are trays with thin plastic side panels that can be removed after installation, creating large openings between adjacent trays. These systems can provide the installation advantages of modular systems and, over time, the stormwater management and long-term plant health advantages of built-in-place systems.

For SCA projects, this study recommends experimentation with built-in-place and hybrid systems procured from a single source. Test cases for this study will assume the use of a built-in-place system.

Green Roofs: Pre-grown vs Grown in Place Vegetation

Illustrations of Grown in Place (left) and Pre-Grown Mat (right) Vegetation
(credit: www.architek.com, www.constructioncanada.net)

Modular green roofs typically include pre-grown plants in the modules and can even include mature plant communities. Advantages of pre-grown plants include:

- increased initial and long-term water retention via evapotranspiration
- reduced initial maintenance
- wide variety of vegetation options
- better resistance to wind uplift and water erosion due to well-established root systems

Disadvantages of pre-grown plants include:

- higher material cost
- cannot be used in built-in-place green roof systems

Built-in-place green roofs are typically initially vegetated with immature plants or, in some cases, seed mixtures into the soil. Advantages of such grown-in-place plants include:

- unlimited variety of vegetation options

- lowest material cost

Disadvantages of grown-in-place plants include:
- vulnerability to wind uplift and water erosion prior to establishment
- bare spots and reduced initial water retention until plants propagate

Both modular and built-in-place systems can be built with pre-grown green roof tiles or mats, which typically consist of a 1” thick mat of low-growing, moss-like species grown in mostly organic soil, held together with plastic or coco fiber netting. The tiles or mats are laid on top of the growing media in modular trays or built-in-place systems. Some pre-grown systems use only a minimal amount of soil, depending instead on a material such as mineral wool to support plant roots. Advantages of pre-grown tiles or mats include:
- reduced initial maintenance
- can be used in both modular and built-in-place green roof systems

Disadvantages of pre-grown tiles or mats include:
- vulnerability to wind uplift and water erosion prior to establishment
- limited variety of vegetation options
- reduced long-term water retention
- poor long-term plant health outcomes for pre-grown systems with minimal soil

For SCA projects, this study recommends the use of pre-grown vegetation in modular trays. Test cases for this study will assume the use of pre-grown vegetation in modular trays. This study does not recommend the use of pre-grown green roof tiles or mats.

Green Roofs: Temporary vs Permanent Irrigation

All green roofs require some irrigation during the initial plant establishment period of 1 to 3 years and most will also require irrigation during long periods of hot, dry weather, which is why SCA requires the installation of non-freeze exterior hose bibbs at all green roofs (SCA DR 4.4.2.4.C). While temporary irrigation is generally sufficient for extensive green roofs, intensive green roofs (greater than 6 inches deep) typically require permanent irrigation.

Green roofs with permanent irrigation systems designed to keep the soil from drying out have potential benefits including:
- increased thermal resistance (R-value)
- decreased temperature flux (more stable roof temperature)
- increased microclimate cooling (due to increased evapotranspiration)
- increased plant growth density and soil coverage, yielding less wind erosion
- healthier, longer-lived plants

These benefits are greater for overhead spray rotor irrigation systems than for sub-irrigation and drip irrigation systems.[1]

Because temporary or permanent irrigation is generally provided during dry periods when plants and soils rapidly evapotranspirate any water, it does not decrease the capacity of a green roof to provide stormwater detention.

Assuming proper selection of plants, water use by permanent green roof irrigation systems is minimal and should not exceed the thresholds for GSG outdoor water use reduction credits. According to the U.S. General Services Administration report on green roofs in temperate climates, a 6-inch deep green roof requires irrigation of approximately 5 gallons per square foot per month from March through November[2].

Permanent irrigation, and particularly spray irrigation, is generally discouraged for SCA projects due to the added expense, complexity, and maintenance requirements. There is some scientific literature[3] that suggests that the added energy use of pumping water for green roof irrigation systems can be exceeded by the cooling energy savings provided by irrigated green roofs when compared to a standard high-reflectivity roof. However, these studies did not take into account the SCA's requirement for R-40 roof insulation on capacity projects.

As noted below, the use of a blue-green roof system can eliminate the need for permanent irrigation. The use of solar PV canopies over green roofs can further reduce green roof irrigation requirements by shading and slowing the drying-out of green roof soils.

For SCA projects, this study recommends continued use of temporary irrigation. Test cases for the study will assume no permanent irrigation.

Blue-Green Roofs

Under the USWR, green roofs alone cannot meet the Vv requirements of CSS areas. Blue roofs, which can meet Vv requirements, do not satisfy the WQv USWR requirement. Therefore neither green nor blue roofs alone can satisfy all USWR requirements, although the combination of green or blue roofs with at-grade or sub-grade stormwater management systems can.

There is a growing body of research exploring the potential of blue-green roof technology to maximize the utility of roof areas for diverse sustainability goals including stormwater management, urban microclimate cooling, and biodiversity. For some SCA projects, these systems have the potential to satisfy all USWR requirements for an entire site using the roof surface alone.

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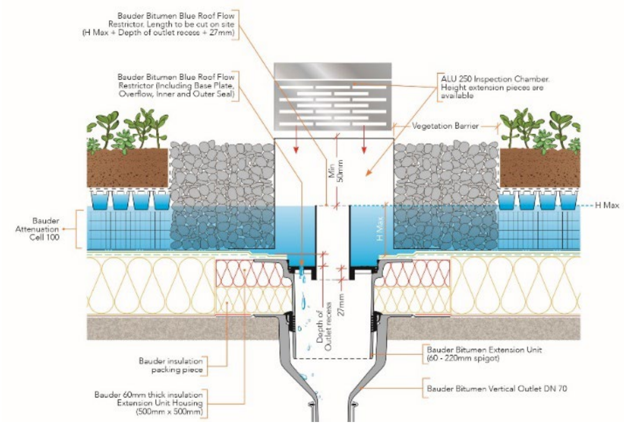
[1] Comparison of Irrigation Efficiency and Plant Health of Overhead, Drip, and Sub-Irrigation for Extensive Green Roofs, Rowe, Kolp, Greer and Getter, *Ecological Engineering* volume 64, March 2014, pp 306-313

[2] *Benefits and Challenges of Green Roofs on Public and Commercial Buildings*, U.S. General Services Administration and Arup, Roofmeadow, Pennsylvania State University, University of Toronto Centre for Climate Change, Columbia University Center for Climate Systems Research, and Lawrence Berkely National Laboratory, 2011

[3] How Green Roofs Partition Water, Energy and Costs in Urban Energy Air Conditioning Budgets, Mankiewicz, Spartos and Dalski, July 2019



Illustrations of Blue-Green Roof Assemblies (credits: ICB Projects (left), Bauder (right))

A Dutch study[4] published in 2018 compared the water and energy balance of a conventional green roof with blue-green roofs equipped with a novel storage and capillary irrigation system. The study concluded that the blue-green roof systems showed a large evaporation rate for systems with sedum vegetation, and a larger evaporation rate for systems with grasses and herbs. The study also found that precipitation storage and capillary irrigation reduced the number of days with dry-out events, which could lead to improved cooling effects for the building.

Another Dutch study[5] published in 2022 compared a conventional green roof and two blue-green roofs with rockwool fiber capillary systems, one with a 4cm substrate layer and the other with 8cm. The study concluded that the resultant water retention of each system type was approximately 12%, 59%, and 70-97%, respectively. The study also found that blue-green roofs yield higher evapotranspiration rates on hot summer days (around 70%) compared to conventional green roofs (30%).

Blue-Green Roof Installation by Permavoid, Margeretha Gardens, Holland (credit: www.permavoid.co.uk)

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[4] Evaporation from (Blue-)Green Roofs: Assessing the Benefits of a Storage and Capillary Irrigation System Based on Measurements and Modeling, Cirkel, Voortman, van Veen, and Bartholomeus, MDPI *Water* volume 10, 2018

[5] Blue-Green Roofs with Forecast-Based Operation to Reduce the Impact of Weather Extremes, Busker, de Moel, Haer, Schmeits, van den Hurk, Myers, Cirkel, and Aerts, *Journal of Environmental Management* volume 301, 2022

As noted above, for some projects, blue-green roofs with wicking may be able to satisfy all USWR requirements in both CSS and MS4 areas, eliminating the need for at-grade or below-grade systems. Additional advantages of blue-green roofs with wicking include:

- all of the advantages of modular green roofs with pre-grown vegetation
- most of the advantages of permanent irrigation, without the need for an irrigation system
- can satisfy DEP USWR Vv requirements at the highest tier (Tier 1) of SMPs
- saturated weight is similar to weight of an SCA standard blue roof

Disadvantages of blue-green roofs with wicking include:

- all of the disadvantages of modular green roofs with pre-grown vegetation
- use of plastic (typically recycled HDPE) in stormwater detention cells as well as green roof trays

While initial research exploring the feasibility and efficacy of blue-green roof technology has shown promising results, additional study is necessary to assess scalability and efficacy in a climate similar to that of the NYC metro area.

Overview Comparison of Green, Blue, and Blue-Green Roofs

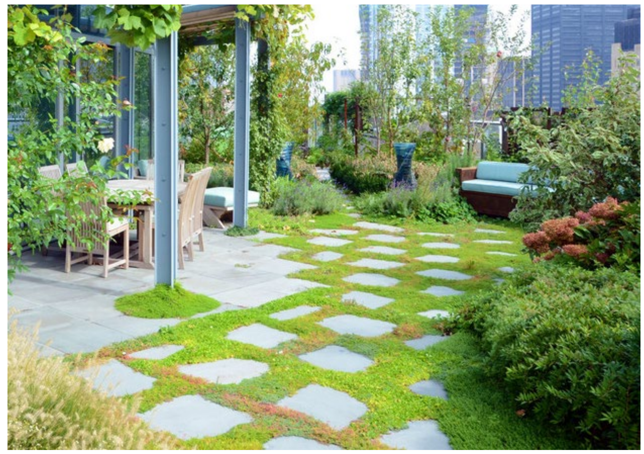
<table>
<tr><th></th><th>SCA Green</th><th colspan="2">SCA Blue</th><th>Blue-Green</th></tr>
<tr><td>Total Thickness</td><td>14”-16”</td><td colspan="2">16”-18”</td><td>18”-24”</td></tr>
<tr><td>Thickness Above Insulation</td><td>5”-7”</td><td colspan="2">7”-9”</td><td>9”-15”</td></tr>
<tr><td>Total Weight (Dry)</td><td>10-25 psf</td><td colspan="2">50 psf</td><td>30-50 psf</td></tr>
<tr><td>Total Weight (Wet)</td><td>20-45 psf</td><td colspan="2">65-75 psf</td><td>45-65 psf</td></tr>
<tr><td></td><td colspan="4">% of Roof Detention Volume that Applies to USWR Requirements</td></tr>
<tr><td>Filtration (WQv)</td><td>100%</td><td>CSS: 100%</td><td>MS4: 0%</td><td>100% (likely)</td></tr>
<tr><td>Runoff Reduction (RRv)</td><td>100%</td><td colspan="2">0%</td><td>100% (likely)</td></tr>
<tr><td>Volume Reduction (Vv)</td><td>0%</td><td colspan="2">100%</td><td>100% (likely)</td></tr>
</table>

Roof Pavers and Rooftop SMPs

While roof pavers are not required at FDNY landings and access paths, they are recommended in high-traffic roof areas such as pathways to frequently maintained equipment and the areas immediately adjacent to bulkhead doors. Current SCA green roof design requirements also call for a “border” of at least one roof paver (two feet) at the roof perimeter and at roof-mounted equipment in order to facilitate maintenance activities, although it is not clear that this is strictly necessary. Pavers may also be used below mechanical dunnage or other areas that are deeply shaded, difficult to access, or otherwise unsuitable for green roof plantings.

The typical depth of an SCA standard blue roof system is approximately 7-9 inches: 3-5 inches of void space for stormwater detention, with pedestals supporting two layers of 2 inch pavers. The shallowest recommended blue-green roof system has a minimum depth of approximately 9 inches, including 4-5 inches of growing media, 2.5-3.5 inches of stormwater detention, and 0.5 inches of drainage. With adjustments to paver pedestal heights, it should be possible to construct green roof systems with surfaces that are level with adjacent roof pavers, and with a continuous blue roof layer beneath both the green roof and the pavers.

In order to further reduce weight while maximizing stormwater detention capacity, SCA may consider embedding individual, lightweight pavers in the growing media of green or blue-green roofs along roof perimeters and frequently traveled maintenance paths. This could reduce damage to vegetation while retaining the stormwater detention capacity of the growing media. Water stored beneath the pavers will take longer to either drain or evaporate, providing longer-term irrigation to adjacent vegetation.

Pavers embedded in a modular green roof at Atlanta City Hall (left, credit: Waterproof! Magazine) and in a built-in-place intensive green roof in Battery Park City, NY (right, credit: MKM Landscape Architecture)

The use of grass block pavers, also known as turf pavers or grow-through-pavers, which are commonly used in at-grade patio areas and driveways, is not recommended for SCA green roofs. These systems, which may be constructed of concrete or plastic, typically provide no more than 50% open area for vegetation, are deeper and heavier (if concrete) than individual solid pavers, and provide less room for continuous vegetation growth. These systems are generally designed to accommodate turf grass, which is not recommended for green roofs because it forms an impenetrable root mat that is not conducive to stormwater storage, and provides limited evapotranspiration or biodiversity benefits.

Grass block pavers with planters on a turf roof at a PS in Manhattan (credit: SCA)

Microplastics in Rooftop SMPs

It should be noted that any green, blue, or blue-green roof system which uses plastic, whether in the form of modular trays (e.g. Hydroventiv and Product 2) or within the storage layer of a built-in-place blue-green roof system (e.g. Manufacturer 3 Detention Roof), will leach microplastics into the stormwater system over time. SCA has expressed interest in continued research into organic plastic options and plastic-free built-in-place systems to reduce microplastics in the stormwater system.

Summary of Rooftop SMP Recommendations

Extensive vs Intensive: Specify extensive green roofs with at least 4 inches of growing media

Growing Substrate and Vegetation: Experiment with 6” substrates with 5%-10% organic matter and a broad mix of vegetation including succulents and meadow species

Modular vs Built-in-Place Systems: Experiment with built-in-place and hybrid systems as an alternative to modular tray systems

Pre-Grown vs Grown in Place Vegetation: Pre-grown vegetation in modular trays

Temporary vs Permanent Irrigation: Specify temporary irrigation during plant establishment period; need for continued irrigation may be reduced or eliminated by use of blue-green roof systems and installation of solar PV canopies over vegetation

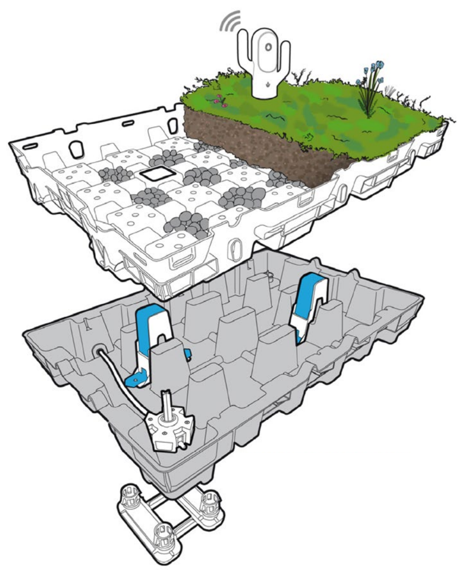
Blue-Green Roofs: Experiment with existing proprietary systems and continue research into built-in-place systems that use less plastic

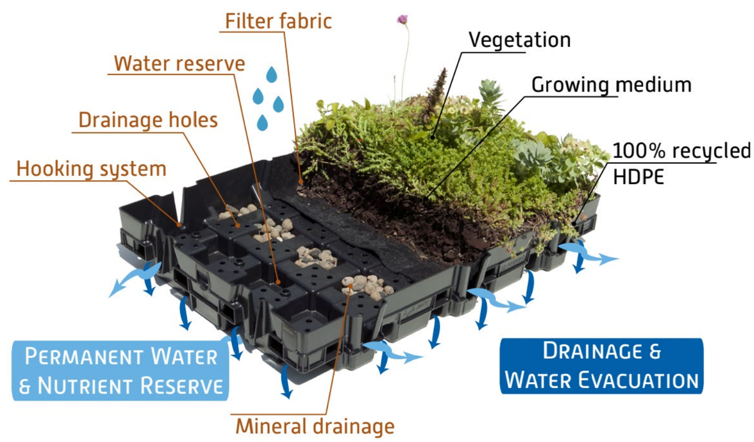
Roof Pavers: Experiment with embedding lightweight pavers in green roof growing media at high-traffic areas

Proprietary Products and Case Studies: Blue-green Roofs

The number of U.S.-based manufacturers of proprietary blue-green roof systems is limited. The majority of existing blue-green roof installations are in The Netherlands, which is at the forefront of advanced SMP techniques and flood control infrastructure due to its low elevation and flood risk. There may be an opportunity to pursue applications which combine separate green roof products and blue roof products, which may provide a significant storage benefit but lack the wicking power associated with a combined blue-green roof system. Additional investigation will be necessary to assess the feasibility of combining separate green and blue roof products.

Product 1 by Manufacturer 1





Physical Properties

Tray material	Black 100% recycled HDPE
Dimensions	15.748” x 23.622” (2.5833 sq. ft.)
Max. water retention	2.06 gallons per square foot
Min. constant flow rate	0.1 gal. per sec. per acre
Max. weight at full saturation	33 lbs per sq. ft.
Depth of the system	6 inches
Max. weight with both vegetation layer and water reserve layer when fully saturated	33 lbs per sq. ft.

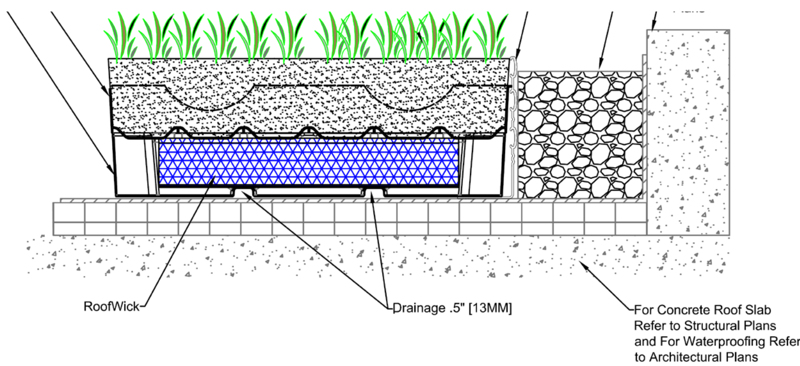
Manufacturer 1 is the American branch of a global company. Manufacturer 1 recently released a new product called Product 1, which combines two systems:

a. Product 1a: a prevegetated tray system that incorporates the components of traditional green roof system, including an aggregate drainage layer, filter fabric and growth media

b. Product 1b: a structured water reserve trey placed underneath the green roof system including two irrigation pedestals per tray to wick water back into the green roof system. As an option it can be connected to a wireless control for irrigation or data monitoring. The flow release rate can be controlled with an additional flow control system.

Product 1 stores up to 2 gallons psf and weighs 33 lbs psf. The drainage layer has a clearance of 1.2'' above the waterproofing membrane, which raises the growth media above any standing water. The water reserve allows the system to retain an additional 2.2 inches of rainfall when the green roof is fully saturated. The water is stored and released slowly into the sewerage system or consumed by being wicked back into the plants when it stops raining. The water runoff coefficient varies depending on the season; research done by the University of Milwaukee measured coefficients between 80% and 98%.

Product 2 by Manufacturer 2



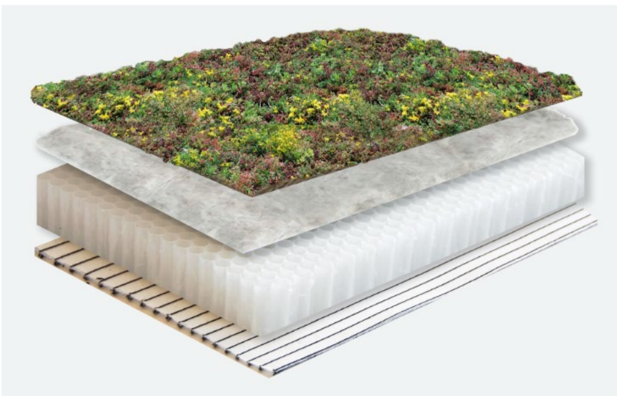
Manufacturer 2 is a Midwest-based wholesale grower of perennials. Product 2 consists of a green roof module on top of a structured water storage module. An interstitial layer of fabric made of recycled material is designed to transfer stormwater upward to the plant roots for evapotranspiration. According to Manufacturer 2, the recycled material used for RoofWick is preferable to mineral wool, which has a large carbon footprint.

Product 2 weighs 11.3 lbs psf and can hold 1.35 gallons per square foot. The Product 2 green roof module adds an additional 12 – 30 lbs psf depending on the depth. Together, these systems can increase storm water retention 42% using the Manufacturer 2 Standard system (4.25") or 55% using the Manufacturer 2 Lite system (2.5"). Product 2 is also compatible with the Manufacturer 2 Deep system (6"). A test study is in progress using a 6" soil layer and native plantings to analyze irrigation benefits and savings.

Product 2 has no drainage from the bottom of the storage layer; instead, it has an "exit point" at approximately 3 inches from its base, above which any additional stormwater will drain to avoid saturating the soil layer. It is assumed that stored water will transpire fully via the wicking mechanism. It is very difficult to estimate exactly how long it will take for water to transpire completely, as it depends on a variety of factors, including temperature, humidity, and plantings. According to Manufacturer 2, a full storage layer with 3 inches of stored water may take a few weeks to transpire fully.

It should be noted that this product does not meet the USWR design requirement which dictates that green roofs and blue roofs have a maximum drawdown time (drainage time) of 24 hours. It is anticipated that an inquiry would need to be filed with the NYC EPA in order to confirm that Product 2 is an acceptable SMP for compliance with the USWR.

Product 3 by Manufacturer 3



Manufacturer 3 is a Dutch-based company with a USA branch offering design services and green roof materials (including vegetation). Manufacturer 3 does not provide installation services; installation of Manufacturer 3 systems is typically completed by a green roof supplier.

Manufacturer 3 claims that even when fully water saturated, the Detention Roof is capable of fully retaining and draining rainwater in a controlled manner. The Detention Roof is made up of four layers, each of which has a unique function to the total structure:

1. Manufacturer 3 Sedum-mix Blanket: Pre-grown vegetated mat consisting of a mix of 8-12 different types of sedum. Vegetation coverage on delivery is at least 95%.
2. Green Roll: Lightweight green roof substrate manufactured from long mineral wool fibers. Due to capillary effects, the collected rainwater first spreads sideways through the layer, before releasing water to the underlying layer. According to Manufacturer 3, this allows for increased water retention and evapotranspiration in comparison to soil.
3. Storage Layer HC40: Lightweight structural storage mat constructed of small-diameter solid-wall plastic tubes, which are vertically fused together as a panel in a honeycomb structure. This structure is >90% void space and horizontal water flow is negligible. Depths range from 2 inches to 6 inches. Water can overflow the tops of the tubes to prevent saturating the plants.
4. Detention Layer T5: Recycled polyester mat with thousands of threads stitched together side by side. According to Manufacturer 3, this layer can delay rainwater runoff by up to 24 hours by creating friction, which pushes the water column up to the overlying Storage Layer HC40.

The Manufacturer 3 Detention roof is a non-proprietary, built-in-place system which is customized to suit the needs of each specific project. The total system thickness and weight depends on the specific storage needs of a project site. The Detention Roof is relatively lightweight solution because the Green Roll layer mitigates the need for a thick soil layer.

While USWR design requirements dictate that green roofs have a minimum 4” planting/filter media depth, the DEP has approved a planting/filter media depth less than 4” for Manufacturer 3 systems which use a mineral wool layer and exceed retention requirements on a volumetric basis.

Case Study: Blue-green Roof at De Boel, Amsterdam

Building Type: Apartment Complex

Location: Amsterdam, The Netherlands

Product: Permavoid 85S drainage and capillary irrigation foundation

Installation Area: 7,535 sf

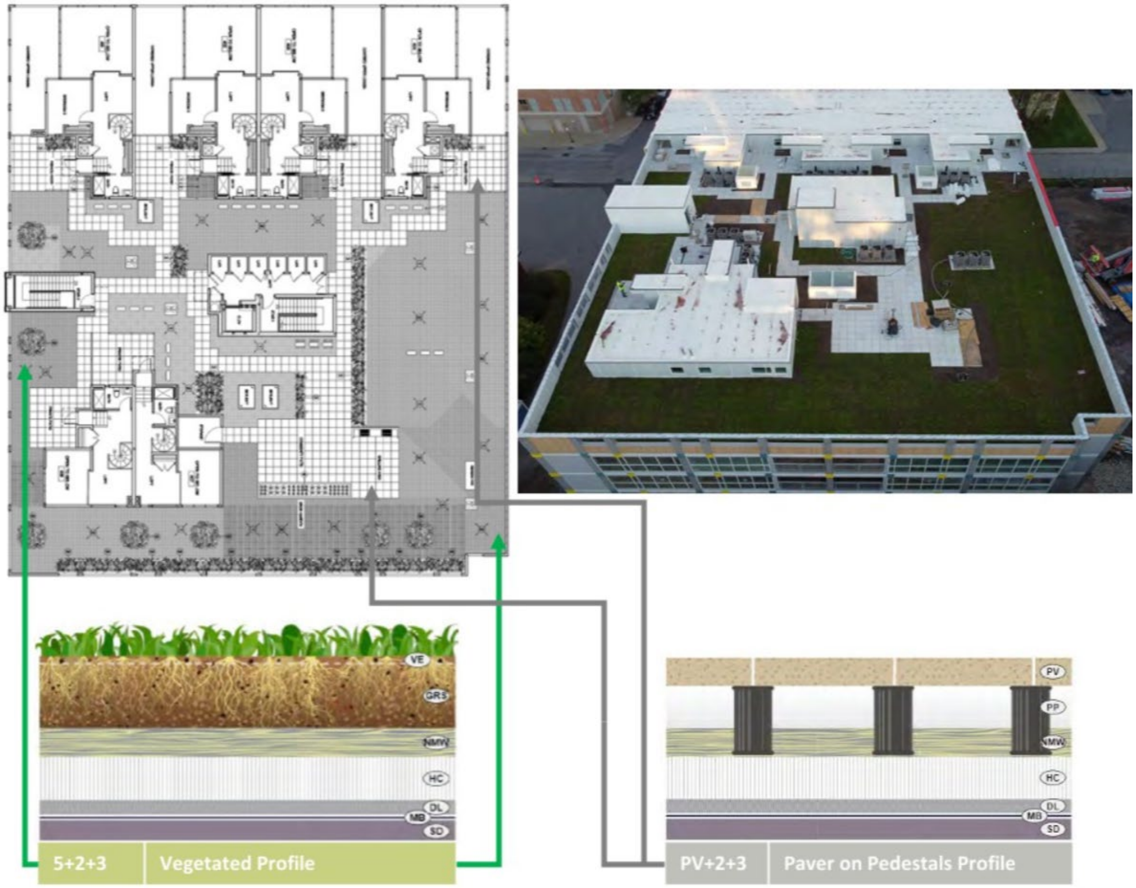
Storage Depth: 2 in

Storage Volume: 1,236 cu ft

Vegetation Type: diverse and local grasses, herbs, perennials and shrubs

Description: Blue-green roof located at the 8-story apartment building ‘De Boel’ located at the Boelelaan in Amsterdam. Constructed on top of the Permavoid 85S drainage and capillary irrigation foundation, located under both hard- and soft-scaped areas in the roof garden. Stored water is reused for plant growth via capillary (zero-energy) irrigation.

Case Study: Condominium, Saratoga Springs NY



Building Type: Multifamily Residential

Location: Saratoga Springs, New York

Product: Manufacturer 3 vegetated ‘5+2+3’ Roof (5” vegetation and growing media) and Manufacturer 3 ‘Paver+2+3’ Roof (concrete pavers on pedestals); each system also has 2” needled mineral wool, 3” honeycomb reservoir, and detention layer

Installation Area: 7,900 sf of ‘5+2+3’ Roof / 3,010 sf of ‘Paver+2+3’ Roof

Storage Depth: 5 in

Storage Volume: 6,336 cu ft (2,185 cu ft retention, 4,151 cu ft detention)

Weight: 48 psf saturated

Vegetation Type: sedum mix

Description: The case study building is a 24-unit condominium completed in 2021. The original design specified a traditional stormwater system using a storage tank, piping, and pumps. During construction, it was determined that managing stormwater on the roof and eliminating the tank system created room for 2 additional parking spaces and 1,200 sf of additional interior spacer.

Combining Solar PV with Rooftop SMPs

Interaction of Solar PV Canopies and Rooftop SMPs

In general, there are no negative impacts of solar PV canopies on green roofs, and no negative impacts of green roofs on solar PV canopies.

Impacts of Solar PV Panels on Green Roofs

Green roofs exposed to day-long direct sunlight with no shade can overheat and dry out on hot days unless provided with irrigation. The partial shade provided by a solar PV canopy raised a few feet or more above the roof helps reduce drying of the soil, thereby supporting the health of the plants while increasing and prolonging the energy and microclimate benefits of a green roof.

While green roof plants can be selected for shade tolerance, deep shade is not generally conducive to the health of green roof plants. A solar PV canopy consisting of separated rows of tilted panels or a high monolithic canopy would expose the plants to more sunlight, particularly incidental or reflected sunlight, than PV panels mounted closer to the green roof surface. A monolithic canopy less than 9 feet above the roof surface is not recommended for a green roof.

PV panels mounted near the green roof surface can help shield green roof plants from wind and help keep plants warmer during cold weather through the absorption and generation of heat. However, these benefits would not apply to PV canopies raised more than a few feet above the roof.

Impacts of Green Roofs on Solar PV Panels

Extensive scientific research has shown that the microclimate cooling effects of extensive green roofs can extend to the undersides of solar panels, increasing their output by as much as 5% compared to a black or gray (gravel) roof surface. There are far fewer comparisons of the effects of green roofs compared to high-albedo (white) roofs such as the standard SCA roof surface.

None of this research used panels raised more than four feet above the surface of the green roof. At and above this height, the cooling effects of increased air circulation and wind are much greater than those of an extensive green roof.

Proprietary Products and Case Studies: Solar PV Panels with Green Roof Ballast

There are no proprietary products combining solar PV canopies with green or blue-green roofs into an integrated system. However, there are proprietary products that combine raised solar PV support systems with green or blue-green roofs, also known as integrated solar green roofs or green roof ballasted PV. While these are not canopies, they can be useful for combining solar PV panels with rooftop SMPs in some circumstances.

Green roof ballasted PV systems have aluminum PV panel support struts attached to solid aluminum or plastic “base plates” which are ballasted by the weight of an extensive, built-in-place green roof above.

They typically use less than 4 inches of lightweight green roof media installed on a water detention layer constructed of mineral wool or other hydrophilic material. They typically raise the panels only 6 to 12 inches above the green roof and keep the tops of the panels below 4 feet.

Advantages of green roof ballasted PV include:

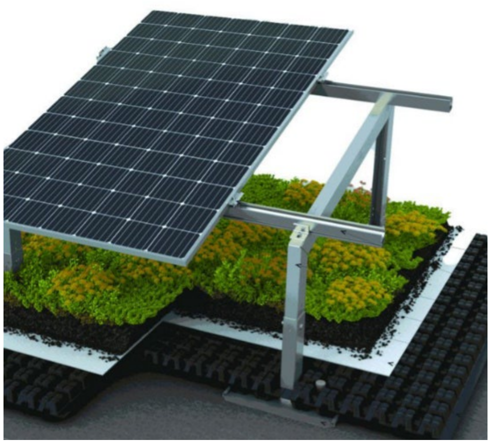
- lighter than concrete ballasted PV systems
- proximity of PV panels to green roof surface maximizes beneficial impacts such as cooling of PV panels by green roof evapotranspiration
- detention layer and base plates can accommodate some stormwater

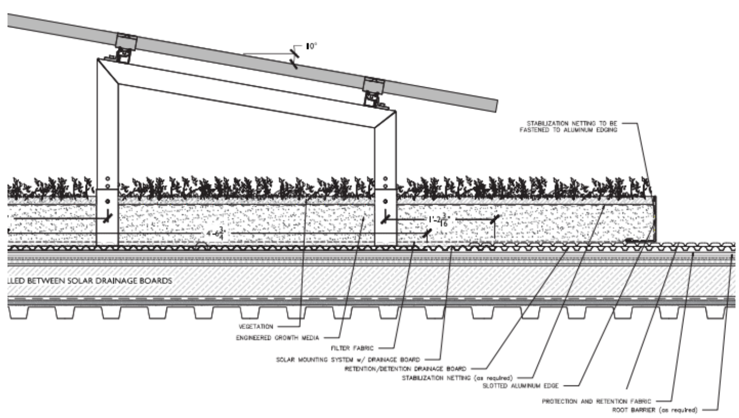
Disadvantages of green roof ballasted PV include:

- requires proprietary systems
- limited to extensive green roofs with minimal soil depth
- deep shade limits plant growth immediately below panels
- accommodate fewer panels per sf of roof space than ballasted systems or canopies
- cannot be installed over blue roofs

A limited number of proprietary green roof ballasted PV systems are described below.

Product 4





Weight: 0.83 or 0.43 lbs/sf (HDPE drainage board and aluminum mounting frame <u>only</u> – does not include green roof materials, PV panels, or saturated weight)
Water Storage Volume: 1.77 gal/sf or 0.122 gal/sf without retention module
Module Inclination: 10°, 15°, or 20°

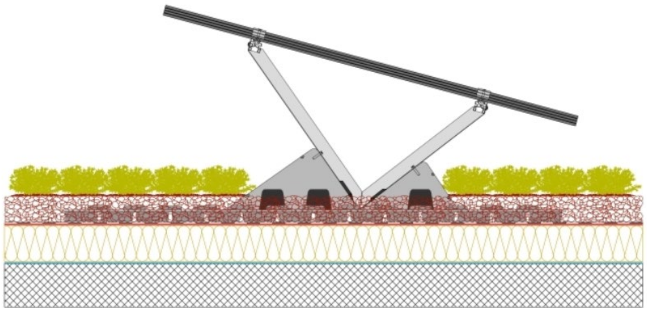
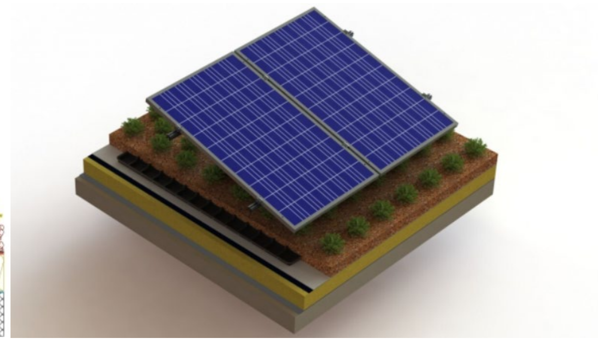
Description: Product 4 is a solar-integrated green roof solution offered both with and without retention. This product uses a proprietary mounting frame. There are no restrictions on panel size in landscape orientation, however the maximum panel size in portrait orientation is 1.8 meters (5.9 ft). The manufacturer claims the water retained in the drainage board (which also anchors the mounting frame) is absorbed through the fleece layer, which is penetrated by the plant roots.

Product 5

Weight: 1.8 kg/m2 (0.37 lbs/sf) dry without PV panels, 176 kg/m2 (36.0 lbs/sf) dry with PV panels
Water Storage Volume: 13.5 L/m2 (0.33 gal/sf)

Description: Product 5 is designed for applications where both a green roof and solar PV solution are required together to meet project requirements. The green roof substrate and vegetation provide the ballast mechanism for the entire solution which removes the need for additional ballast or penetrating the waterproofing to secure the units to the roof and maximizes the available area for vegetation.

Product 6

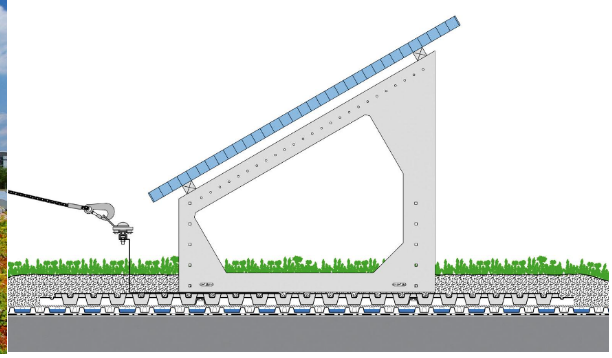
 

Weight: 6.25 kg/m2 (1.28 lb/sf) dry, without PV modules
Water Storage Volume: 22.4 L/m2 (0.55 gal/sf)
Module Inclination: 15° standard, 10° or 20° optional

Description: According to the manufacturer, the advantages of the Product 6 system include:

- Penetration-free, ballast through green roofs
- Quick and easy assembly
- Optimal use of roof space
- No yield loss due to shading of the plants
- Module height lower edge min. 30 cm from substrate
- Snow slides faster
- Lightweight design (substructure: 6.25 kg/m2, without PV modules)

Product 7

Weight: 94 kg/m2 (19.3 lb/sf) dry, 120 kg/m2 (24.6 lb/sf) saturated
Module Inclination: 5° to 45°

Description: The solar energy module is screwed onto the solar base frame, which in turn is mounted on a 1m × 2 m solar base and stabilized using cross bracing. The superimposed load required to protect against wind uplift is provided by the substrate layer of the green roof. According to the manufacturer, the advantages of their system include:

- Protection of the roof membrane
- Thermal insulation benefits
- Stormwater retention
- Habitat for flora and fauna
- Increased efficiency of PV panels due to cooling effect of green roof

Product 8

Weight: 110 kg/m2 (22.5 lb/sf) saturated
Water Storage Volume: 25 L/m2 (0.61 gal/sf)
Module Inclination: 10°, 15°, or 20°

Description: According to the manufacturer, their proprietary Drainage and Storage Board offers a spacious water reservoir and reliably drains excess water. Combined with filter fleece, optimum water distribution is guaranteed so that the vegetation is well supplied, even under the rows of PV modules.

Product 8 Case Study

NYC Department of Parks and Recreation, 2012

Building Type: Institutional (Maintenance Garage and Office)

PV Support: Aluminum struts attached to linked HDPE water retention mats ballasted by extensive green roof, bottom of panels approximately 0.5 ft above green roof surface

PV Panels: (4) LG 330 W panels (landscape) / 15° tilt / 4 foot separation / 180° azimuth

PV Generation: 1.3 kW / 1,700 kWh/yr (estimated)

Stormwater Summary: Approximately 250 sf of modular extensive green roof with moss and sedum in 3" pumice on 1" water retention and drainage mat

Stormwater Detention: Approximately 80 cf

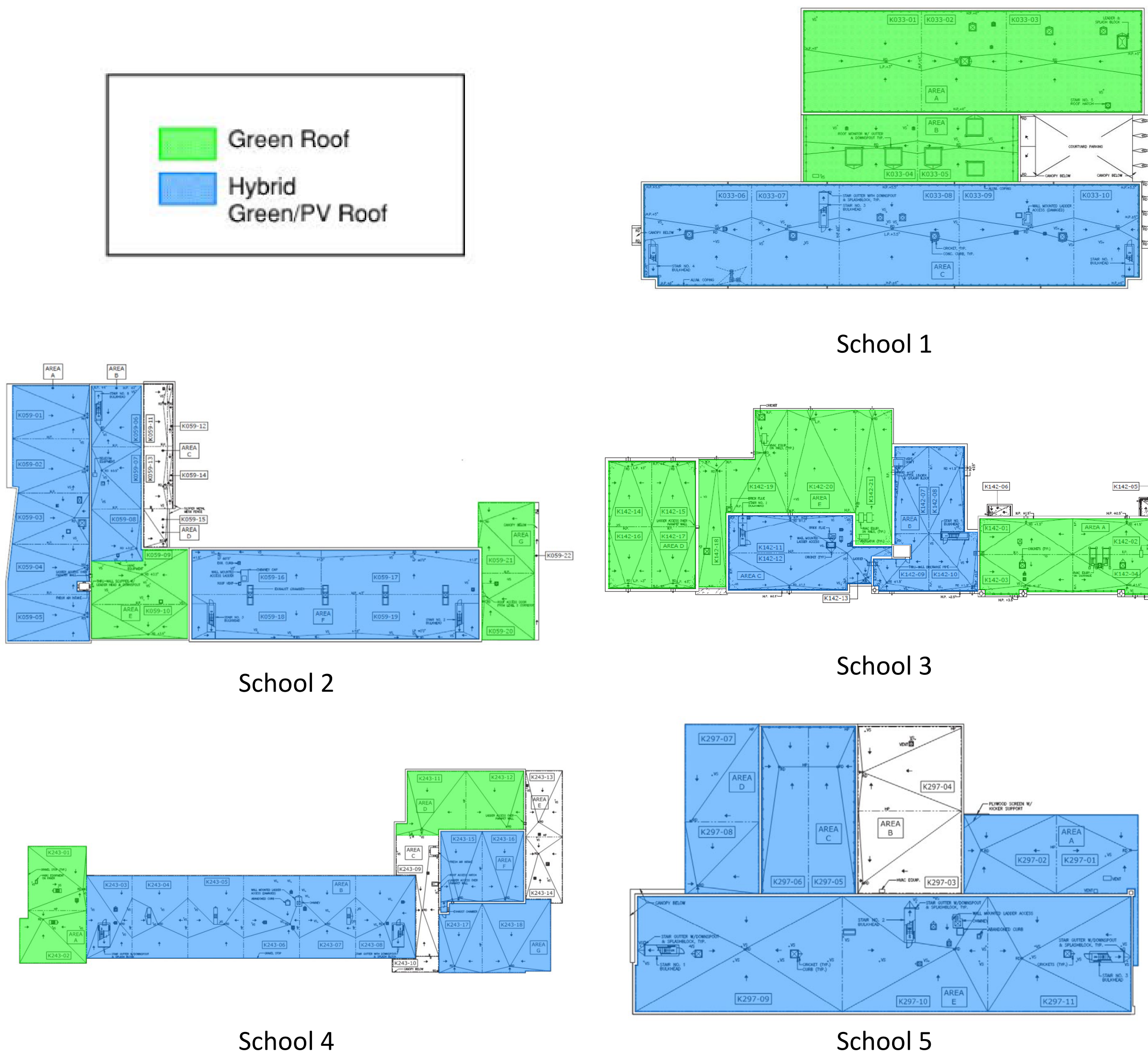
Design Limitations: Because no structural analysis was performed, a lightweight proprietary system was used. The total system weight, including the solar PV panels, is approximately 22 psf (saturated). The system is modular for installation, but the retention mats connect to each other and the vegetation and growing medium are not separated by trays, so a monolithic green roof is ultimately formed. Code and zoning limitations were not a consideration.

Lessons Learned

- According to DPR staff, the system seems to be growing well, but not directly under the panels due to continuous shading.
- The panels can be oriented in any direction. The system is also available with 10° or 20° tilt angles, and with a wide variety of green roof and water retention substrates. Similar systems are available from other manufacturers.

Custom Designs and Case Studies

NYC DOE/DEP Hybrid Green/Solar Roof Feasibility Studies
Developed for DOE/DEP, 2021



Feasibility Study Recommendations for Green Roof/Hybrid Solar Systems at NYC Schools

A consultant was retained by the NYC DEP to perform green roof/hybrid solar feasibility assessments for several existing NYC schools scheduled for roof replacements. Each report included a structural analysis and conceptual design plan for a green roof or green roof ballasted PV panels (termed a "hybrid system" by the study) on all or part of the roof area. The five schools described below were found to have at least partial feasibility for a hybrid system. Other schools in the study had structural limitations that made them unsuitable for hybrid systems, which were assumed to weigh 5 psf more than green roof systems alone.

Building Type: Schools

PV Support: Aluminum struts connected to aluminum or HDPE anchor board held in place by 20 psf of green roof ballast; bottom of panels approximately 3 ft above green roof surface.

PV Properties:

Property	**School 1**	**School 2**	**School 3**	**School 4**	**School 5**
PV Area	6,840	8,604	2,628	7,560	10,008
PV Panels (300 W each)	380 panels landscape arrangement	478 panels landscape arrangement	146 panels landscape arrangement	420 panels landscape arrangement	556 panels landscape arrangement
Tilt	10°				
Row Spacing	4 ft				
Azimuth	351°	81°	21°	184°	172°
PV Generation	116 kW	146 kW	44.5 kW	128.1 kW	169.6 kW
Annual PV Generation	130,000 kWh/yr	170,000 kWh/yr	50,000 kWh/yr	175,000 kWh/yr	230,500 kWh/yr

Green Roof Properties:

Property	**School 1**	**School 2**	**School 3**	**School 4**	**School 5**
Green Roof Area	27,579 sf	20,023 sf	22,919 sf	19,646 sf	16,138 sf
Green roof Type	Extensive Green Roof Trays				
Depth of Growing Media	3 in.				
Depth of Stormwater Retention	1 in.				
Stormwater Detention	1,954 cf 44% of 1.25-in. rainfall event	1,418 cf 33% of 1.25-in. rainfall event	1,623 cf 41% of 1.25-in. rainfall event	1,392 cf 31% of 1.25-in. rainfall event	1,143 cf 31% of 1.25-in. rainfall event

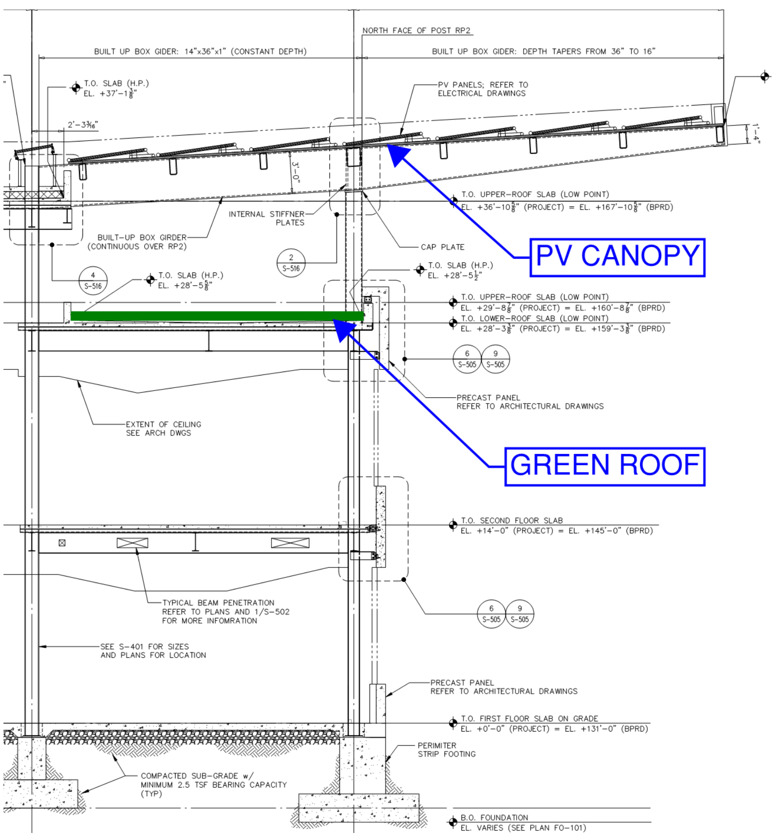
Design Limitations: Structural, code, and zoning limitations. The study limited additional structural loading to 10% of the existing roof weight in order to avoid triggering building code requirements. The study assumed that all existing roofing would be replaced, including the removal of 2 inches of crushed stone or gravel ballast and the installation of a new roofing system weighting 10 psf, including 6 inches of XPS insulation. The study did not calculate wind uplift forces, but excluded green or hybrid roofs from any roof areas within wind zones 2 or 3.

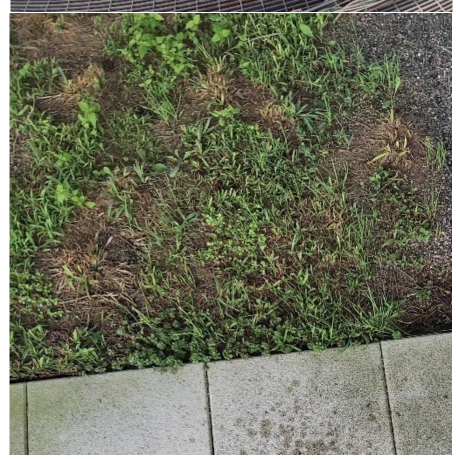
Lessons Learned:

- Equivalent allowable saturated green roof weights (psf) were applied over each roof area (sf), subtracting setbacks and offsets required by zoning or maintenance access requirements, to determine whether a green roof or a hybrid system was feasible.
- Extensive green roof systems considered for the study weighed between 20 – 40 psf (saturated weight). In cases where the available additional psf loading was under 20 psf according to the study's structural analysis, a green roof was not considered feasible and the reports recommend further analysis in the next phase of design to identify either a lighter-weight green roof system or a smaller green roof footprint.
- The study noted that green roofs below 30 psf (saturated weight), while feasible, might be too shallow to sustain plant health, and recommended further analysis.

PV Canopy and Green Roof at a PS in Staten Island

SOM and AKF for SCA, 2016





Mix 3			
SHADY MIX	20%	*Allium schoenoprasum*	Chives
	20%	*Carex flaccosperma*	Blue Wood Sedge
	20%	*Sedum ellacombianum*	Yellow Stonecrop
	20%	*Sedum kamtschaticum 'Variegatum'*	Variegated Kamschatka Stonecrop
	20%	*Sedum makinoi 'Ogon'*	Ogon Stonecrop

Building Type: School

PV Support: IronRidge panel rail and QuickMount L-Foot bolted to QuickMount QBase bolted to 2" metal grate, supported by cantilevered steel box girders on HSS posts; bottom of lowest panels approximately 0.25 ft above grate and at least 10.5 ft above green roof surface on terrace below

PV Panels (*only includes panels on the cantilever above the green roof): (245) Sunpower 327 W panels (landscape arrangement) / 9.4° tilt / 1.67 foot separation / 180° azimuth

PV Generation (see note* above): 23.3 kW / 28,000 kWh/yr (estimated)

Stormwater Summary: Approximately 2,067 sf of monolithic extensive green roof with "shady mix" of sedum, sedge, and herbs in 4" lightweight soil growing medium on 3/16" fiber and polyethylene water retention mat with molded polyethylene retention and drainage panel

Stormwater Retention: Approximately 700 cf

Stormwater Retention: 4,635 cf or 15% of 1.25-in. rainfall event, according to the project's civil stormwater drawings.

Design Limitations: PV yield maximization was the driving factor. The building massing, including the structure supporting the panels, was designed to fit just within zoning limitations.

Lessons Learned:

- The massive steel canopy structure is unique to this building and not suitable as a replicable model for SCA.
- The original panel connection to the metal grate included plastic components that failed and were replaced with metal components.
- The original green roof plantings, located on a setback on the north side of the building, do not appear to be growing well in all-day, year-round shade with competition from extensive weed species growth.
- More extensive maintenance should be provided to keep the roof plantings in good condition.

Direct-Mounted PV and Green Roof at DPR 5-Boro Complex, Randall's Island
NYC Department of Parks and Recreation, 2009


Building Type: Institutional (Maintenance Garage and Office)

PV Support: Unistrut members attached with 1/4" expansion bolts to either (a) the masonry parapet (86 panels) or (b) the concrete roof deck (60 panels); the latter are additionally ballasted by 40-lb bags of minerals draped over the base of the support structure (visible above during installation) for each group of 12 connected panels; bottoms of panels approximately 0.5 ft above surface of green roof

PV Panels: (146) Solar World 275 W or 295 W panels (doubled landscape arrangement) / 55° tilt / 8 foot separation / 208° azimuth

PV Generation: 41 kW / 54,000 kWh/yr (estimated)

Stormwater Summary: Approximately 6,350 sf of monolithic extensive green roof with sedum in 2" pumice on less than 1" synthetic fleece for water retention (XeroFlor XF + Fleece system)

Stormwater Detention: Approximately 1,500 cf

Design Limitations: Because no structural analysis was performed, an extremely lightweight proprietary green roof system was used (8 psf dry / 11 psf saturated total weight). Code and zoning limitations were not a consideration.

Lessons Learned

- The extremely lightweight XenoFlor XF + Fleece system did not yield sufficiently healthy plants, and led DPR to add 1" of custom-mixed mineral soil when the system was used elsewhere on the roof.[6]
- The ballast bags of minerals stayed much cooler than standard concrete ballast blocks when exposed to summer sun. However, they were not structurally vetted for resistance to wind uplift and cannot be recommended as models for SCA.

PV Canopy and Green Roof at Private Residential Project, Brooklyn
Brooklyn SolarWorks and Highview Creations for Private Residence, 2019

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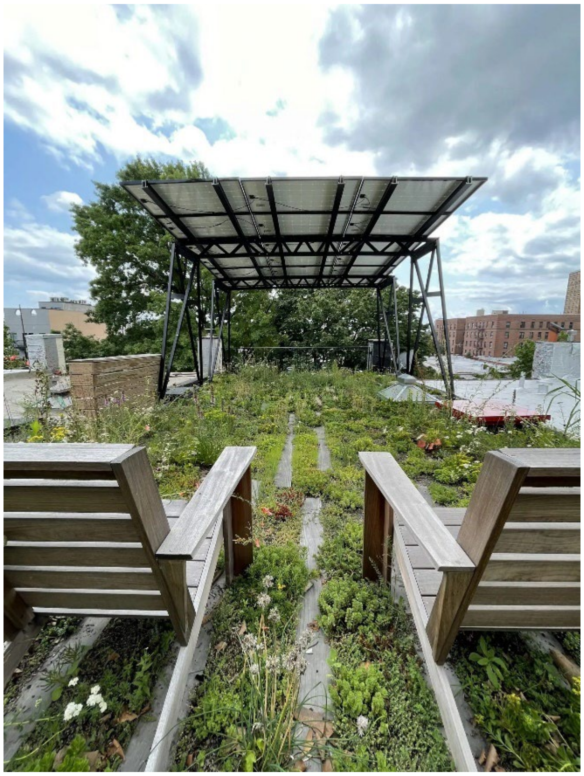
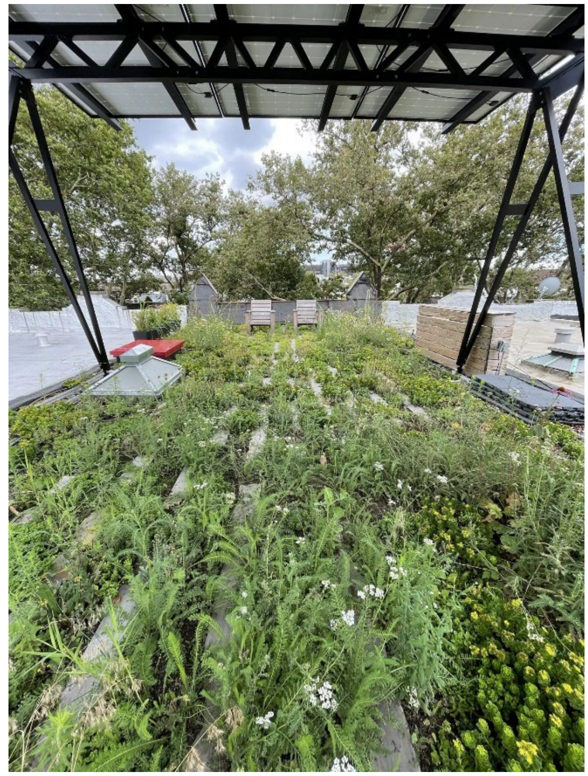
[6] According to interview with Artie Rollins, Assistant Commissioner for Citywide Services, NYC Department of Parks and Recreation, May 14, 2002





Building Type: Single-Family Residential

PV Support: BSW “Solar Pergola Roof” Canopy System; bottom of panels approximately 10 ft above green roof surface

PV Panels: (18) panels (landscape arrangement)

PV Generation: 6 kW / 7,000 kWh/yr (estimated)

Stormwater Summary: Approximately 800 sf of mixed Sedum green roof with 4” growing medium

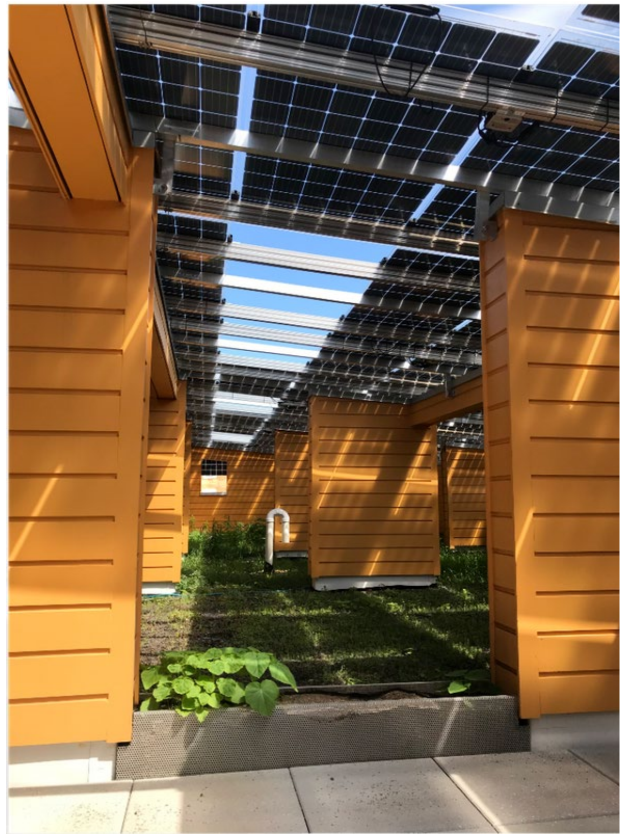
Stormwater Detention: Unknown

Design Limitations: Code limitations.

Lessons Learned

- A high, monolithic PV canopy is compatible with rooftop meadow plantings.

PV Canopy and Green Roof at Front Flats, Philadelphia
Onion Flats Architecture, 2019

(credit: Onion Flats Architecture)

Building Type: Multifamily

PV Support: Custom structural steel and Unistrut canopy 10’ above roof surface

PV Panels: (213) custom semi-transparent bi-facial panels / zero tilt / 0.25 ft separation

PV Generation: 75 kW / 80,000 kWh/yr (estimated)

Stormwater Summary: Approximately 2,000 sf monolithic extensive green roof with sedum and 30 sf of low planters

Stormwater Detention: Unknown

Design Limitations: The roof is divided into outdoor “rooms” by partial walls that conceal the steel supports for the PV canopy. Most of the rooms are dedicated to the green roof, which is separated by low planters from a central occupiable space with roof pavers. There is no rooftop HVAC equipment.

Bi-facial panels were selected for aesthetic reasons; because they provide desirable partial shade for people using the roof and for the plants; and because they provide up to 20% more generation over the areas with white roof pavers, although these areas are minimal. Code and zoning limitations unknown.

PV Canopy and Green Roof at The Battery Phase 3, Philadelphia

Onion Flats Architecture, 2017

Building Type: Multifamily

PV Support: Custom structural steel and Unistrut canopy 10’ above roof surface

PV Panels: (217) custom semi-transparent bi-facial panels (triple and quadruple landscape arrangement) / approximately 5° tilt / approximately 2 foot separation between arrays / 190° azimuth

PV Generation: 72 kW / 80,000 kWh/yr (estimated)

Stormwater System: Approximately 3,500 sf monolithic extensive green roof with sedum

Stormwater Detention: Unknown

Design Limitations: Half of the green roof area is designed for limited access; the other half of the green roof has no parapet and is fenced off. Rooftop HVAC equipment is limited to two central ERVs.

Bi-facial panels were selected for aesthetic reasons; because they provide desirable partial shade for people using the roof and for the plants; and because they provide up to 20% more generation over the areas with white roof pavers, although these areas are minimal. Code and zoning limitations unknown.

TECHNOLOGY IMPACTS AND CONSTRAINTS

Building Code and Regulatory Issues

Regulatory requirements are the primary driver of this study.

The Unified Storm Water Rule (2022)

The NYC DEP's Unified Storm Water Rule (USWR) took effect in February 2022 and is described in the New York City Stormwater Manual, included as an appendix to Chapter 19.1 of Title 15 of the Rules of the City of New York published as final on February 15, 2022. The descriptions of the USWR and its criteria included in the following section are intended to summarize the contents of the New York City Stormwater Manual.

Summary of USWR changes and anticipated impacts

The USWR brings together two DEP stormwater regulation programs: Site/House Connection Proposal Certification and Stormwater Construction/Stormwater Maintenance Permitting (Stormwater Permitting). The USWR provides a consolidated technical approach for implementing Stormwater Management Practices (SMPs) which satisfy both application objectives. The USWR implements a consistent approach to water quality and sewer operation objectives across Combined Sewer System (CSS) and Municipal Separate Stormwater Sewer System (MS4) areas. Specifically, the USWR implemented the following updates to existing programs:

- Updated release rate requirements and increased on-site stormwater detention requirements for CSS areas;
- Imposed new release rate requirements for Sewer Certification and Sewer Connection Permitting for MS4 areas;
- Expanded Stormwater Permitting requirements citywide to include CSS areas;
- Reduced the soil disturbance threshold from 1 acre to 20,000 square feet, and added the creation of 5,000 square feet of impervious area or covered maintenance activities as additional triggers;
- Requires a retention-first approach to SMP design for Stormwater Permitting requirements; and
- Provides a clear technical path for constructing SMPs to satisfy both Stormwater Permitting and Sewer Certification and Sewer Connection Permitting requirements.

It is anticipated that the USWR will have significant impacts on future SCA projects in both CSS and MS4 areas. Critically, the USWR requires both retention/detention and filtration SMPs for CSS areas, where SCA has historically used blue roof systems to satisfy stormwater requirements. Blue roofs alone will no longer satisfy the new requirements, and additional filtration SMPs will need to be explored for projects in CSS areas. Additionally, the maximum release rate for CSS areas has been reduced from 0.25 cfs/acre to 0.1 cfs/acre and a new maximum release rate of 1.0 cfs/acre has been imposed for MS4 areas.

Requirement Criteria (WQv, RRv, Vv, NNI)

The following section outlines the specific criteria per the USWR that must be met for each stormwater management requirement applicable to a project.

Water Quality Criteria (WQv)

The water quality (WQ) requirement aims to manage runoff from small, frequent storm events that can significantly impact the quality of receiving waters in both MS4 and CSS areas. The WQ criterion is met by managing runoff from the applicable small storm design event. NYS DEC defines this design event as the 90th percentile rain event. In New York City, the 90th percentile rain event is 1.5 inches of rainfall. The contributing area, runoff coefficient, and Water Quality Volume (WQv) must be determined for each individual SMP – and, in total, the practices must manage the WQv across the entire site. The WQv is calculated according to the following equation:

$$WQ_V = \frac{1.5"}{12} * A * R_V$$

where:
WQ_V: water quality volume (cf)
A: contributing area (sf)
R_V: runoff coefficient relating total rainfall and runoff
R_V: 0.05 + 0.009(I), I: percent impervious cover

Runoff Reduction Criteria (RRv)

The runoff reduction (RR) requirement aims to maintain a minimum level of runoff reduction during small storms in order to preserve natural hydrologic functions. This requirement is satisfied by implementing SMPs which allow for infiltration, evapotranspiration, or reuse. Ideally the entire WQv will be reduced by SMPs when the SMP hierarchy is followed (discussed in the following section), however if site constraints are such that reducing the entire WQv is not possible, the application must demonstrate that the minimum Runoff Reduction Volume (RRv) has been met. In no case shall the RRv of SMPs be less than the minimum RRv resulting from the newly constructed impervious areas. The RRv is calculated according to the following equation:

$$RR_V = \frac{1.5"}{12} * 0.95 * Aic * S$$

where:
Aic: total area of new impervious cover (sf)
S: specific reduction factor, see NYC Stormwater Manual Table 2.5 below

Sewer Operations Criteria (Vv)

The sewer operations volume (Vv) requirement aims to manage runoff from larger storm events in order to maintain optimal flow rates in the City's sewer system and, in turn, improve overall sewer operations. This requirement is usually satisfied by detention practices, but some retention practices may also be used. There are two elements to the sewer operations criteria; a volume (Vv) that must be provided to temporarily store water, and a maximum release rate (Q_{DRR}) that must be maintained via flow control systems. The Vv is calculated according to the following equation:

$$V_V = \frac{R_D}{12} * A * C_W$$

where:
V_V: sewer operations volume (cf)
R_D: rainfall depth (in) of the 10YR rainfall event – see table below
A: contributing area (sf)
C_W: weighted runoff coefficient relating peak rate of
rainfall and runoff

R_D	Description
1.85	CSS areas with SCP
1.50	CSS areas with HCP
1.50	MS4 areas with SCP
1.10	MS4 areas with HCP

The Q_{DRR} is calculated according to the following equation:

$$Q_{DRR} = \frac{q\left(\frac{cfs}{acre}\right) * A(sf)}{43560(\frac{sf}{acre})} \quad or\ 0.046\ [whichever\ is\ greater]$$

Where:
Q_{DRR}: maximum release rate, site (cfs)
q: maximum release rate, per acre (cfs/acre) – see table below
A: contributing area (sf)

q (cfs/acre)	Description
1.0	MS4 areas
0.1	CSS areas

<u>No Net Increase Criteria (NNI)</u>

The NNI requirement aims to reduce Pollutants of Concern (POCs) in MS4 areas that discharge to an impaired waterbody. The relevant POCs and associated compliance paths are as follows:

- *Pathogens:* to meet the NNI requirements for pathogens, BMPs must be implemented as provided in the postconstruction O&M manual to mitigate potential sources of pathogens present at the developed site. Table 2.6 of the NYC Stormwater Manual lists examples of BMPs that may address pathogen sources per land use. This list is not exhaustive or prescriptive, and applicants may propose additional BMPs to mitigate site-specific pathogen sources.
- *Floatables:* to meet the NNI requirements for floatables, refer to Chapter 4 of the NYS SWMDM to determine the required garbage and refuse removal features of postconstruction SMPs.
- *Phosphorus:* part II.B.1.b.ii of the NYC MS4 Permit states, "For phosphorus-limited waterbodies, compliance with Chapter 10 of the NYS SWMDM (January 2015) will satisfy the No Net Increase requirement." To meet the NNI requirements for phosphorus, refer to Chapter 10 of the NYS SWMDM to design SMPs.

- *Nitrogen:* to meet the NNI requirements for nitrogen, use the NYC MS4 No-Net-Increase Calculator.

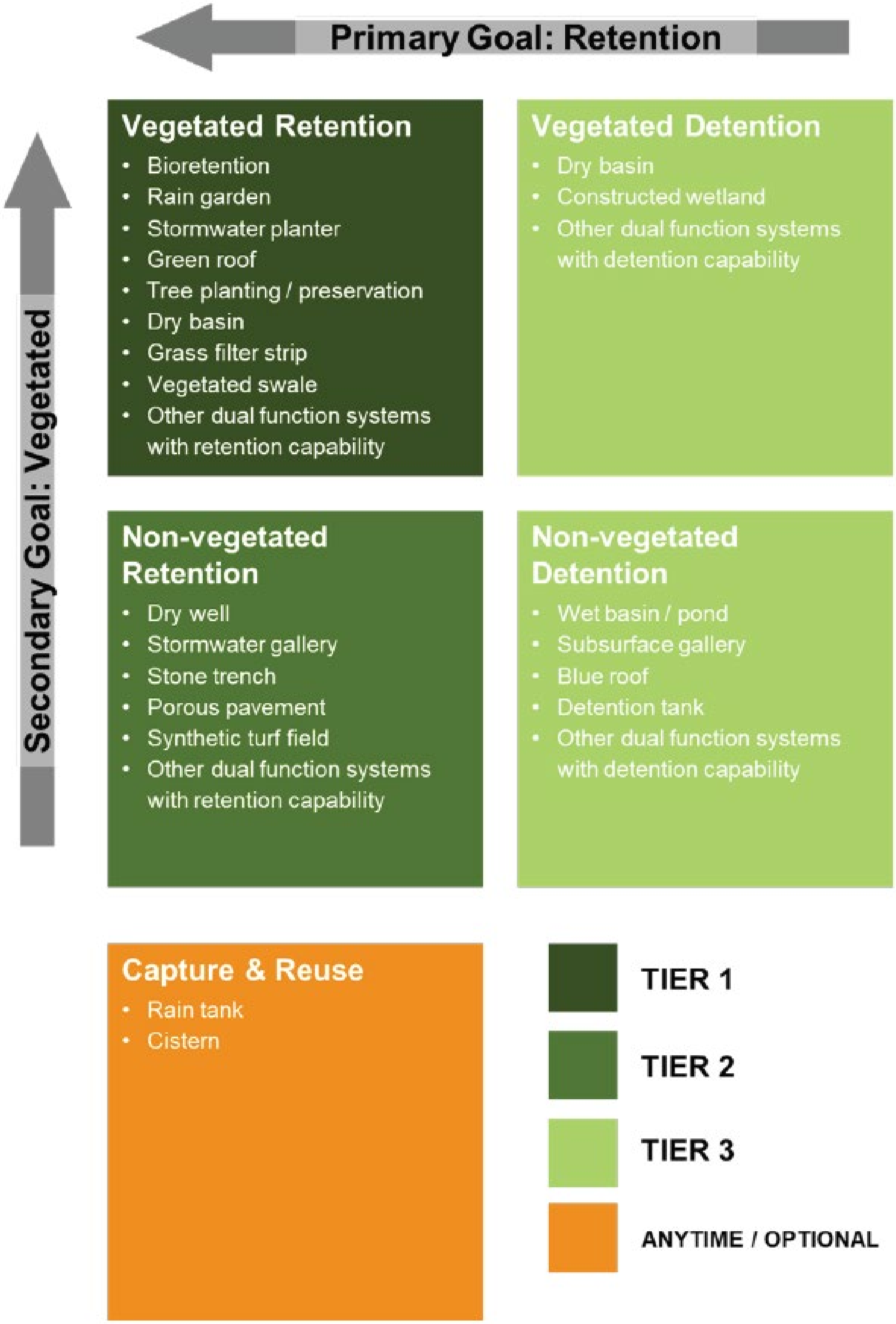
SMP Types and Tiers

SMPs are systems that are designed to retain, detain, and/or treat stormwater runoff with the goal to protect, restore, or mimic the natural water cycle within built environments. Runoff that enters an SMP is typically managed via one or more of the following physical processes:

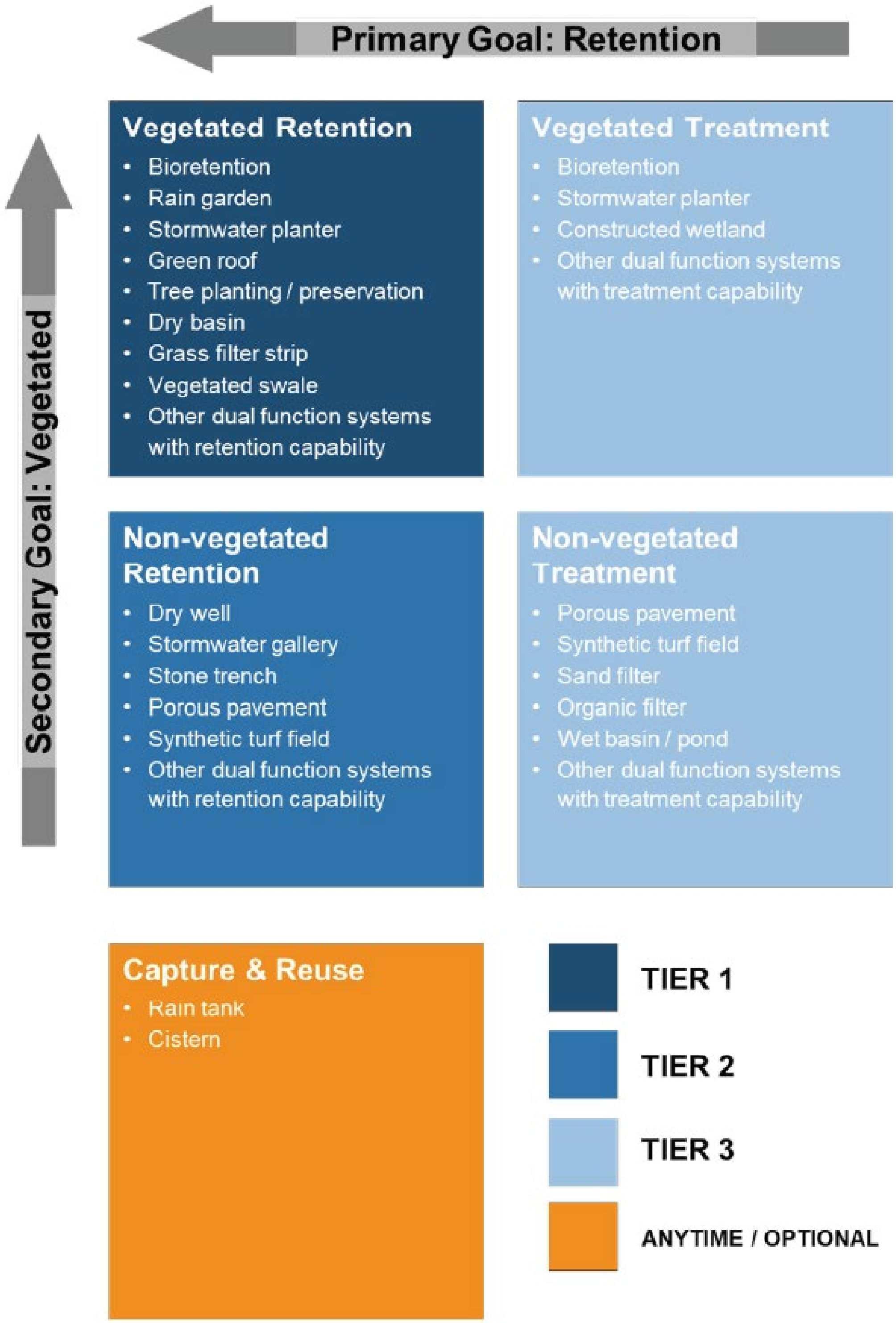
- Infiltration – water is captured and infiltrated into the underlying soils (sometimes referred to as exfiltration).
- Evapotranspiration (ET) – water is captured and evaporated or transpired back into the atmosphere.
- Reuse – water is captured and reused for purposes other than SMP irrigation (which can reduce water storage potential of other SMPs).
- Filtration – water passes through a filtration medium to remove various pollutants.
- Detention – water is temporarily stored and released at a lower flow rate.

Among the five primary functions, infiltration, ET, and reuse SMPs are considered retention-based practices, while filtration SMPs and some extended detention SMPs are considered treatment-based practices. In addition to primary function, SMPs are further categorized by surface types, i.e. vegetated SMPs and non-vegetated SMPs. Vegetated SMPs offer a variety of co-benefits such as air filtration, reduction of heat island effects, and ecological benefits.

In order to help design teams select the appropriate SMP(s) for a given project, the USWR sets forth an SMP hierarchy based on several guiding principles. The SMP hierarchies for CSS areas and MS4 areas are shown in the figures below. SMP groups are shown in a grid that is arranged by their order of preference, with more preferred practices at the top-left and least preferred practices at the bottom-right. Designers must assess and implement SMPs in higher tiers to the maximum extent practicable before moving to lower tier systems. The SMP hierarchy checklist, included below, lists SMPs by implementation tier, function type, and practice type and indicates which constraints would impact SMP feasibility. The SMP hierarchy checklist also indicates the extent to which different SMPs can apply towards the stormwater management volume requirements set forth in the USWR (WQv, RRv, and Vv).



SMP Hierarchy for CSS Areas



SMP Hierarchy for MS4 Areas

SMP HIERARCHY CHECKLIST - CSS AREAS

Tier[c]	Function Type[d]	Practice Type[e]	Percent of SMP volume applied[a]: WQv	RRv	Vv	Site constraints that limit SMP feasibility[b]: Soil	Subsurface	Hotspot	Surfaces	Space
Tier 1	Infiltration (Vegetated)	Bioretention	100	100	50	X	X	X	X	X
		Rain garden	100	100	50	X	X	X	X	X
		Stormwater planter	100	100	50	X	X	X	X	X
		Tree planting / preservation	SC	SC	0					
		Dry basin	100	100	50	X	X	X	X	X
		Grass filter strip	SC	SC	0	X	X	X	X	X
		Vegetated swale	SC	SC	0	X	X	X	X	X
	Evapotranspiration[f]	Rain garden	100	100	0		X		X	X
		Stormwater planter	100	100	0				X	
		Tree planting / preservation	SC	SC	0					
		Green roof	100	100	0					
Tier 2	Infiltration (Non-vegetated)	Dry well	100	100	50	X	X	X		X
		Stormwater gallery	100	100	50	X	X	X		X
		Stone trench	100	100	50	X	X	X	X	X
		Porous pavement	100	100	50	X	X	X		X
		Synthetic turf field	100	100	50	X	X	X	X	X
Anytime / Optional	Reuse	Rain tank	100	100	SC					
		Cistern	100	100	SC					
Tier 3	Detention[g,h,i]	Dry basin	100	0	100		X		X	X
		Constructed wetland	100	0	100		X		X	X
		Wet basin / pond	100	0	100		X		X	X
		Stormwater gallery	100	0	100		X			X
		Blue roof	100	0	100					
		Detention tank	100	0	100					

[a]Values marked "SC" are special cases for criteria-based practices, see Section 4.11 for details on criteria and application.

[b]An "X" marker indicates the site constraints that would prevent each practice from being used, contingent on the appropriate documention for that constraint.

[c]All practices of higher tiers must be used to the maximum extent possible or eliminated due to site constraints, before moving to lower tier practices

[d]Details on the design criteria and applied volumes for dual function systems are available in Section 4.9 on Innovative Systems.

[e]Other practice types not shown here may be proposed, subject to DEP approval, see Section 4.9 on Innovative Systems.

[f]Where permeablity rates of the site are 0.5 in/hr or greater, rain gardens, stormwater planters, and tree planting/preservation must be designed as infiltration practices

[g]High groundwater (subsurface constraint) limits the use of most practices, except those enclosed in concrete with adequate anchoring, as determined by an engineer

[h]Detention practices may be used to manage WQv in CSS areas when the release rate complies with the sewer operations requirement (i.e., 0.1 cfs/acre)

[i]Detention practices in series (e.g., blue roof to detention tank) require special calculations to account for changes in required detention volumes

SMP HIERARCHY CHECKLIST - MS4 AREAS

Tier[c]	Function Type[d]	Practice Type[e]	Percent of SMP volume applied[a]			Site constraints that limit SMP feasibility[b]				
			WQv	RRv	Vv	Soil	Subsurface	Hotspot	Surfaces	Space
Tier 1	Infiltration (Vegetated)	Bioretention	100	100	50	X	X	X	X	X
		Rain garden	100	100	50	X	X	X	X	X
		Stormwater planter	100	100	50	X	X	X	X	X
		Tree planting / preservation	SC	SC	0					
		Dry basin	100	100	50	X	X	X	X	X
		Grass filter strip	SC	SC	0	X	X	X	X	X
		Vegetated swale	SC	SC	0	X	X	X	X	X
	Evapotranspiration[f]	Rain garden	100	100	0		X		X	X
		Stormwater planter	100	100	0				X	
		Tree planting / preservation	SC	SC	0					
		Green roof	100	100	0					
Tier 2	Infiltration (Non-vegetated)	Dry well	100	100	50	X	X	X		X
		Stormwater gallery	100	100	50	X	X	X		X
		Stone trench	100	100	50	X	X	X	X	X
		Porous pavement	100	100	50	X	X	X		X
		Synthetic turf field	100	100	50	X	X	X	X	X
Anytime / Optional	Reuse	Rain tank	100	100	SC					
		Cistern	100	100	SC					
Tier 3	Filtration[g]	Bioretention	100	40	0		X		X	X
		Stormwater planter	100	40	0		X		X	X
		Porous pavement	100	0	0		X			X
		Synthetic turf field	100	0	0		X		X	X
		Sand filter	100	0	0		X		X	
		Organic filter	100	0	0		X		X	
	Detention[g,h]	Constructed wetland	100	0	100		X		X	X
		Wet basin / pond	100	0	100		X		X	X
Other	Detention[g,i,j]	Dry basin	0	0	100		X		X	X
		Stormwater gallery	0	0	100		X			X
		Blue roof	0	0	100					
		Detention tank	0	0	100					

[a] Values marked "SC" are special cases for criteria-based practices, see Section 4.11 for details on criteria and application.
[b] An "X" marker indicates the site constraints that would prevent each practice from being used, contingent on the appropriate documention for that constraint.
[c] All practices of higher tiers must be used to the maximum extent possible or eliminated due to site constraints, before moving to lower tier practices
[d] Details on the design criteria and applied volumes for dual function systems are available in Section 4.9 on Innovative Systems.
[e] Other practice types not shown here may be proposed, subject to DEP approval, see Section 4.9 on Innovative Systems.
[f] Where permeablity rates of the site are 0.5 in/hr or greater, rain gardens, stormwater planters, and tree planting/preservation must be designed as infiltration practices
[g] High groundwater (subsurface constraint) limits the use of most practices, except those enclosed in concrete with adequate anchoring, as determined by an engineer
[h] Select detention practices with treatment abilities may be used to manage WQv in MS4 areas when all design criteria are met
[i] Remaining detention practices may only be used to meet sewer operations criteria, included here for completeness
[j] Detention in series (e.g., blue roof to detention tank) require special calculations to account for changes in required detention volumes

USWR Hierarchy and Applicability

In both CSS and MS4 areas, *green roofs* are a Tier 1 evapotranspiration SMP and:

- Cannot be used to satisfy Sewer Operations Volume (Vv) requirements
- Can apply 100% of their stormwater detention capacity toward the Water Quality Volume (WQv) requirements of the USWR
- Can apply 100% of their stormwater detention capacity toward the Runoff Reduction Volume (RRv) requirements of the USWR

In CSS areas, *blue roofs* are a Tier 3 detention SMP and:

- Cannot be used before *Tier 1 and Tier 2* SMPs have been used to the maximum extent possible or eliminated due site constraints
- Cannot be used to satisfy Runoff Reduction Volume (RRv) requirements
- Can apply 100% of their stormwater detention capacity toward the Sewer Operations Volume (Vv) requirements of the USWR
- Can apply 100% of their stormwater detention capacity toward the Water Quality Volume (WQv) requirements of the USWR, if the project also complies with Vv requirements

In MS4 areas, *blue roofs* are an “untiered” SMP and:

- Cannot be used before *Tier 1, Tier 2, and Tier 3* SMPs have been used to the maximum extent possible or eliminated due site constraints
- Cannot be used to satisfy Water Quality Volume (WQv) requirements
- Cannot be used to satisfy Runoff Reduction Volume (RRv) requirements
- Can apply 100% of their stormwater detention capacity toward the Sewer Operations Volume (Vv) requirements of the USWR

Acceptable site constraints that can be used to demonstrate why an SMP is not feasible:

- Soil: Permeability < 0.5 in/hr
- Surbsurface: Groundwater or bedrock < 3 feet from bottom of SMP
- Hotspot: Contaminated soil or groundwater (a list of existing land uses assumed to create hotspots is provided in the NYS SWMDM)
- Surfaces: Code requirements necessitating impervious surfaces
- Space: Required setbacks from structures, utilities, property lines, etc.

USWR Design Requirements and Assumptions

USWR design requirements for a qualifying *blue roof* include:

- Maximum 24 hour drawdown time for detained stormwater

USWR calculation parameters for all green infrastructure systems, including green roofs, assume the following “available porosity” values:*

- 0.2 cf/cf for all soils, including green roof media
- 0.4 cf/cf maximum for stone base and sand, unless otherwise approved by DEP

* From the USWR FAQ (1/28/2022) #32: How is evapotranspiration factored into the new calculations? Are designers calculating the water quality volume by evapotranspiration or is it only soil porosity volume? Response: The SMP volume for an evapotranspiration (ET) practice is calculated as the volume available in the soil media at the start of a rainfall event. This available volume can be used to store rainfall, which is then evapotranspired over longer periods between rainfall events. Note that Equation 4.4 uses "available porosity" of soil instead of "porosity" to calculate the volume available in soil, recognizing that, in practice, a portion of soil porosity already contains moisture due to recent rainfall or other factors. The available porosity of soil shall be set to 0.2 cf/cf as indicated in Section 4.3 of the NYC SWM.

USWR design *requirements* for a qualifying *green roof* include:
- Minimum 4" planting and filter media depth, although *6" is preferred*
- Stone or geosynthetic drainage layer

USWR design *guidance* for a *green roof* recommends:
- Green roof media maximum water holding capacity: 35%-65%
- Green roof media pH: 6.0-8.5
- Green roof media composition (by weight):

<20%	Gravel	>2.0mm
65%-70%	Sand	0.05mm-2.0mm
<2%	Clay	<0.002mm
<8%	Organic Matter	

- Non-woven geotextile fabric
    - Not heat-bonded
    - Minimum 16" overlap

USWR design *requirements* for a qualifying *blue roof* include:
- No permanent pool
- Maximum drawdown time of 24 hrs

Enhanced Green Roofs

From the USWR FAQ (1/28/2022) #33: Can the volume of drainage media in ET practices be counted towards the total storage volume of practice? Response: No. Typically, the drainage media and soil media in ET practices are separated by geotextile. Therefore, once runoff enters the drainage media there are limited pathways for water uptake to plants and soil that would otherwise promote ET. This is especially true for drainage media on green roofs, where runoff in the drainage media can quickly travel to rooftop drainage systems.

The 2015 NYS Storm Water Management Design Manual (SWMDM) establishes an approval process for "innovative" systems beyond those detailed in the NYC SWM. These include "enhanced green roofs" described in the SWM as "green roofs that manage stormwater using proprietary media other than soils, such as retention fabrics, detention meshes, and modular storage components" – i.e., green/blue roofs.

The FAQ for the USWR further clarifies that "innovative evapotranspiration [i.e., green roof] systems that use alternative storage methods (e.g., storage cells below the soil media) may be approved by DEP for [meeting the Vv requirements of] CSS areas provided that designers can demonstrate wicking of water to soil media to promote evapotranspiration."

Thus, under the USWR, it is possible that a green/blue roof with wicking could satisfy the Vv requirements that cannot be satisfied by green roofs alone.

Approval Process

The phases of the DEP SWPPP submittal and approval process are enumerated below.

1. Prepare SWPPP Materials
   To begin the DEP submittal and approval process, the applicant for the covered development project must:
   - Complete the online application in the SWPTS;
   - Upload a complete SWPPP in the SWPTS; and
   - Pay the associated permit fees.

2. SWPPP Acceptance
   If DEP disapproves the submitted SWPPP application, it will provide the applicant with a notice identifying the deficiencies within the SWPPP. If DEP approves the submitted SWPPP application, DEP will provide the applicant with a signed SWPPP Acceptance Form for the project. For projects in MS4 areas, the applicant then includes the signed SWPPP Acceptance Form with the NYSDEC Notice of Intent (NOI) when applying to obtain coverage for the proposed project under the CGP.

3. Permitting and Approvals
   - *SWPPPs without Post- Construction SMP(s)*
     If the SWPPP does not require a post-construction SMP, the Permit Initiation Form may be submitted in the SWPTS without a stormwater maintenance easement. Once the DEP Stormwater Construction Permit has been issued, construction may begin. After the completion of construction, the applicant will inform DEP of construction completion. For projects in MS4 areas, the applicant will submit the NYSDEC Notice of Termination (NOT) to DEP for the MS4 acceptance signature. DEP may inspect the project site and, if satisfied, will provide the signed NOT to the applicant. The applicant will then submit the signed NOT to NYSDEC.

   - *Permitting (SWPPPs with Post- Construction SMP(s))*
     If a SWPPP includes one or more post-construction SMPs, the applicant must obtain a maintenance easement. DEP will issue a Stormwater Construction Permit for the project once all the required information in the Permit Request Form has been submitted and approved. Once the DEP Stormwater Construction Permit has been issued, construction may begin. Once construction is completed, the applicant must also submit the application for a Stormwater Maintenance Permit to DEP. Once the SMP(s) is installed

and operating as designed, DEP will provide the acceptance signature for the NOT and issue the Stormwater Maintenance Permit. For projects in MS4 areas, the applicant will then submit a signed NOT to NYSDEC. The owner must submit an annual certification for the SMP as well as a 5-year permit renewal to DEP via the SWPTS.

Local Law 94 of 2019, the Sustainable Roofs Law

Requires all new roofs and roof reconstructions (involving the replacement of all roofing layers down to the structural roof surface) to be covered by either green roofs or solar PV panels. The following areas are exempted from the resulting "sustainable roofing zone":

- Setbacks or access areas required by code or zoning, including FDNY landing areas and access paths for buildings less than 100 feet in height
- Areas occupied by rooftop structures, mechanical equipment, or equipment access pathways
- Obstructions related to SMPs installed to comply with DEP requirements
- Setbacks comprising less than 25% of the largest building floor plate area
- Recreational areas integral to the principal building use
- Areas with slope of greater than 17% that would accommodate less than 4kW of PV capacity
- Areas otherwise determined by DOB to be unfavorable for green roofs or solar PV panels

To date, the SCA has pursued the following strategies for LL94/2019 compliance, in order of preference:

- Solar PV panels covering the entire sustainable roofing zone
- Green roof covering the entire sustainable roofing zone
- Combination of PV or green roof covering the entire sustainable roofing zone

To date, the SCA has generally used blue roofs only where required in order to meet DEP stormwater volume and flow reduction regulations. Typically these instances were limited to sites where a lack of site area or unsuitable conditions such as contaminated or poorly draining soils precluded sufficient below-grade stormwater management systems.

Local Law 31 of 2016

Local Law 31 of 2016 requires city-funded capital projects to significantly reduce energy consumption and established stringent source EUI limits. This law's 2030 source EUI target (38 kBtu/sf/yr for all new public buildings, a 46% decrease from the current target of 70 kBtu/sf/yr for schools) predicated the SCA's LL31 study.

Local Law 97 of 2017

Local Law 97 of 2017 requires all projects eligible to comply with Local Law 31 of 2016 to complete a green infrastructure feasibility study.

Local Law 21 of 2011 (updated by Local Law 94 of 2019), the Cool Roofs Law

Local Law 21 of 2011 required all new roofs and new roof surfaces to be "cool" roofs with an initial SRI of at least 82 for low-slope roofs. It was updated by Local Law 94 of 2019, which includes more stringent emittance and reflectance requirements for flat roofs and requires pitched roofs and roof areas under solar panels to be "cool" as well.

Local Law 86 of 2005 (updated by Local Law 32 of 2016), the Green Buildings Law

Local Law 86 of 2005 requires all City-funded new construction and substantial reconstruction projects to achieve LEED v4 Gold certification or better. The SCA has received approval from the NYC Mayor's Office to use its own certification system, the Green Schools Guide (GSG), in order to satisfy this law. The 2019 version of GSG is considered to be more stringent than LEED v4 Gold and incorporates the requirements of the laws below.

Procurement Issues

Compliance with Procurement Rules

The following requirements may impact procurement:

- Local Laws 118, 119, 120, and 121 of 2005 require establishing standards for goods and materials purchased by the City according to a list of environmental priorities regarding energy and water efficiency, hazardous materials and recycled content. The resulting Environmental Preferable Purchasing (EPP) laws establish minimum requirements for numerous goods and construction products.
- The number of U.S.-based manufacturers of proprietary blue-green roof systems is severely limited, and it may be difficult to identify three suitable manufacturers. There may be an opportunity to pursue applications which combine separate green roof products and blue roof products, which may provide a significant storage benefit but lack the wicking power associated with a combined blue-green roof system. Additional investigation will be necessary to assess the feasibility of combining separate green and blue roof products.

Procurement Path

Section 13602 of the SCA Standard Specification describes the current SCA design requirements for PV systems, including approved manufacturers. Custom PV canopies utilize standard PV panels, rails (Unistrut or other manufacturer), and steel shapes. No procurement issues are anticipated.

Section 07561 of the SCA Standard Specification describes the current SCA design requirements for green roof systems, including approved manufacturers. Green roofs utilize standard, widely available materials and common plant species. No procurement issues are anticipated.

Availability

No availability issues are anticipated.

Construction, Operations and Maintenance Issues

Critical Path for Design Decision-Making

Decisions about PV canopies and rooftop SMPs must be made no later than the end of Schematic Design so that they can be fully incorporated into structural design, zoning and other approvals, and stormwater permitting. The addition of a large or high (9 feet or greater) PV canopy to an SCA capacity project after the completion of Design Development is not recommended.

The most important decisions, in order of importance, are:

1. Extent and height of PV canopy: In general, an increase in canopy height above the roof surface will increase wind loads, particularly on a building greater than 2 stories in height, and particularly if the canopy extends toward the perimeter of the building. In some circumstances, an increase in canopy size can result in a more efficient canopy structural design, as loads are distributed across an increased area. PV canopy extent and height also impact the visibility of the canopy from street level, which may require additional public approvals.

2. Method of PV canopy connection to building structure: Wind and seismic loads, rather than self-weight, are the primary determining factors for the structural design of a PV canopy. PV canopies require direct attachment to the building's roof slab, to the columns and beams supporting the roof, or to the columns supporting rooftop bulkhead walls. The structural complexity and impact of these connections will increase significantly if the building structure below the canopy is irregular or includes long spans such as those required over Gymatorium spaces. Ideally, PV canopy posts can also serve to support mechanical dunnage.

3. Extent and depth (weight) of rooftop SMP: In general, when compared to a standard SCA roof covered by two layers of concrete pavers, rooftop SMPs such as green, blue, and blue-green roofs will add only the live load of detained water to the structural requirements of the roof. However, they will weigh substantially more than an SCA roof covered by concrete board laminated to tongue-in-groove insulation board. Because rooftop SMP loads are distributed, they are most likely to impact the design of the roof slab.

Constructability and Impacts on Construction Schedule

Construction sequencing and phasing considerations include the following:

- Canopy posts should be constructed before the roof waterproofing membrane is installed.
- Green or blue-green roof materials should be installed after most PV installation is complete in order to minimize trampling of plants.
- Canopy and ballasted PV panel layouts should set aside space for storing and staging pallets of PV panels and bulk SMP materials.

Additionally, it may be necessary to leave some panels uninstalled in order to facilitate craning of bulk rooftop SMP materials onto the roof if contractors install the SMP after the PV system is installed.

Impacts on Building Operations, Maintenance, Repair and Replacement

Maintenance for PV Canopies

PV systems generally require very minimal maintenance; however, repair and replacement of parts may be necessary on rare occasions. PV panels themselves can be expected to last 25-30 years. Steel canopy structures can be expected to last at least three times as long (75+ years), so they should be designed to facilitate panel removal and replacement.

The highest PV canopies, offering the most rooftop PV coverage with the least shading of panels, may span over rooftop equipment such as air handling units (AHUs) and chillers. Like PV panels, this equipment has a typical useful life of 25-30 years and may need to be replaced two or three times during the life of the canopy. Depending on how the canopy is designed, PV panels and some canopy beams may need to be removed to facilitate rooftop equipment replacement using cranes. Scheduling PV panel replacement at the same time as rooftop equipment replacement – approximately every 25-30 years – will minimize disruption and costs.

It is recommended that all PV canopy designs include maintenance clearance of no less than 3 ft below the panels to allow for adequate access from below, unless the panels can be accessed from above. A standard 18 sq ft PV panel weighs approximately 50 pounds, and larger panels are proportionally heavier. PV panels can typically be removed or installed on a raised canopy from below by one person on a ladder; however, a scissor lift may be necessary in certain cases.

All DOB, SCA, and OSHA fall protection standards must be followed during the installation and continued maintenance of PV arrays. Because there is a higher fall risk for workers holding and raising PV panels to a canopy level, all workers should be harnessed and secured to the roof or canopy. Therefore, canopies should include attachments for fall protection harnesses at the perimeter of each roof area.

Maintenance for Rooftop SMPs

While green roof suppliers sometimes advertise their products as "maintenance-free," in reality regular maintenance is important for plant health and longevity, effective water retention and evapo-transpiration, soil cohesiveness and resistance to erosion by wind and rain, and protection of the roofing system. Maintenance is particularly critical during the plant establishment period, which can be up to 3 years for a built-in-place green roof using seedlings, but less than 1 year for pre-planted tiles or trays.

The current NYC Department of Parks and Recreation (DPR) estimates that its sedum green roofs require maintenance approximately 4-5 times per year, at an annual cost of $1 per square foot. DPR maintains 350,000sf of green roofs across New York City.

Best practices for green roof maintenance include periodic inspections (lasting approximately 30 minutes) during the growing season (March through November) for:

- Removal of weeds, especially woody plants that can damage roofing membranes
- Leveling or top-up of soil displaced by wind, rain, or wildlife
- Clearing of roof drains
- Pest control

- Soil moisture and watering if needed

Best practices for watering of green roofs (NOT blue-green roofs) with up to 6 inches of soil include:
- Regularly during the growing season, and more frequently during temperatures above 75 degrees and/or periods without steady rain that last more than a few days in a row.
- Less frequent watering to the point of soil saturation is preferable to more frequent light watering, which can encourage shallow rooting and a build-up of salts in the soil.
- Green roofs that receive partial shade from PV canopies may require less irrigation. However, green roofs below monolithic PV canopies may require more irrigation unless the canopies are high enough to allow wind-blown rain to reach all areas of the green roof.

Best practices at the beginning of the growing season include annual soil testing for pH, salts, nutrients, and organic matter. Soil samples should be sent to a qualified lab. If indicated by the test results, fertilizer and/or pH adjustment should be applied early in the growing season.

Best practices at the end of the growing season include thorough weeding, roof drain clearing, and raking of fallen leaves and twigs from nearby trees. During the winter, salt or other deicing chemicals should not be used on rooftop pathways adjacent to green roof areas. Green roofs should not be walked on when plants or soils are frozen. Snow shoveled from pathways should be distributed across parts of the green roof rather than piled deeply in one place.

Blue-green roofs are likely to require less irrigation than traditional green roofs. However, exterior non-freeze hose bibs should still be required for blue-green roofs to allow for watering during extreme drought conditions. There may be additional maintenance associated with the stormwater storage layer, i.e., periodic monitoring may be required to ensure proper drainage during storm events. For blue-green roof systems lacking a drainage mechanism in the bottom of the drainage layer (e.g. Manufacturer 2’s Manufacturer 2 RETAIN), periodic monitoring may be required to ensure that standing water is being properly evapotranspirated by the vegetation and removed from the storage layer.

TECHNOLOGY APPLICABILITY

Recommendations for SCA Implementation

This report addresses the implementation of rooftop solar PV canopies and rooftop SMPs on new SCA capacity projects where these systems can be fully integrated into building design. The report does not directly address the implementation of these systems on existing school buildings.

However, some aspects of this report, including the comparison of SMP types and the discussion of green roof ballasted PV, may be useful for aiding in the consideration of such systems for existing buildings planned for roof replacement.

Changes to SCA Specifications, Details and Design Requirements

This report does not recommend specific changes to SCA specifications, details or design requirements. However, it does recommend that the SCA evaluate the following changes in rooftop SMP design through pilot projects to test initial costs and impacts on rooftop temperatures, stormwater detention and retention volumes, plant health and longevity, and SMP maintenance:

Current SCA Standard	***Recommended for Pilot Projects to Increase Surface Water Detention and Plant Longevity***
Green or blue roofs	Blue-green roofs with wicking via capillary action in specialized fabrics or microtubules
Built-in-place or fully modular green roofs	Hybrid modular green roofs with removable side panels
4” growing substrate depth	6” growing substrate depth (as recommended by latest NYC DEP Stormwater Design Manual)
0%-5% organic content in substrate	5%-10% organic content in substrate
Sedum mix	Sedum, grasses, and perennials (6” substrate only)

Project Types/Selection Matrix

This report recommends the following combinations of rooftop SMP and PV systems:

Recommendations	***PV Array Type and Height Above Finished Roof Surface (AFR)***				
Rooftop SMP Type	**Conventional Ballasted**	**Green Roof Ballasted**	**Canopy 6’-9’ AFR**	**Canopy 9'-15' AFR**	**Canopy 15' AFR +**
White Roof (no SMPs)	X		X	X	X
Blue Roof	X		X	X	X
Extensive Green Roof (up to 6” depth)		X	X	X	X
Blue-Green Roof			X	X	X
Intensive Green Roof*				X	X

Canopies 6’-9’ above the finished roof surface (AFR) are assumed to span typical rooftop vents and exhaust fans. Canopies 9’-15’ AFR are assumed to span FDNY and maintenance landings and access paths. Canopies 15’ AFR and higher are assumed to span upblast exhaust fans for kitchens and science labs, air handling units with horizontal exhaust, and other equipment except for chillers.

* Note: This report does not generally recommend the application of intensive green roofs (green roofs with substrates greater than 6” deep) to SCA capacity projects.

This report recommends the following application of PV array types and heights to specific building zoning and structural conditions:

Recommendations	***PV Array Type and Height***		
Zoning & Structural	**Green Roof Ballasted**	**Low Canopy ≤ 9’ AFR**	**High Canopy > 9’ AFR**
Zoning	Any	Any	R6-R10, C (except C3, C4-1)
Array Type	Green roof ballasted	“Sawtooth” or tilted monolithic	“Sawtooth”
Posts	Aluminum (by definition)	Steel or concrete	Steel
Structural Anchors	None (by definition)	Building structure, mechanical dunnage, or roof slab	Building structure or mechanical dunnage

This report recommends the following application of PV array types and PV panel configurations to specific building rooftop geometries and layouts:

Recommendations	***PV Array Type and Panel Configuration***		
Array & Panel Layout	**Green Roof Ballasted**	**Tiled Monolithic Canopy**	**“Sawtooth” Canopy**
Roof Configurations	Best for large areas over long structural spans	Best for bulkheads and isolated areas with limited N-S dimension	All other roofs
Green and Blue-Green Roofs	Yes (by definition)	Only if canopy > 9’ AFR or using semi-transparent panels	Yes
Alignment	With building or azimuth	With building	With building
Tilt	15-30 degrees	5-15 degrees	5 degrees

Conceptual Design and Analysis

In order to test the applications of various rooftop solar PV canopy systems and rooftop SMP systems researched by this report, a hypothetical design and analysis were developed for a representative SCA capacity project. Several potential projects were considered. A primary school in the Bronx (Test Case School), was selected because:

- It had a complete set of design documents available for analysis.
- The original design already included both a blue roof and a limited area of green roof. (The green roof, which served a purely educational purpose, was changed after design completion into a series of deep roof planters with permanent irrigation. Neither the green roof nor the planters were incorporated into the project's stormwater calculations.)
- The building included multiple roof conditions useful for testing the application of different PV canopy configurations: a main roof with multiple obstructions, a small bulkhead above the main roof, and a lower setback roof with no obstructions.

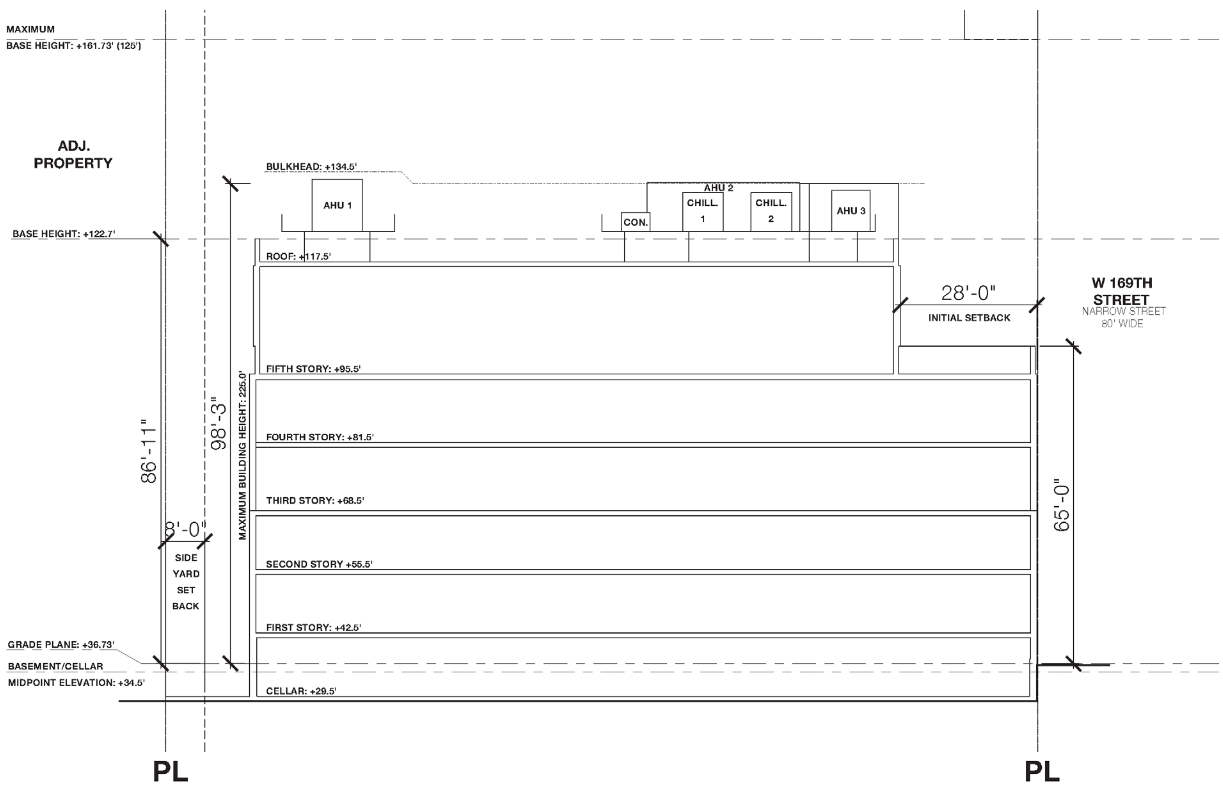
While this exercise proceeded under the assumption that the rooftop PV canopy and SMP would have been integrated into the building design from the beginning, it necessarily had to reconcile with a design that had not considered the implications of a rooftop PV canopy. Therefore, the Test Case School had some design conditions that, while less than ideal for the application of a rooftop PV canopy, contributed to a better understanding of the interaction of PV canopy design with the design of SCA capacity projects:

- The Test Case School has a Gymatorium on the top level, which required long structural spans and an irregular column arrangement to support the roof. In general, a roof with long structural spans would be a good candidate for a green roof ballasted PV system. However:
- The location of the Gymatorium also impacted the locations of the rooftop bulkhead and mechanical equipment, which were pushed to the north and south ends of the main roof. As a result, the central part of the roof, which spans the Gymatorium, is partially shaded by mechanical equipment year-round and therefore not ideal for a green roof ballasted PV system.
- As a 5-story building with a relatively small footprint, the Test Case School cannot accommodate a PV system large enough to offset all of its energy use, even if a PV canopy were to cover the entire building footprint. The implementation of new SCA standard energy conservation measures that postdated the project design (per SCA Bulletin 2022-03) would have increased the percentage of annual building use offset by PV generation.

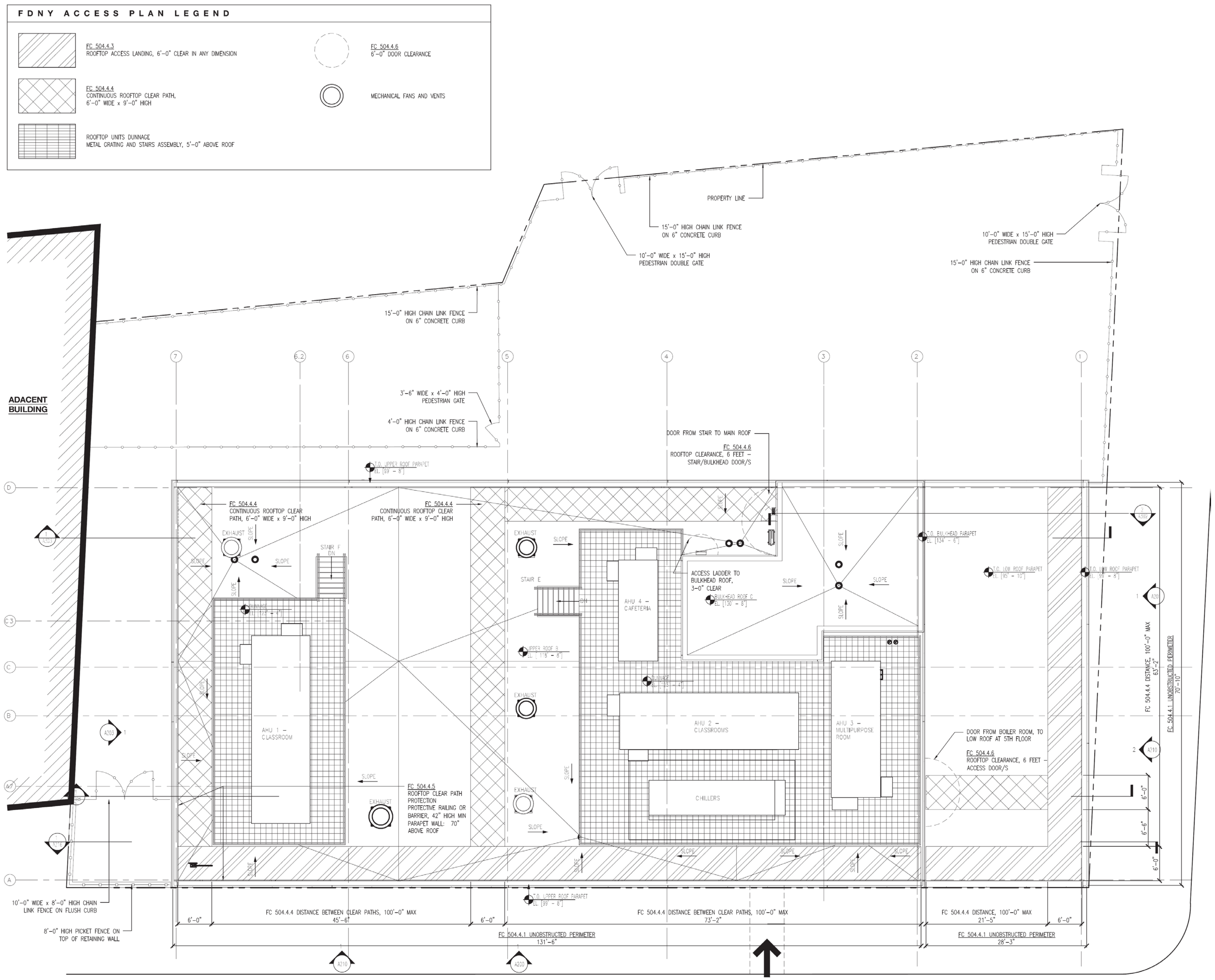
General properties of the Test Case School are provided below.

- Building Gross Area: 68,013 sf (full cellar + 5 floors + elevator bulkhead
- Building Footprint: 11,510 sf
- Net Roof Surface: 10,820 sf
- Lot Area: 21,152 sf
- Zoning District: R9A + C2-4 overlay
- Max. Zoning Height Limit: 225'
- Max. Building Height: 98'
- Source EUI: 60.3 kBtu/sf/yr
- Energy Consumption: 683 MWh/yr (includes gas consumption converted to equivalent electricity units)
- Peak Electricity Demand: 236 kW
- Capacity: 433 Seats

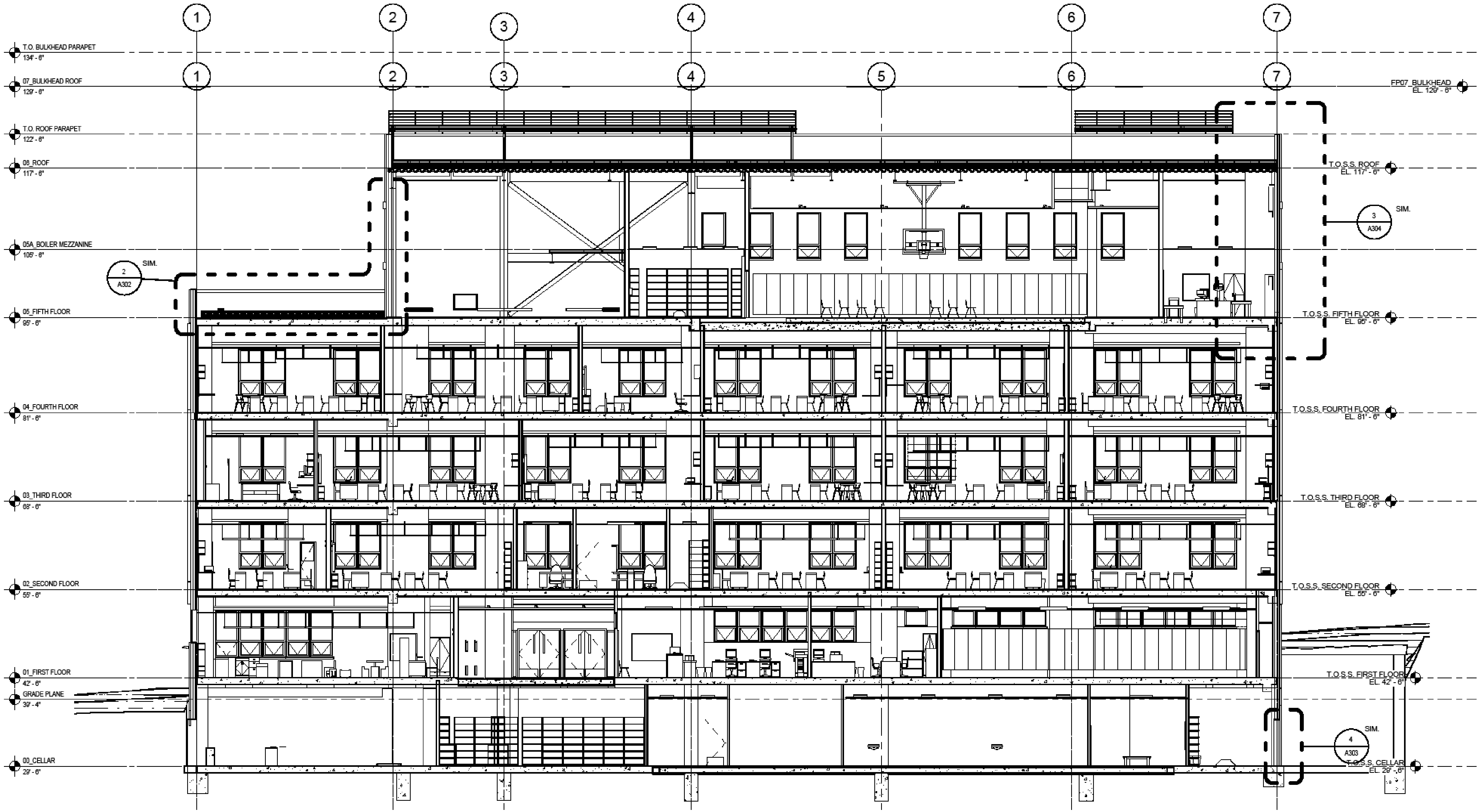
Rendering of the Test Case School (credit: SBLM)



Longitudinal Zoning Section (credit: SBLM)



Site Plan / Roof Plan Showing FDNY Access Requirements (credit: SBLM)



Longitudinal Section (Rooftop Bulkhead Not Shown) (credit: SBLM)

Rooftop Stormwater Management Concepts

Four conceptual rooftop stormwater management designs were proposed and investigated for this study. Other than the "baseline" (Scheme A), which represents the actual building design, all schemes utilize a blue-green roof system in order to maximize the potential stormwater management volume of the building's limited roof area. As described under the "Building Code and Regulatory Issues" section of this report, a blue-green roof is the only solution that would allow a building's roof – and only the roof – to fulfill all of a site's stormwater management requirements.

Scheme A represents the actual stormwater management design for the Test Case School, which predated the USWR. Scheme A has 9,271 sf of blue roof area. Under the DEP regulations in effect at that time, the blue roof contributed 1,264 CF of stormwater detention against a required volume of 1,069 CF for stormwater landing on the roof. A subgrade detention tank below the play yard provided an additional 1,465 CF against a required volume of 1,421 CF for stormwater landing on the rest of the site.

Scheme B includes 9,580 sf of blue roof area, some of which is covered by 3,544 sf of green roof. This blue-green roof covers all roof areas excluding mechanical and FDNY landings and access paths, the areas below the mechanical dunnage, and a high-traffic area adjacent to the bulkhead access door and bulkhead roof ladder. The excluded areas are covered with SCA standard roof pavers on pedestals, as per the actual building design, that are level with the surface of the proposed blue-green roof areas.

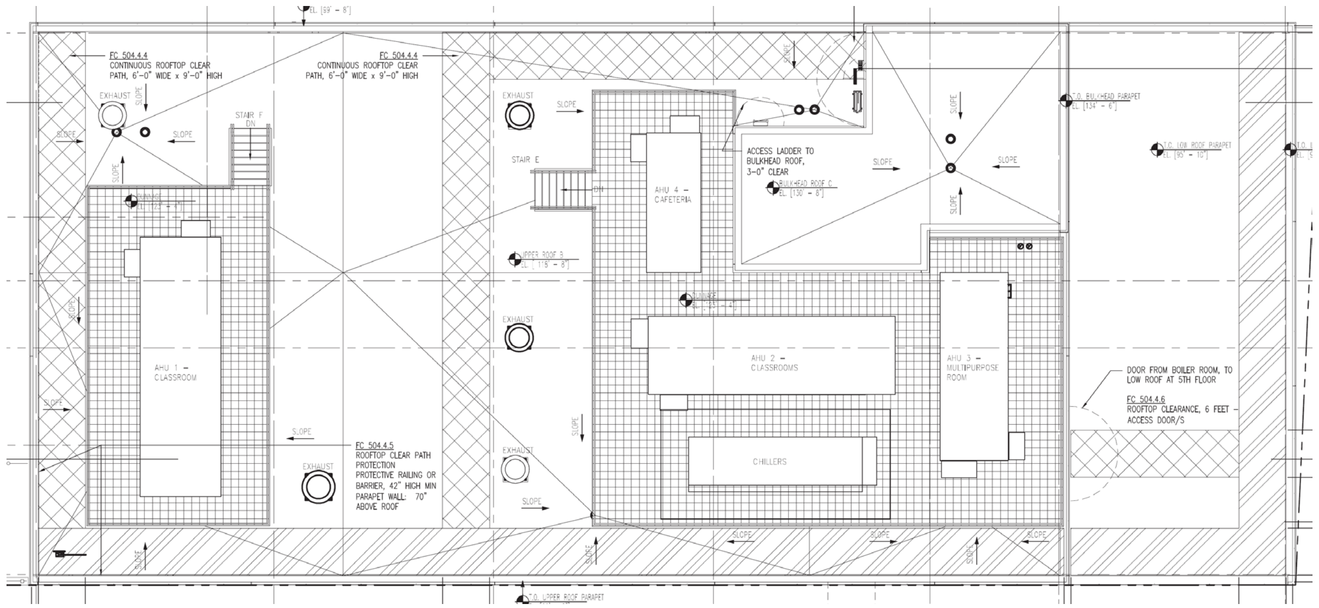
Scheme C extends the green roof area to include all access paths, for a total of 6,962 sf. FDNY allows green roofs to cover required landings and access paths as long as the vegetation is less than 12 inches high. At the suggestion of the SCA, this scheme includes scattered pavers – more like lightweight concrete flagstones – set into the green roof growing media along mechanical and FDNY landings and access paths in order to reduce the need to walk on the plants.*

* This study was unable to determine whether DEP would agree to treat green roof or blue-green roof areas with scattered pavers as a standard green roof for purposes of calculating stormwater volume treated by these areas. This study was also unable to confirm whether any blue-green roof systems would be able to support such pavers. The study looked into the use of grass block pavers, which are concrete lattices that provide space for vegetation, but determined that they would reduce the effective green roof area too much to be useful for rooftop stormwater management.

Scheme D further extends the green roof area to include the area below the mechanical dunnage, maximizing the green roof coverage at 9,580 sf. Scheme D was included for conceptual analysis at the suggestion of SCA. This study was not able to determine whether DEP would agree to treat green roof or blue-green roof areas below the dunnage as a standard green roof for purposes of calculating stormwater volume treated by these areas. While the dunnage is composed of metal grating that allows penetration of stormwater and some sunlight, most of the dunnage is covered by large equipment, and it is not clear that even shade-tolerant species would grow well in these areas.

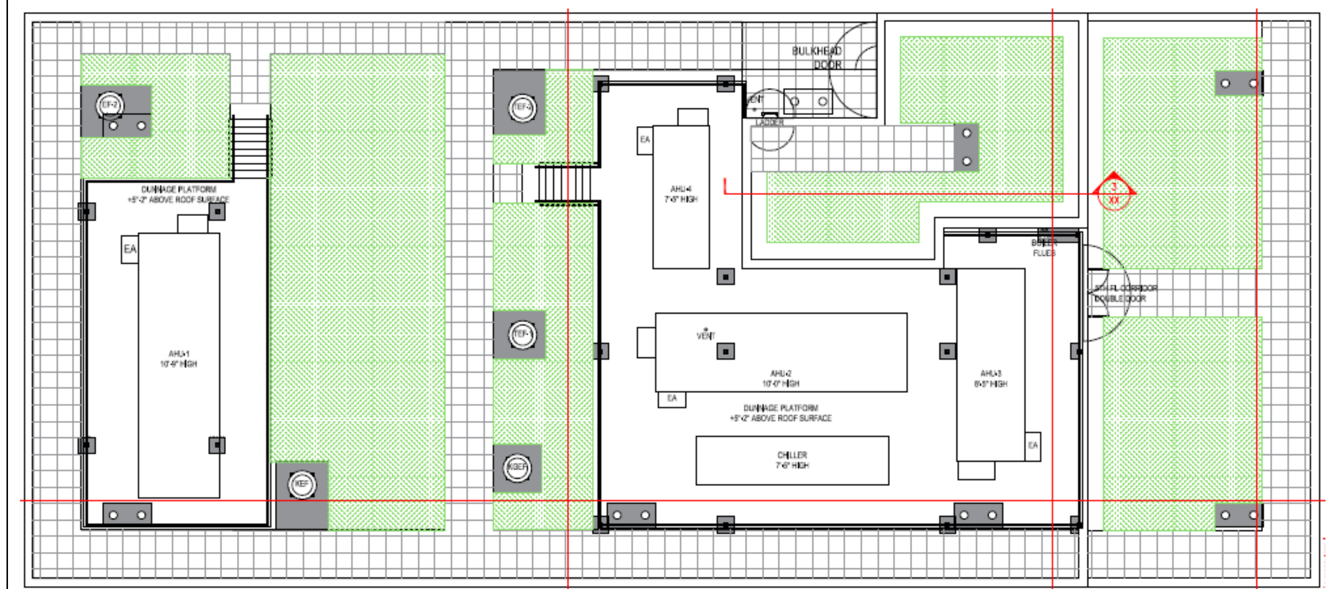
Diagrams of the four schemes are on the following page.

SCHEME A ("BASELINE"): BLUE ROOF



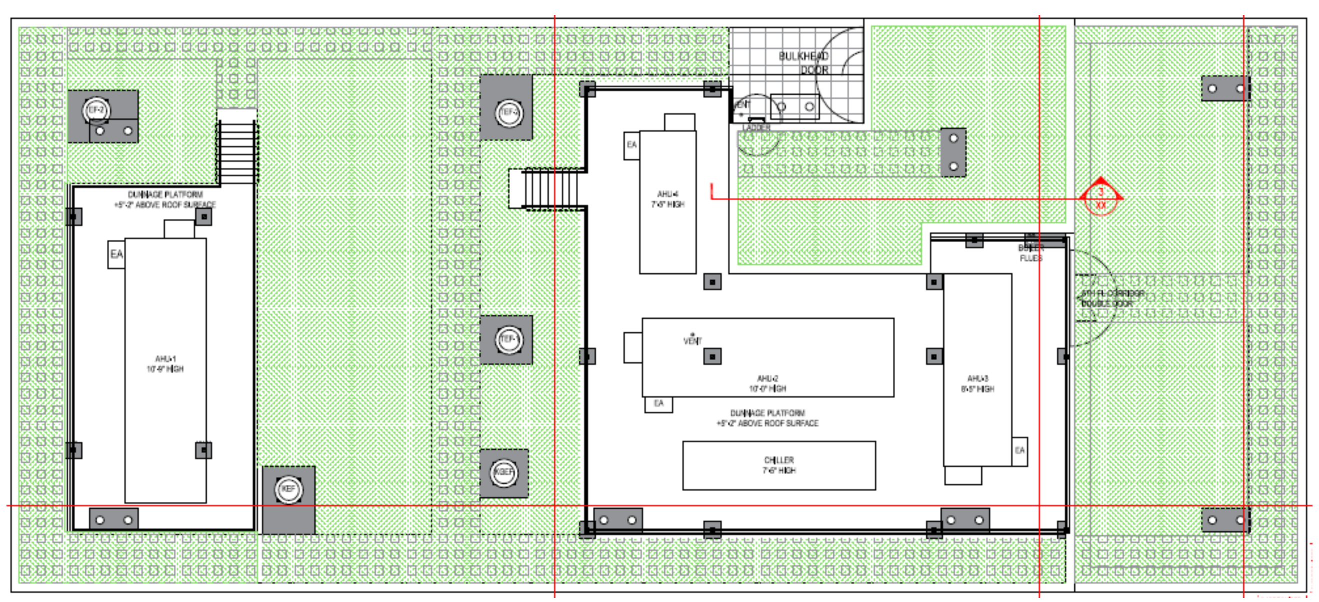
9,271 SF Blue Roof
SCA standard pavers throughout

SCHEME B: ACCESS PATHS AND DUNNAGE EXCLUDED FROM GREEN ROOF



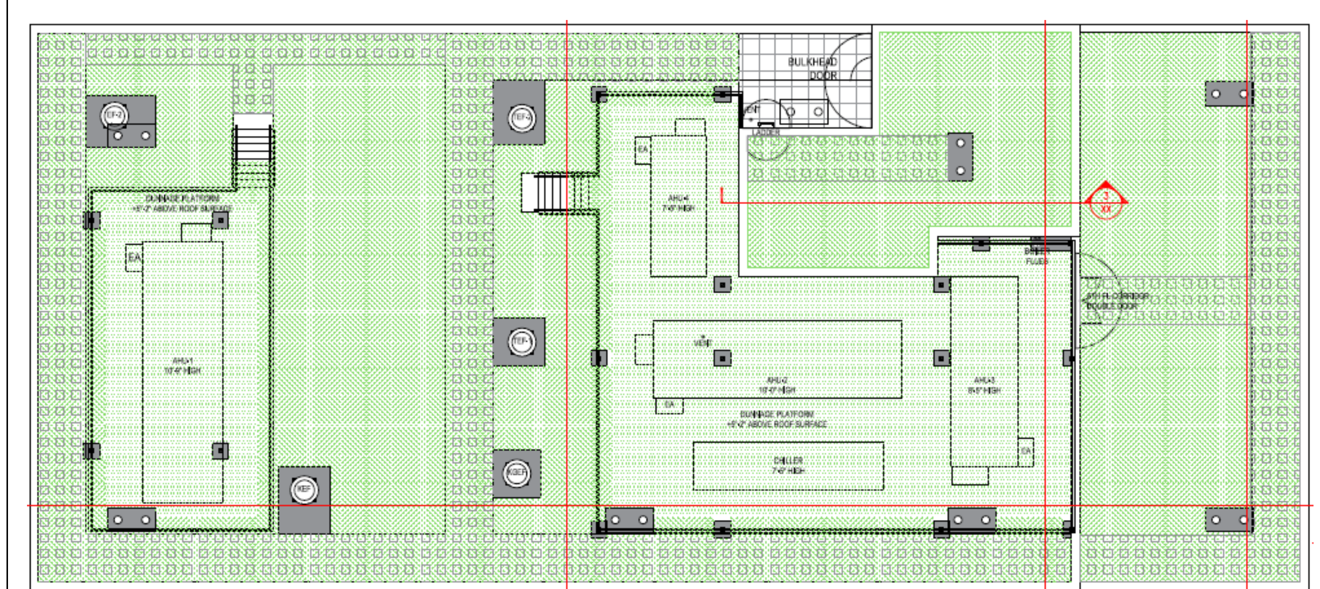
3,544 SF Green Roof / 9,580 SF Blue Roof
SCA standard pavers at FDNY and mechanical access

SCHEME C: DUNNAGE EXCLUDED FROM GREEN ROOF



6,962 SF Green Roof / 9,580 SF Blue Roof
Separated pavers set into green roof substrate

SCHEME D: MAX GREEN ROOF COVERAGE



9,580 SF Green Roof / 9,580 SF Blue Roof
Separated pavers set into green roof substrate

Under the USWR, the required stormwater management volumes and SMP hierarchies for CSS areas differ from those of MS4 areas due to the different stormwater management priorities for each sewer system: CSS areas prioritize stormwater volume and flow, while MS4 areas prioritize stormwater filtration. While the Test Case School is located in a CSS area, all four conceptual rooftop stormwater management designs were evaluated under both the CSS and MS4 requirements of the USWR.

Test Case: Stormwater Management Conceptual Design Options Considered

	Scheme A	*Scheme B*	*Scheme C*	*Scheme D*
Stormwater Management System	Existing blue roof	Access paths and dunnage excluded	Dunnage excluded	Maximum coverage
Blue Roof Area	9,271 sf	9,580 sf	9,580 sf	9,580 sf
Green Roof Area	0 sf	3,544 sf	6,962 sf	9,580 sf
Unified Stormwater Rule Calculations (CSS Area)				
Water Quality Volume (WQv)	2,897 CF	3,348 CF	3,690 CF	3,952 CF
Runoff Reduction Volume (RRv)	0 CF	354 CF	696 CF	958 CF
Sewer Operations Volume (Vv)	2,897 CF	2,994 CF	2,994 CF	2,994 CF
USWR Compliance	NO	NO	***YES***	***YES***
Unified Stormwater Rule Calculations (MS4 Area)				
Water Quality Volume (WQv)	0	354 CF	696 CF	958 CF
Runoff Reduction Volume (RRv)	0	354 CF	696 CF	958 CF
Sewer Operations Volume (Vv)	2,897 CF	2,994 CF	2,994 CF	2,994 CF
USWR Compliance	NO	NO	***YES***	***YES***

PV Canopy Concepts

Four conceptual PV canopy designs were proposed and investigated for this study. It should be noted that while the actual zoning for the Test Case School (R9A + C2-4) would allow rooftop PV canopies of almost any height, the conceptual PV canopy schemes assumed more typical zoning height limitations for R6-R10, C, or M districts (see table on following page).

Scheme 1 represents a "baseline" scenario with SCA standard ballasted panels covering 22% of the building footprint.

- Limiting PV coverage to areas that are not shaded, covered by equipment, or required for FDNY or mechanical access provides only a minimum amount of solar PV production
- Cannot be used with a green roof unless a green roof ballasted PV system is used, which would slightly reduce the number of panels

Scheme 2 uses monolithic tilted arrays which allow for a modest amount of additional coverage, allowing for 26% coverage of the building footprint.

- Monolithic tilted arrays are best for roof areas with short N-S spans, as shown in this scheme, due to the increase in array height from S to N
- Not recommended over green roofs unless at least 9' AFR (as at the lower setback roof) or using semi-transparent panels
- Not recommended over upblast exhaust fans

Scheme 3 uses higher "sawtooth" arrays which allow for PV coverage above the required FDNY clear paths across the roof (but not above the required FDNY access landings at the building perimeter), allowing for 40% coverage of the building footprint.

- PV coverage still excludes large areas at building perimeter, AHUs, upblast fans, shadows from bulkhead and equipment
- The use of separate arrays at the main roof and the bulkhead roof causes some structural inefficiency – the larger the array, the greater the resistance against wind uplift

Scheme 4 represents the most ambitious scenario, with a continuous "sawtooth" array covering the upper roof and bulkhead and a more steeply tilted monolithic array on the lower roof, allowing for 83% coverage of the building footprint.

- Openings in array over chiller and bulkhead access ladder
- Maximum coverage with almost no shading of panels
- Better structural efficiency with one continuous array over main roof and bulkhead
- More steeply tilted monolithic array over lower roof maximizes PV yield but is high enough for sunlight to reach green roof below

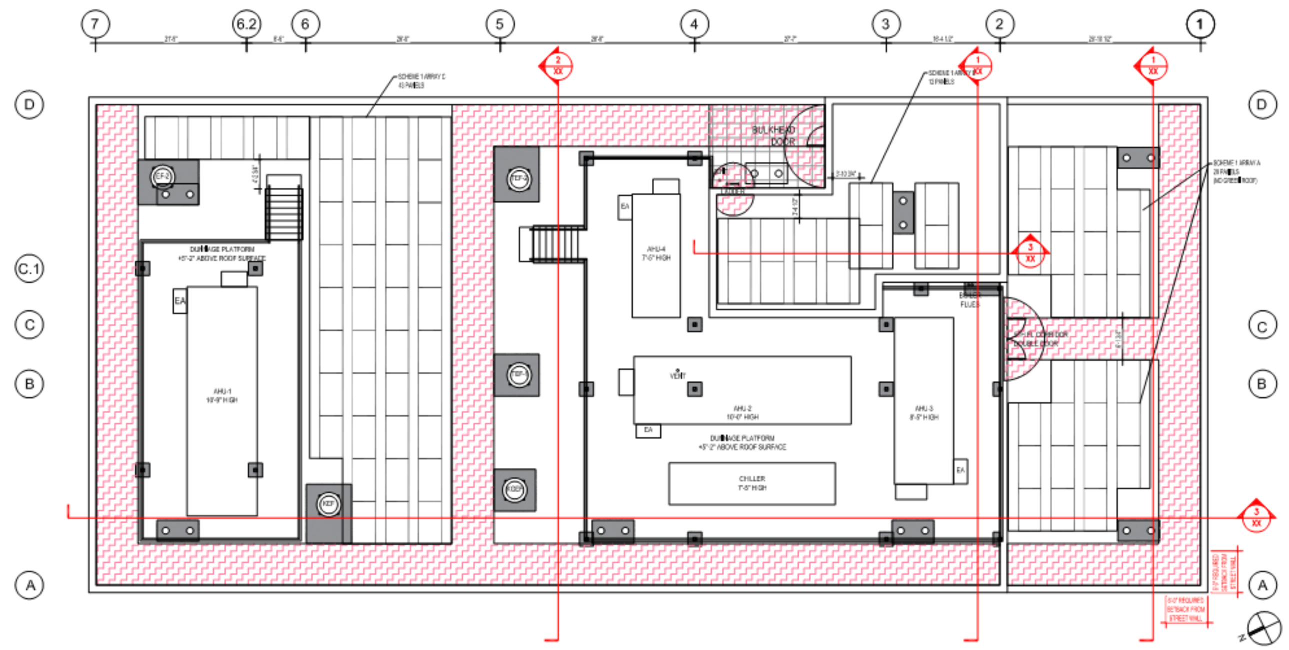
Key characteristics of these schemes are summarized in the following table.

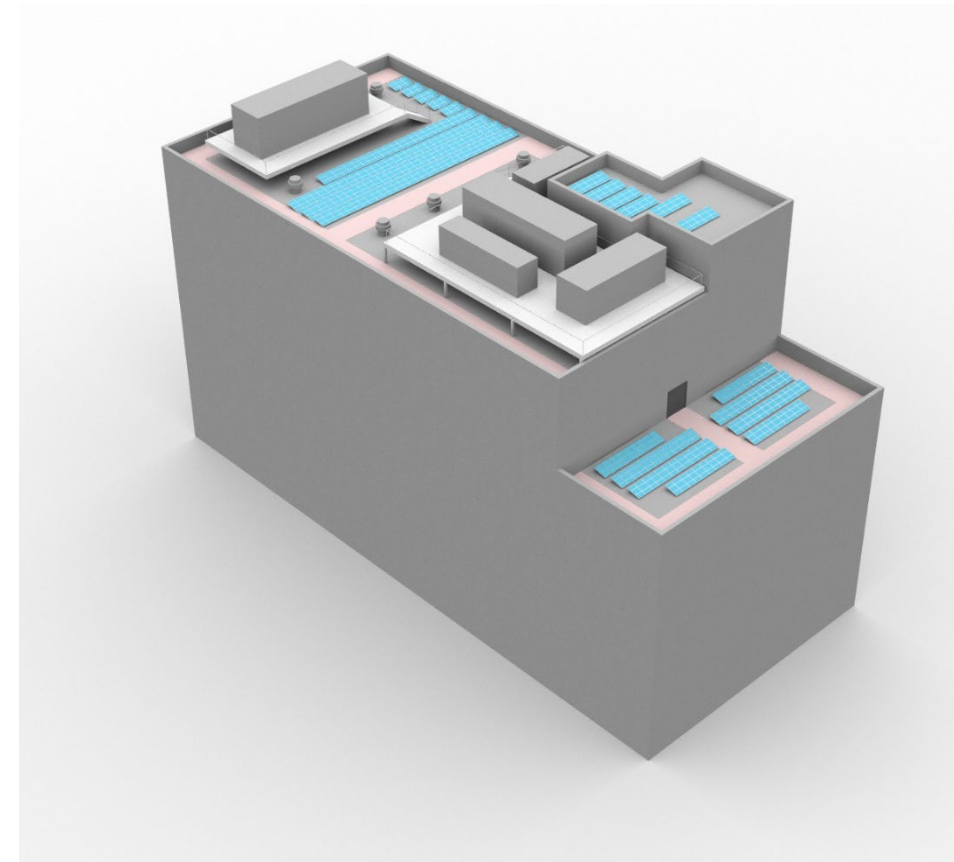
Test Case: PV Canopy Conceptual Design Options Considered

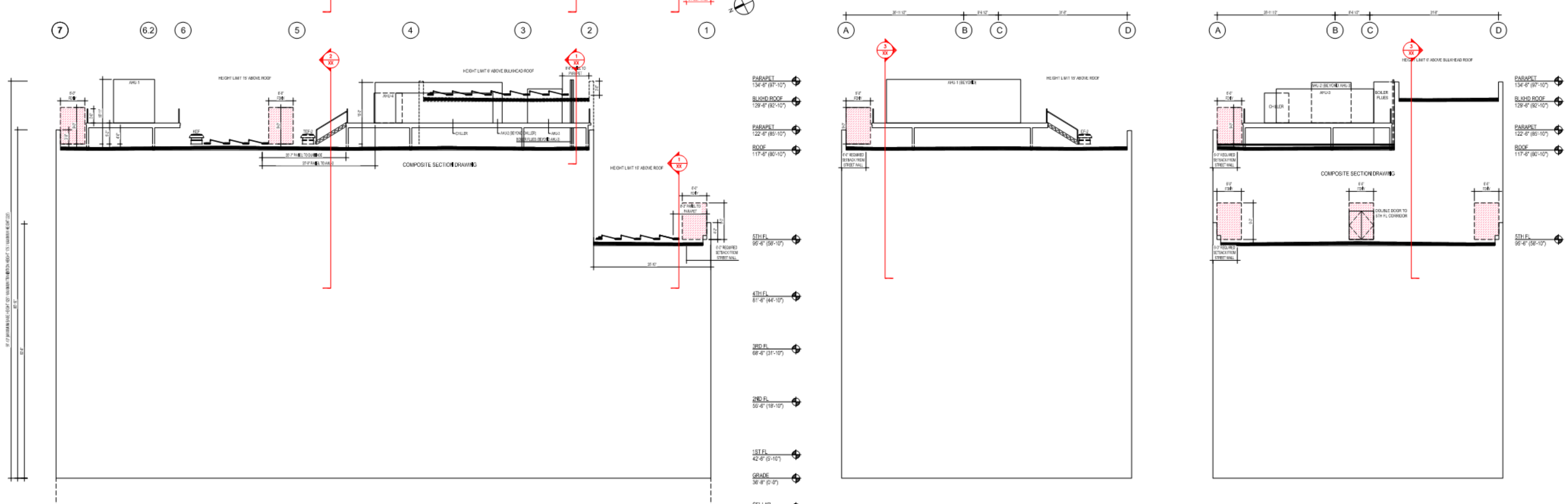
	Scheme 1 (Baseline)	*Scheme 2*	*Scheme 3*	*Scheme 4*
PV System	SCA Standard Ballasted PV Panels	Monolithic Tilted Arrays at all Roofs	“Sawtooth” Arrays at all Roofs	“Sawtooth” Array at Main Roof and Bulkhead; Monolithic Tilted Array at Lower Setback Roof
Maximum PV Height Above Finished Roof	1’-0”	Bulkhead: 6’-0” Upper Roof: 7’-0” Lower Roof: 11’-10”	Bulkhead: 6’-0” Upper Roof: 11’-7” Lower Roof: 10’-5”	Bulkhead: 8’-0” Upper Roof: 20’-0” Lower Roof: 18’-5”
Number of PV Panels and Tilt	83 Panels at 10°	174 Panels (146 at 10° / 28 at 5°)	207 Panels at 5°	437 Panels (346 at 5°/ 91 at 15°)
PV System Size	30.7 kW	64.4 kW	76.6 kW	161.7 kW
PV Panel Coverage	22% of Building Footprint	26% of Building Footprint	40% of Building Footprint	83% of Building Footprint
Zoning Variances Required*	None	Coverage (> 25%)	Coverage (> 25%)	Height (All Roofs) Coverage (> 25%) Setback (< 6’ at Street Wall)
Average Solar Exposure of Panels	86.9%	92.3%	95.0%	98.7%
Annual PV Production	40.0 MWh	64.5 MWh	89.1 MWh	212.0 MWh
Annual Energy Offset	6%	12%	15%	31%
Emissions Reduction	11 MTCO2e	23 MTCO2e	27 MTCO2e	61 MTCO2e

* Assumes Zoning District R6-R10, C, or M with 15’ maximum obstruction height above main roof and lower roof and 6’ maximum obstruction height above bulkhead. In Zoning District R1-R5, C3, or C4-1 any obstructions > 6’ (i.e., Schemes 2, 3, and 4) would require height variances.

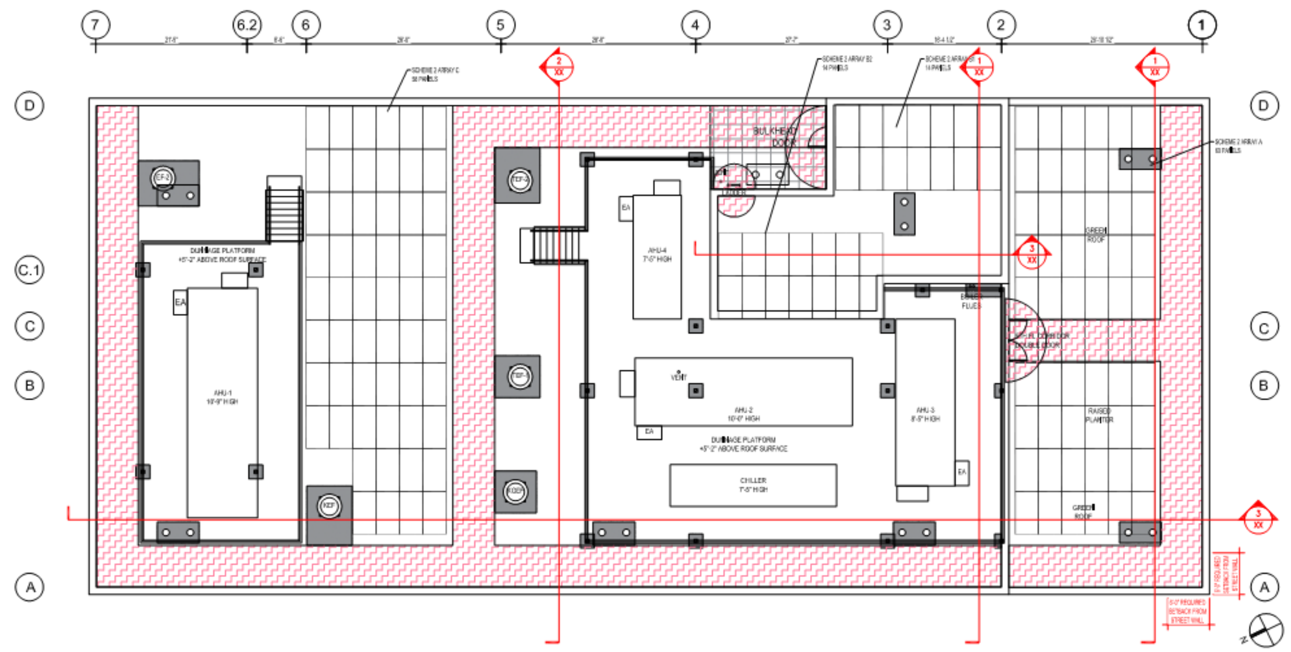
PV SCHEME 1

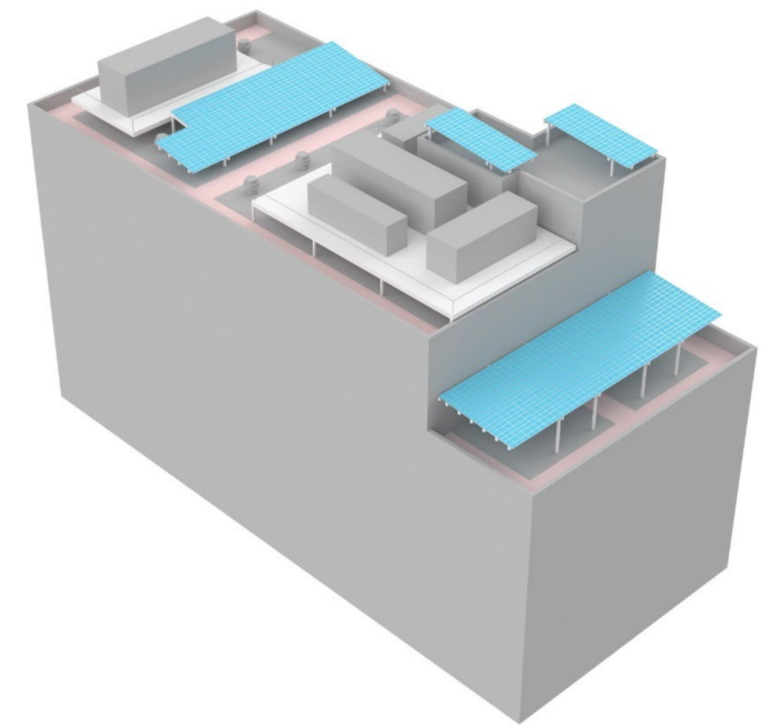


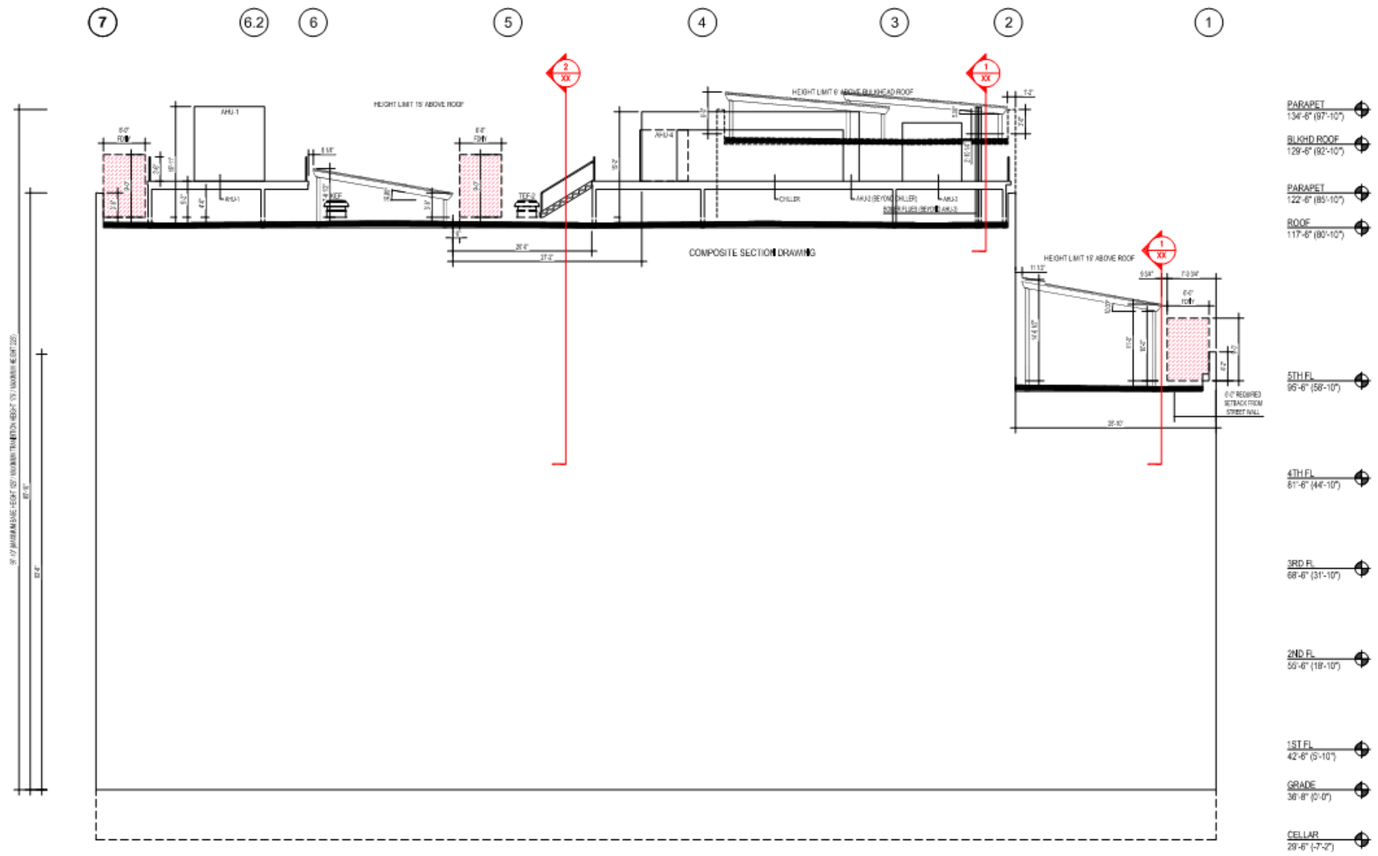


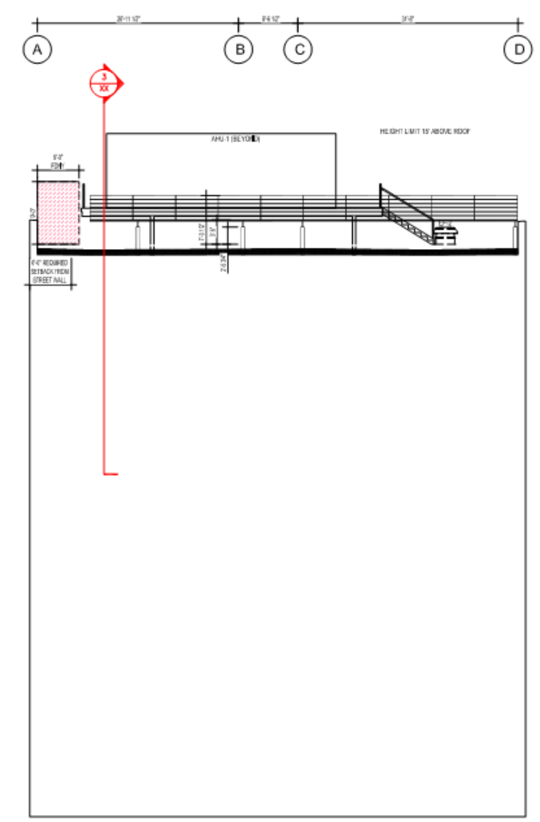

PARAPET
BLKHD ROOF
PARAPET
ROOF
5TH FL
4TH FL
3RD FL
2ND FL
1ST FL
GRADE
CELLAR

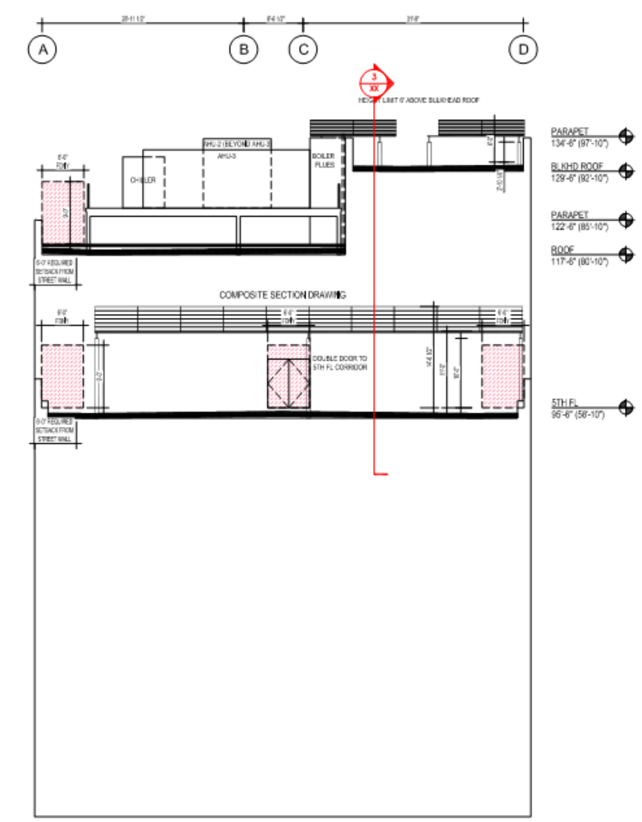
PV SCHEME 2



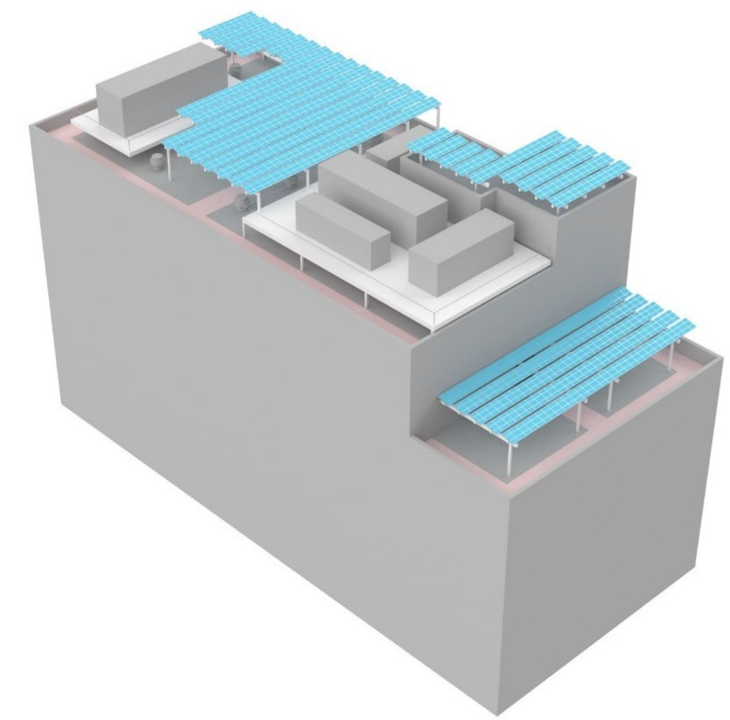


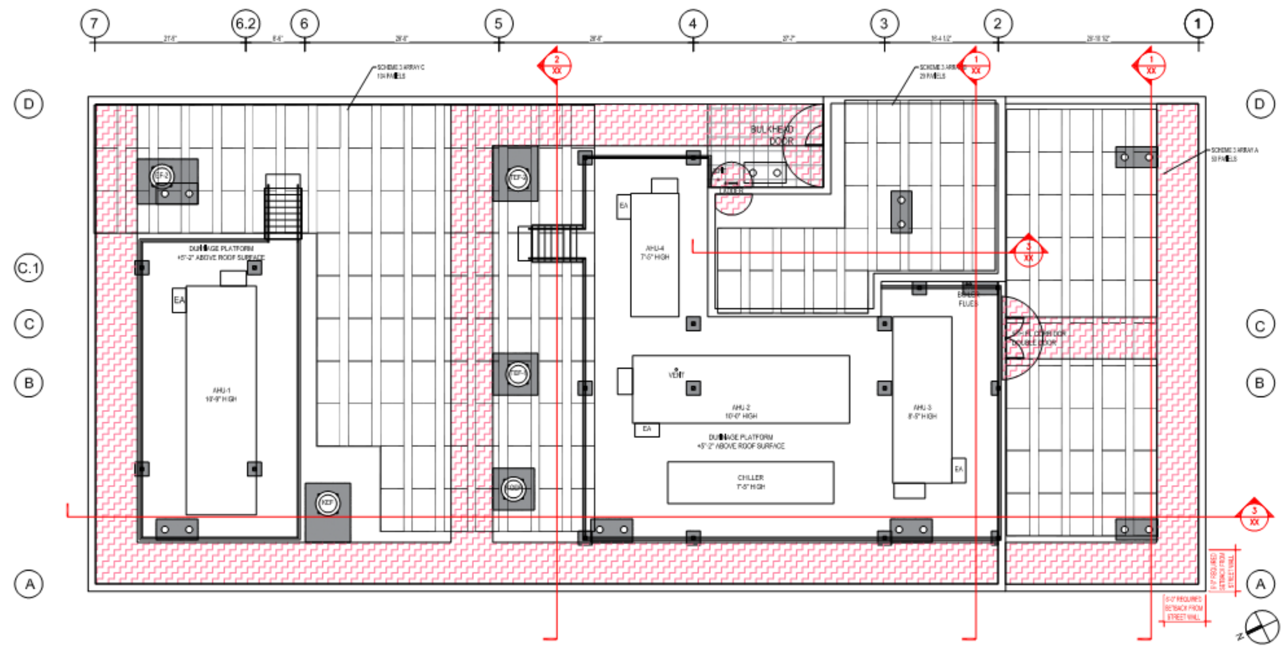


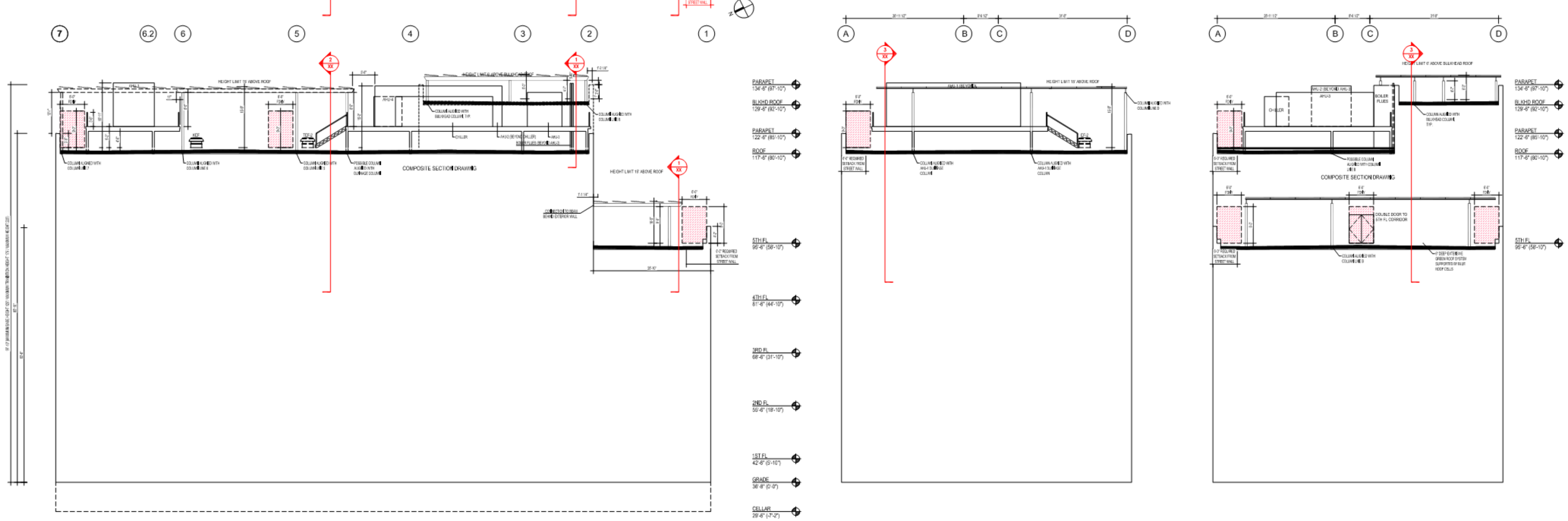




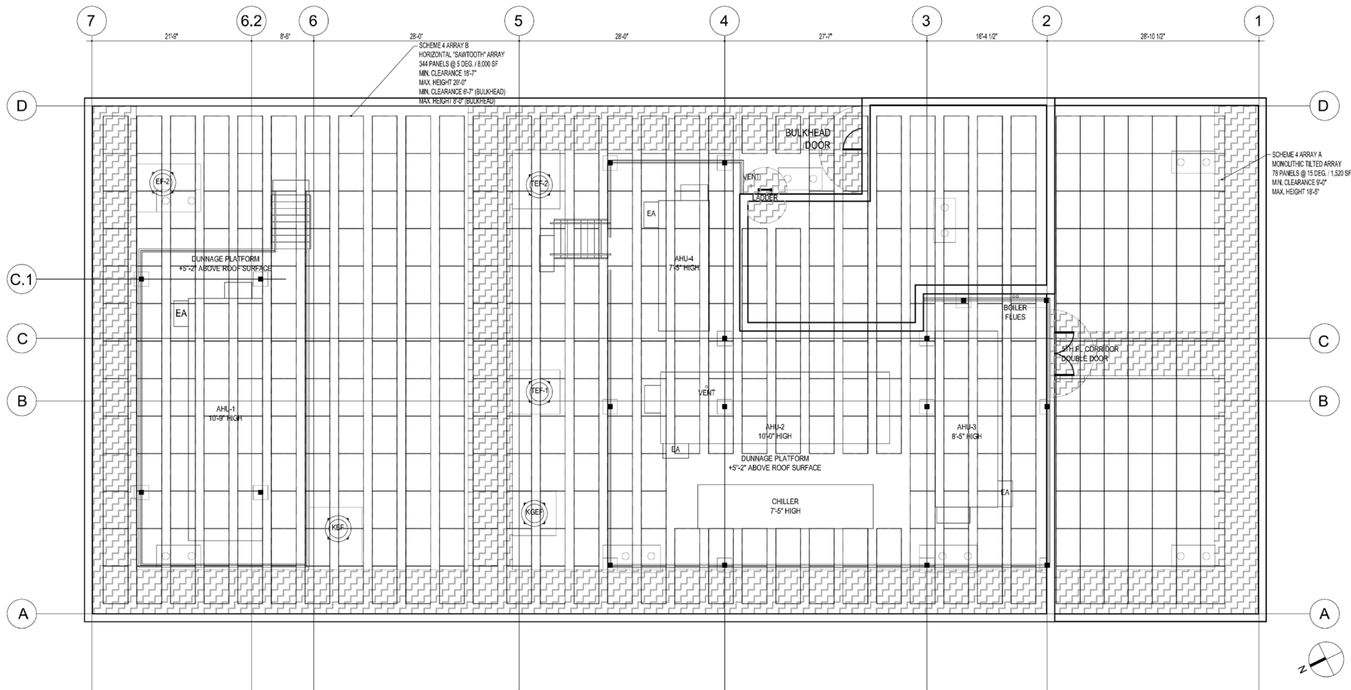
PV SCHEME 3

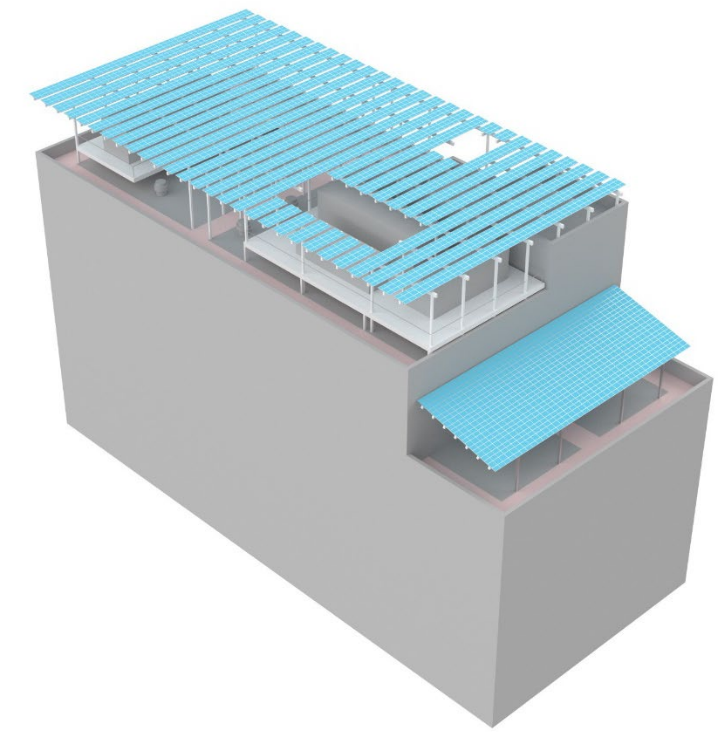


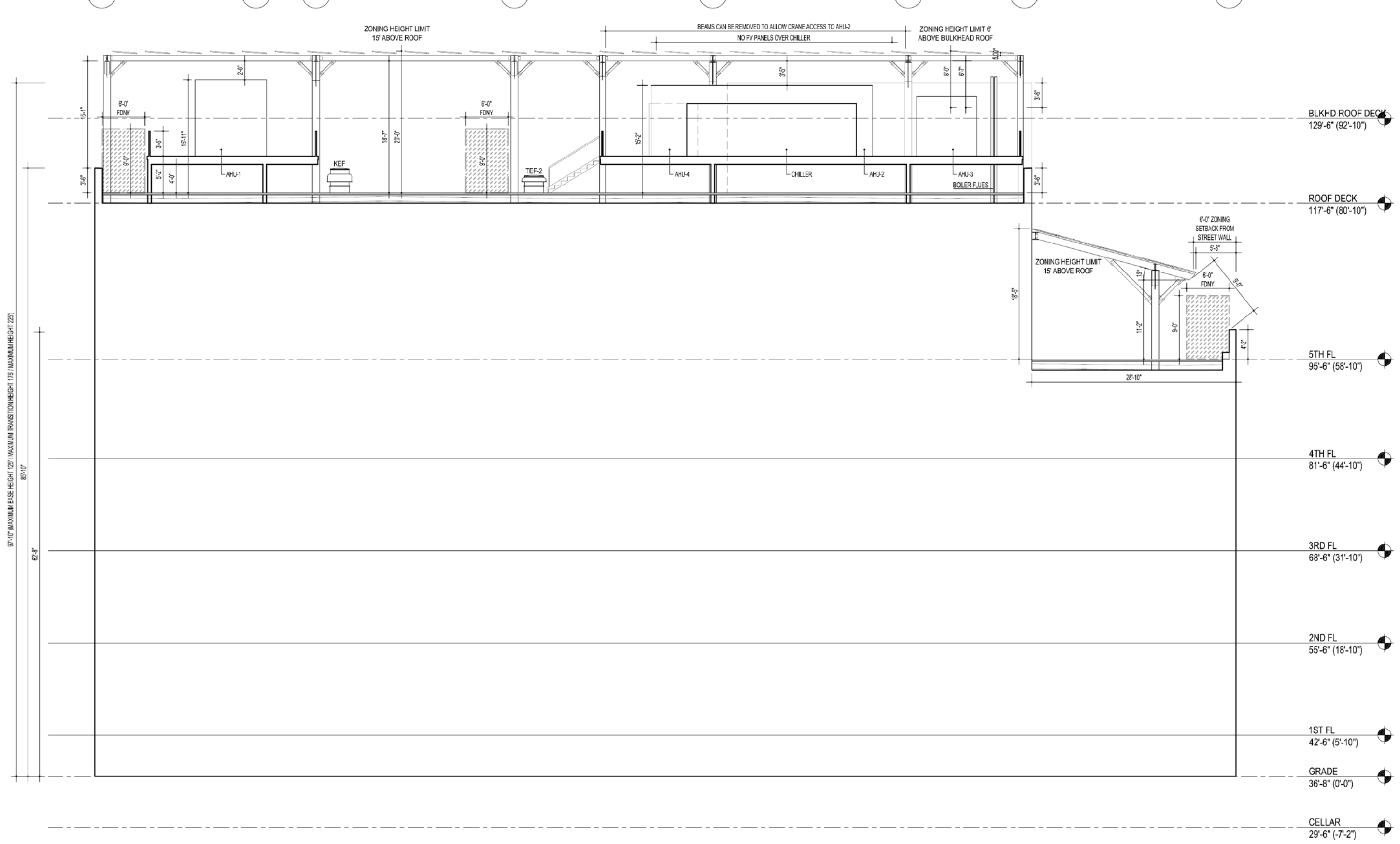


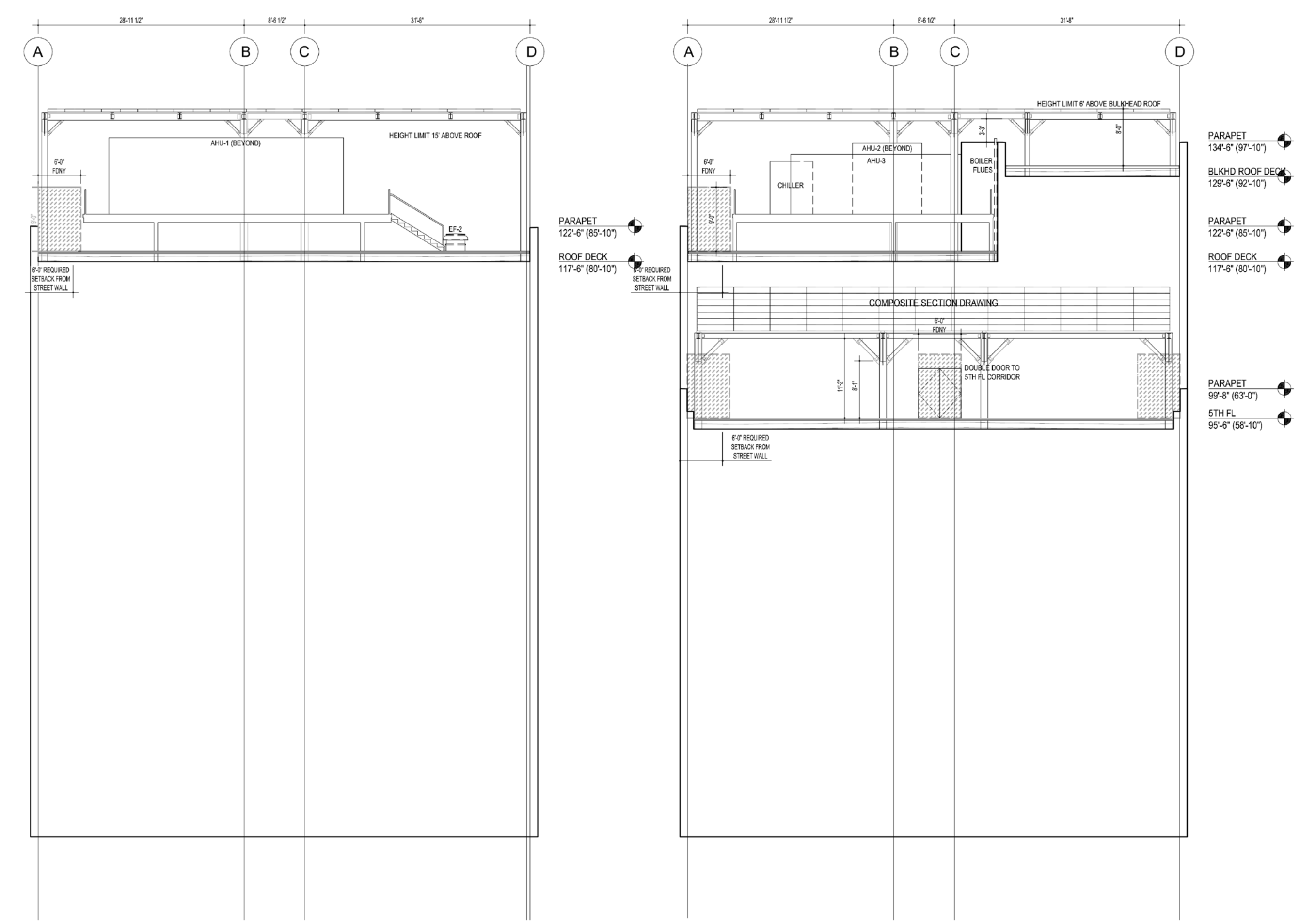


PV SCHEME 4


BULKHEAD DOOR
DUNNAGE PLATFORM
CHILLER




BLKHD ROOF DECK
ROOF DECK
5TH FL
4TH FL
3RD FL
2ND FL
1ST FL
GRADE
CELLAR


PARAPET
ROOF DECK
BLKHD ROOF DECK
COMPOSITE SECTION DRAWING
5TH FL

Combined PV Canopy + Rooftop Stormwater Management Concepts

Scheme 4 was selected for further technical investigation of the PV canopy system design, paired with Scheme C for the rooftop stormwater management design.

Scheme 4 was selected because it provides the maximum feasible rooftop PV production. The continuous array also allows for certain structural efficiencies and uses the same posts to support the PV canopy and mechanical dunnage. Further, the monolithic array over the lower roof maximizes PV yield but is raised high enough below the roof surface for sunlight to reach the green roof beneath.

Scheme C was selected because it provides maximum rooftop coverage without extending the green roof underneath mechanical dunnage and equipment, where access to sunlight would be severely limited. Additionally, Scheme C provides sufficient stormwater management volumes for compliance with all criteria set forth in the USWR.

Technical Demonstration Package

Zoning Compliance

The project is located in zoning district R9A with C2-4 overlay. Effective limitations on any rooftop solar PV canopy more than 4 feet above the finished roof surface (AFR) include:

- Building base height limit: 125' above street level
- Height limit for initial setback: 175'
- Initial setback from street walls: 15'
- Overall building height limit: 225'
- Canopy height limit: 15' above zoning height limit or AFR, whichever is *higher*
- Canopy height limit at bulkhead: 6' above zoning height limit or AFR, whichever is *higher*
- Roof lot coverage of canopy: 25% (x roof area of 11,510 sf = 2,878 sf)
- Canopy setbacks: 6' from street walls (south and west sides of building)

These limitations do not apply to ballasted PV systems, which would be less than 4 feet AFR.

Because the rooftop bulkhead parapet of the Test Case School is 98' above street level, far below the overall building height limit of 225', there are no effective zoning height limitations on a rooftop PV canopy for the building. However, most SCA capacity projects have much lower building height limitations. In a more typical district, assuming that the building's height is at or above the overall building height limit, a rooftop PV canopy would be limited to 15' AFR, with any canopy over the bulkhead limited to 6' AFR.

The proposed (hypothetical) scheme 4 rooftop PV canopy would require the following zoning variances:

- Roof lot coverage of 83% > 25%
- Street wall setback of 5'-8" < 6' at south street wall
- Street wall setback of 2'-6" < 6' at west street wall

In a more typical district, scheme 4 would also require zoning height variances at both the main roof (canopy height of 20'-0" > 15' AFR) and bulkhead roof (canopy height of 8'-0" > 6' AFR).

Because it is unoccupied and unenclosed, the rooftop PV canopy does not count against the building's zoning floor area ratio (FAR) allowance.

FDNY Compliance

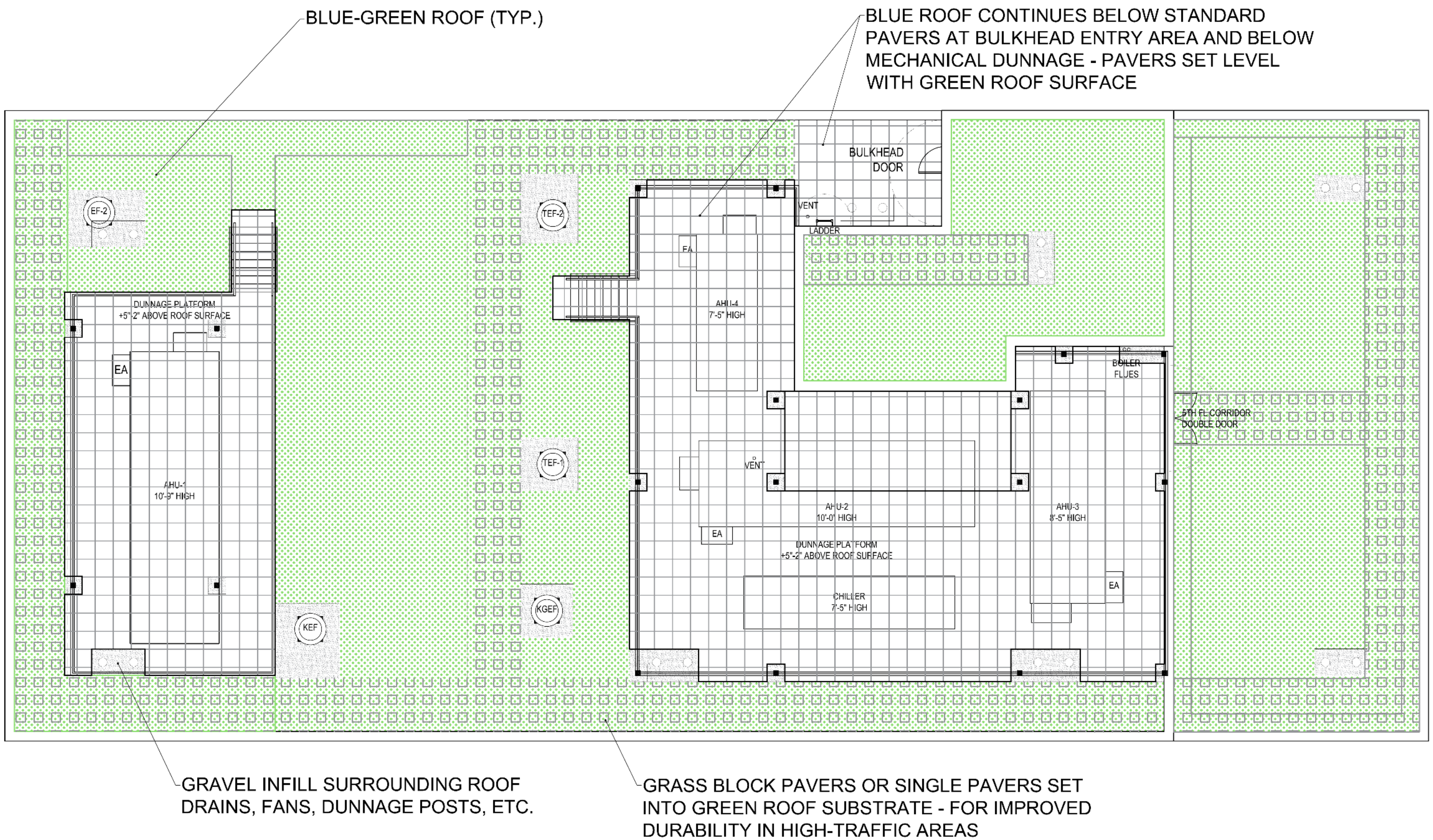
Scheme 4 meets the FDNY requirements for landings at all roof perimeters accessible to firefighting apparatus (south and west perimeters) and clear paths across each roof from front to back and side to side. Small bulkheads are exempted from these requirements.

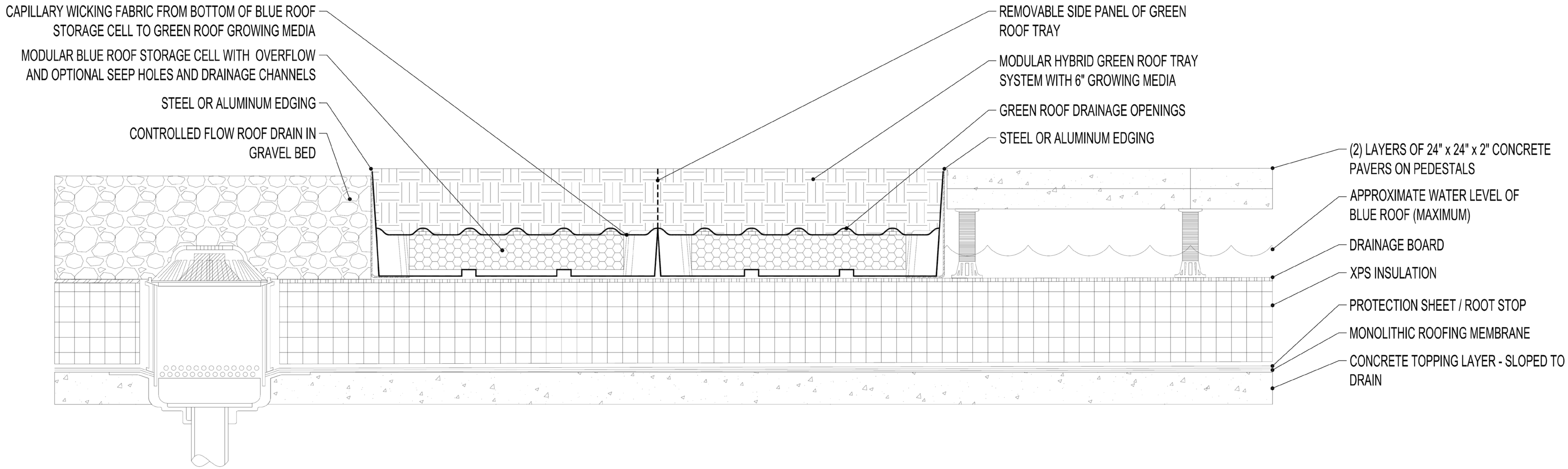
NYC 2014 Building Code Compliance

Scheme 4 meets Building Code requirements for wind and seismic resistance and fire resistance.

Scheme 4 meets Building Code requirements for the sustainable roofing zone.

Rooftop SMP Drawings



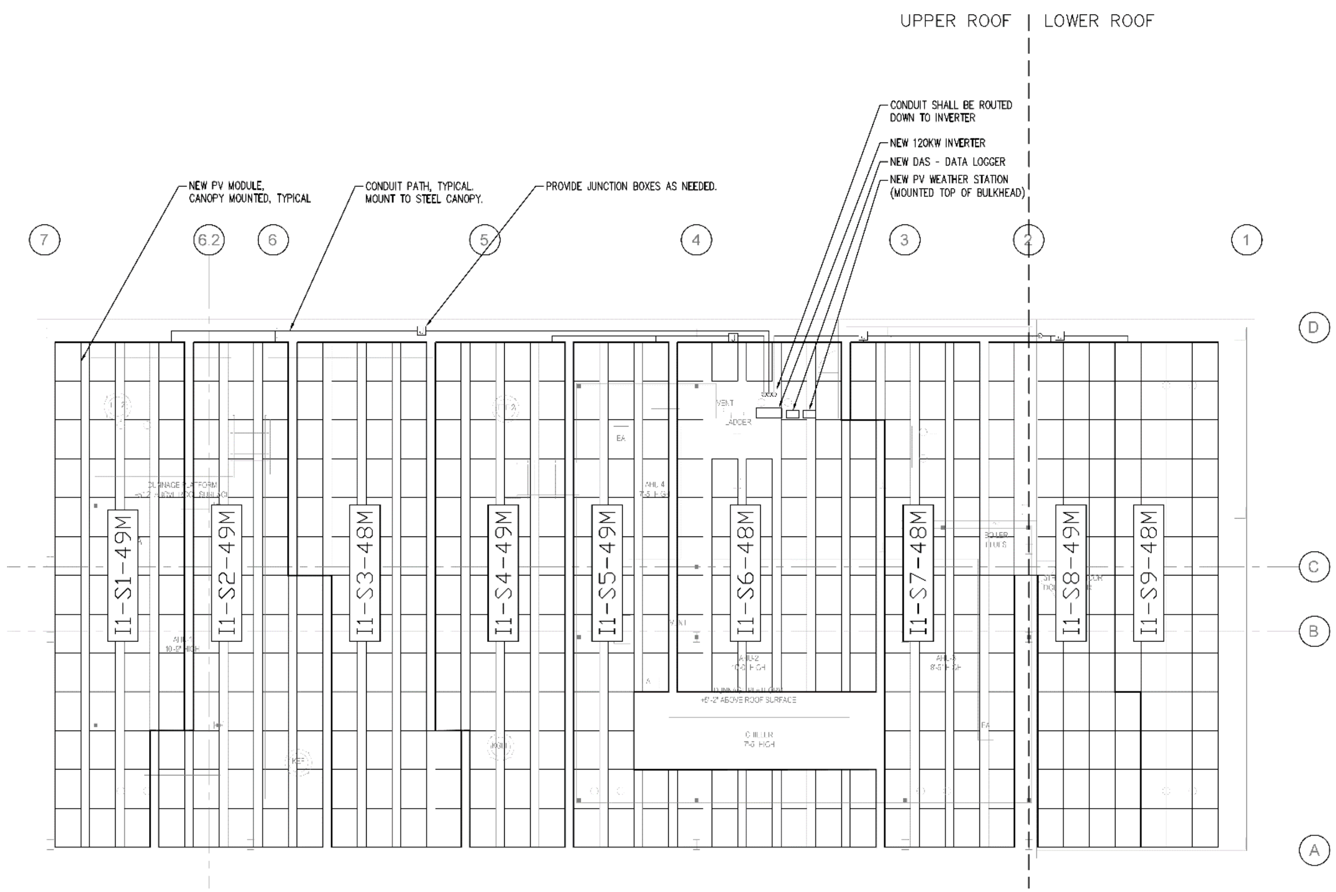


01 **BLUE-GREEN ROOF DETAIL**

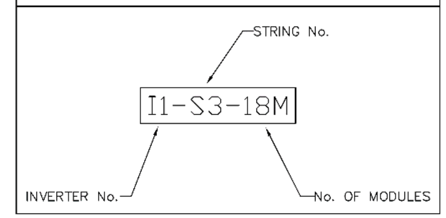
SCALE: 1" = 1'-0"

PV Canopy Drawings

PV SYSTEM INFORMATION	
PV CAPACITY (DC @STC)	161.690 KW - (437) SUNPOWER X22-370-COM, 370W MODULES
POWER OPTIMIZERS (DC)	(221) SOLAREDGE P860, 860W OPTIMIZERS
INVERTERS (AC)	SOLAREDGE: (1) SE120KUS - 120KW INVERTER
RACKING SYSTEM	UNISTRUT ANCHORED TO STEEL CANOPY
MODULE ORIENTATION	7° & 15° TILT @ 206° AZIMUTH (ROOF 0° TILT)
ROW SPACING	17" (N-S) & 3/8" (E-W) [LEVEL PV CANOPY], 3/8" (N-S) & 3/8" (E-W) [MONO-SLOPED PV CANOPY]

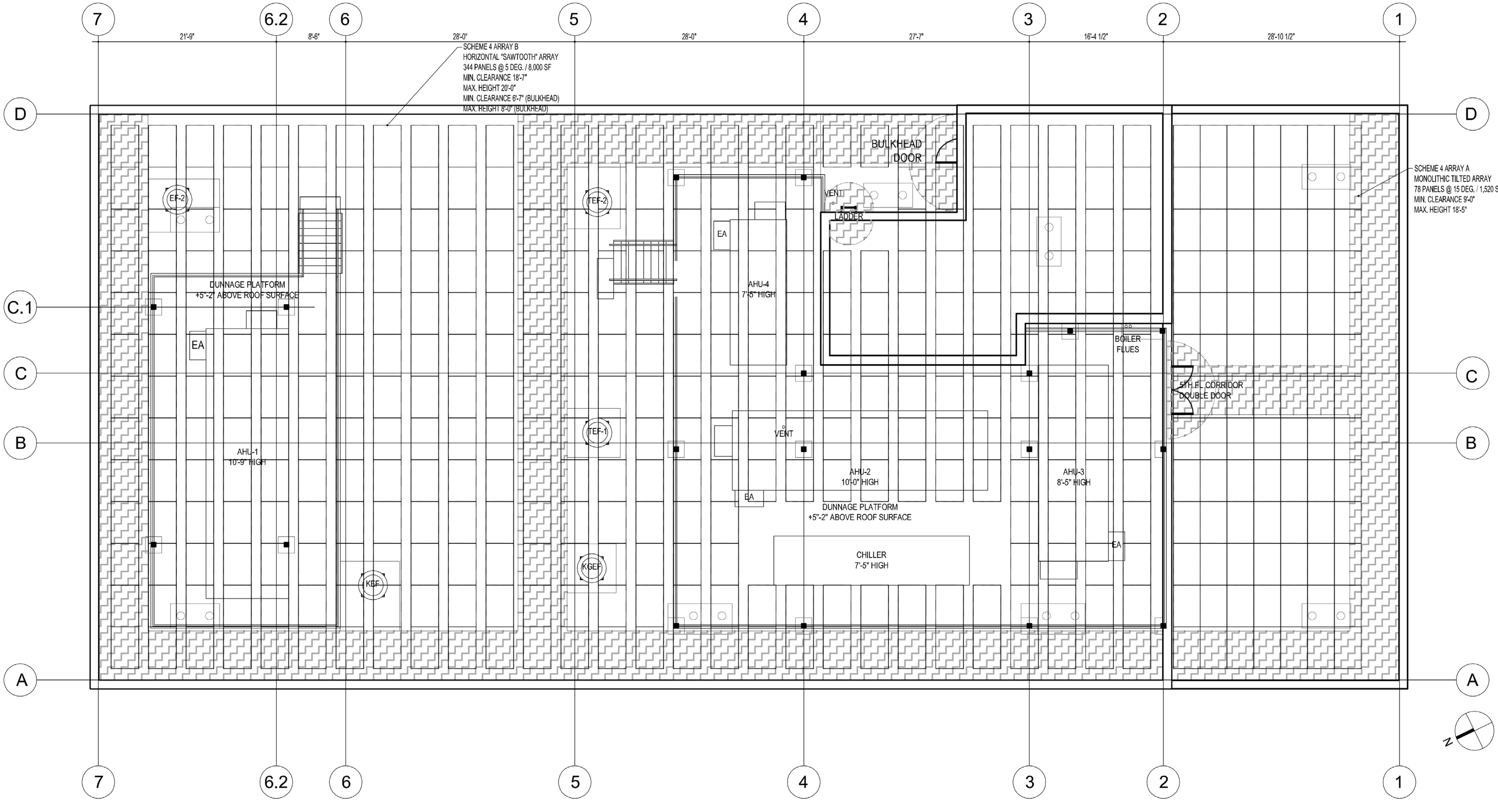


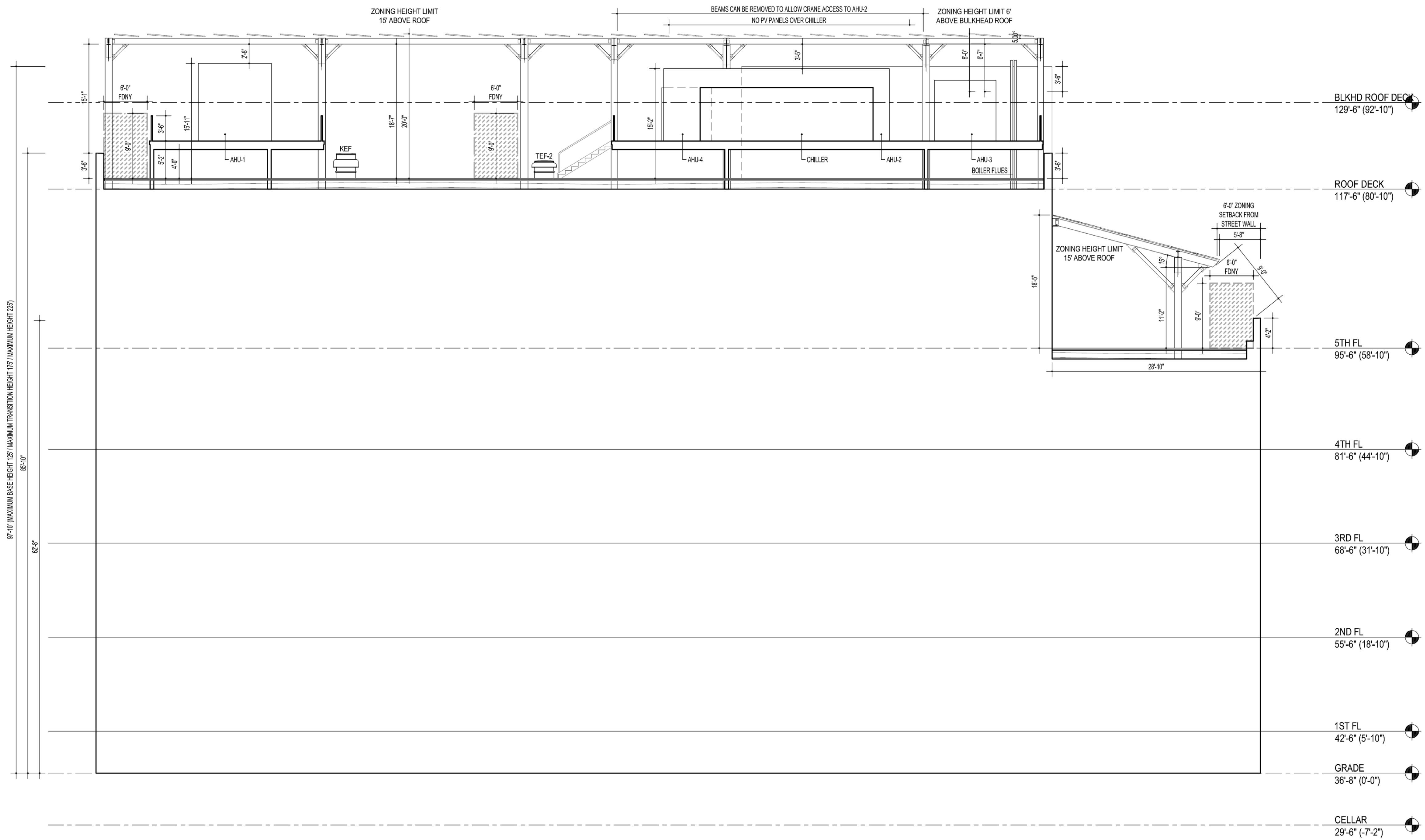
LEGEND

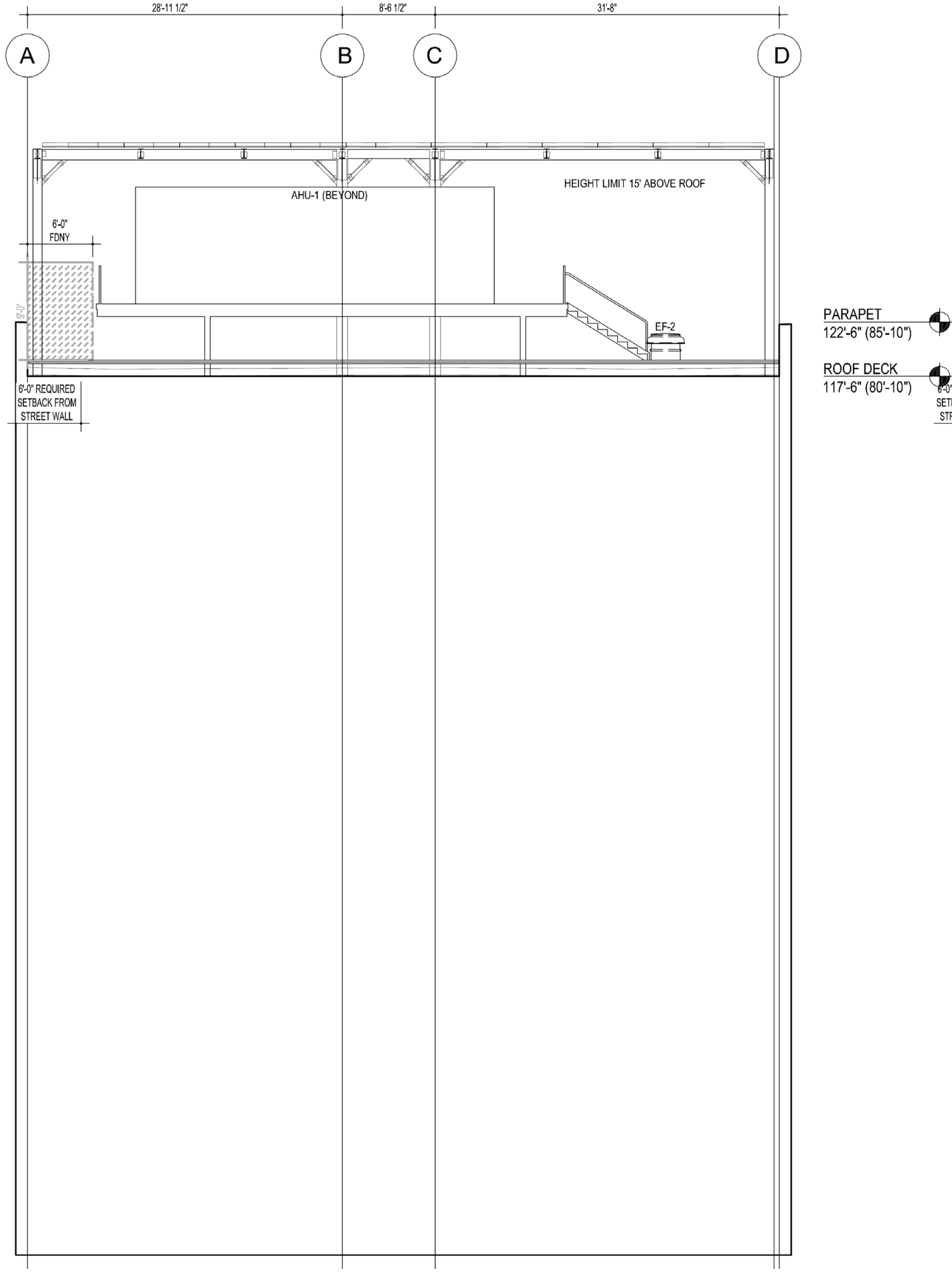


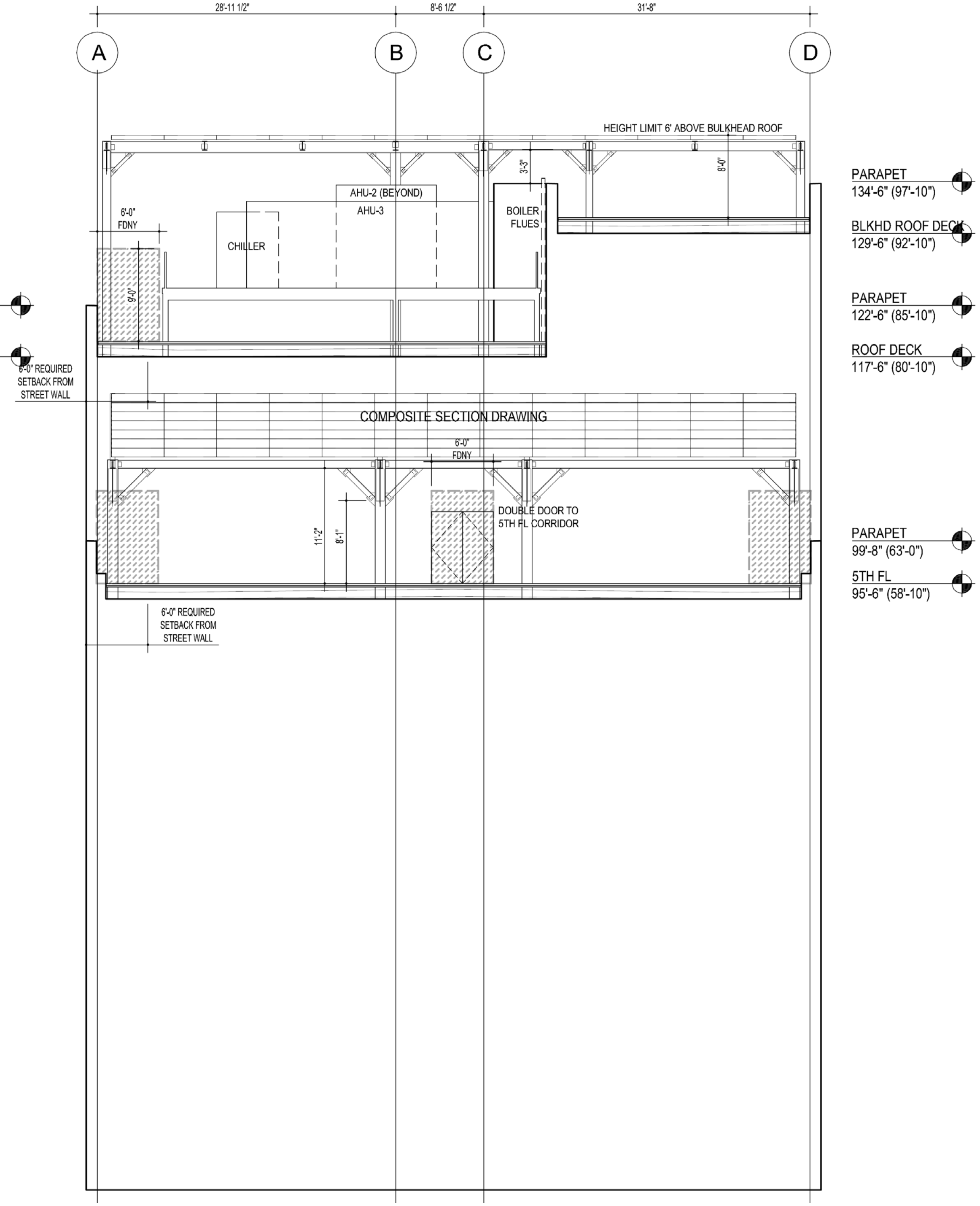
PLAN NOTES:

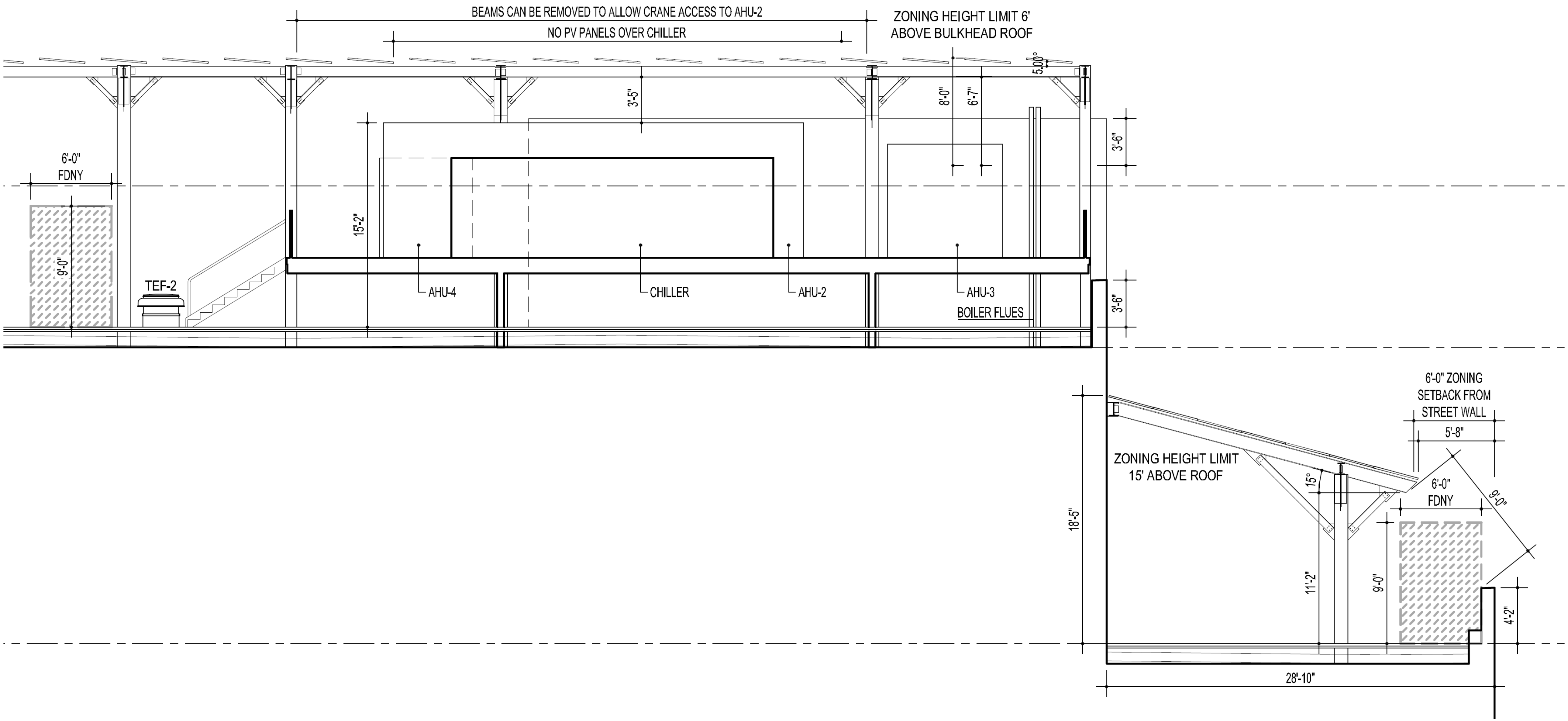
1. ALL OUTDOOR EQUIPMENT SHALL BE NEMA 3R RATED, U.O.N
2. ALL CONDUCTORS IN CONDUIT OR EXPOSED SHALL COMPLY WITH THE CABLE MANAGEMENT DETAILS 1,2,3 ON PAGE PV502. ALL EXPOSED WIRING SHALL BE SECURED USING METAL CLIPS AS PER NECA 1-2015.
3. HIGH VOLTAGE CONDUIT SHALL BE SHALL BE COLOR-CODED WITH CONTINUOUS, DURABLE AND WEATHERPROOF REFLECTIVE OR LUMINESCENT RED MARKINGS AS PER FDNY 504.4.7 - ROOFTOP CONDUITS AND PIPING.
4. USE MANUFACTURER TRUNK CABLES FOR POWER OPTIMIZER WIRING.
5. ALL CONDUIT PENETRATIONS SHALL BE SEALED WITH APPROVED FIRE RESISTANT CAULK.
6. ADHERE TO ALL WIRE SIZES AND CONDUIT FILL RATE SPECIFIED ON PV301, AND AS PER NEC, ARTICLE 310.
7. MOUNT ALL AC ELECTRICAL EQUIPMENT ON WALL USING MANUFACTURER RECOMMENDED WALL MOUNT.
8. ALL AC EQUIPMENT SHALL BE MOUNTED AT LEAST 2 FT ABOVE FLOOR AND MUST COMPLY WITH MANUFACTURER'S CLEARANCES, AS WELL AS NEC, ARTICLE 110.
9. SEE PV301 FOR ALL ELECTRICAL EQUIPMENT DATA.
10. CONTRACTOR SHALL COORDINATE WITH SOLAREDGE MANUFACTURER FOR DAS INTEGRATION & MONITORING; PROVIDE REVENUE GRADE METER, DATA LOGGER (W NEMA-3 ENCLOSURE), COMPLETE SET OF WEATHER SENSORS, AND SHALL BE HARD WIRED TO MDF CLOSET. RUN SHALL FOLLOW PV CONDUIT RISER. SEE PV301/PV501 FOR MORE DETAILS, AND SPEC 13602 FOR SPECIFICATIONS.


7
6.2
6
5
4
3
2
1
21'-9"
8'-6"
28'-0"
28'-0"
27'-7"
16'-4 1/2"
28'-10 1/2"
SCHEME 4 ARRAY B
HORIZONTAL "SAWTOOTH" ARRAY
344 PANELS @ 5 DEG. / 8,000 SF
MIN. CLEARANCE 18'-7"
MAX. HEIGHT 20'-0"
MIN. CLEARANCE 6'-7" (BULKHEAD)
MAX. HEIGHT 8'-0" (BULKHEAD)
SCHEME 4 ARRAY A
MONOLITHIC TILTED ARRAY
78 PANELS @ 15 DEG. / 1,520 SF
MIN. CLEARANCE 9'-0"
MAX. HEIGHT 18'-5"
D
C.1
C
B
A
BULKHEAD
DOOR
VENT
LADDER
EF-2
TEF-2
EA
DUNNAGE PLATFORM
+5'-2" ABOVE ROOF SURFACE
AHU-4
7'-5" HIGH
BOILER
FLUES
5TH FL CORRIDOR
DOUBLE DOOR
AHU-1
10'-9" HIGH
TEF-1
VENT
AHU-2
10'-0" HIGH
AHU-3
8'-5" HIGH
DUNNAGE PLATFORM
+5'-2" ABOVE ROOF SURFACE
CHILLER
7'-5" HIGH
KGEF
KEF
N

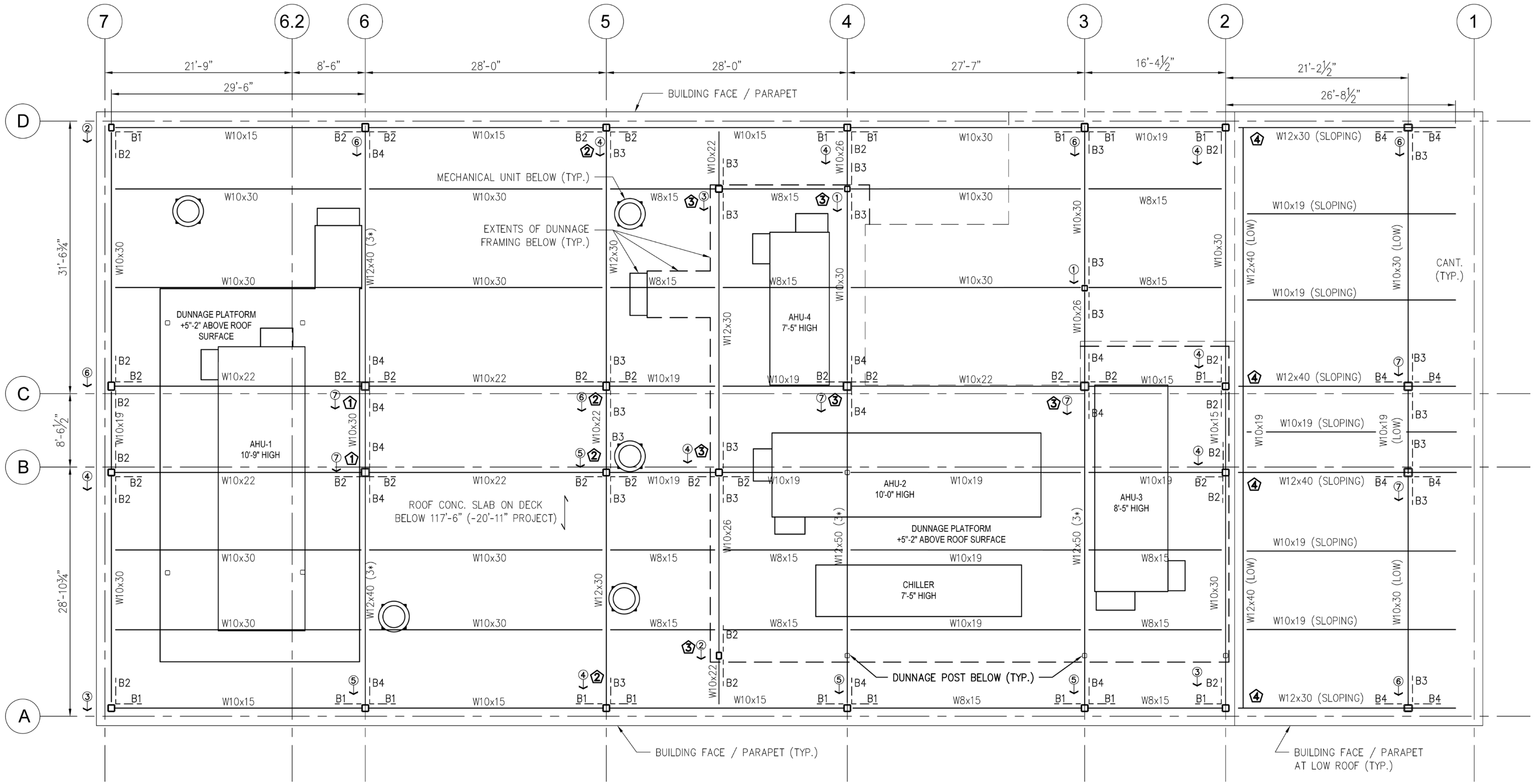

ZONING HEIGHT LIMIT 15' ABOVE ROOF
BEAMS CAN BE REMOVED TO ALLOW CRANE ACCESS TO AHU-2
NO PV PANELS OVER CHILLER
ZONING HEIGHT LIMIT 6' ABOVE BULKHEAD ROOF
FDNY
KEF
TEF-2
AHU-1
AHU-4
CHILLER
AHU-2
AHU-3
BOILER FLUES
BLKHD ROOF DECK 129'-6" (92'-10")
ROOF DECK 117'-6" (80'-10")
6'-0" ZONING SETBACK FROM STREET WALL
ZONING HEIGHT LIMIT 15' ABOVE ROOF
5TH FL 95'-6" (58'-10")
4TH FL 81'-6" (44'-10")
3RD FL 68'-6" (31'-10")
2ND FL 55'-6" (18'-10")
1ST FL 42'-6" (5'-10")
GRADE 36'-8" (0'-0")
CELLAR 29'-6" (-7'-2")
28'-10"
97'-10" (MAXIMUM BASE HEIGHT 125' / MAXIMUM TRANSITION HEIGHT 175' / MAXIMUM HEIGHT 225')
85'-10"
62'-8"


28'-11 1/2"
8'-6 1/2"
31'-8"
A
B
C
D
HEIGHT LIMIT 15' ABOVE ROOF
AHU-1 (BEYOND)
6'-0"
FDNY
EF-2
6'-0" REQUIRED
SETBACK FROM
STREET WALL
PARAPET
122'-6" (85'-10")
ROOF DECK
117'-6" (80'-10")


28'-11 1/2"
8'-6 1/2"
31'-8"
A
B
C
D
HEIGHT LIMIT 6' ABOVE BULKHEAD ROOF
AHU-2 (BEYOND)
AHU-3
CHILLER
BOILER
FLUES
6'-0"
FDNY
6'-0" REQUIRED
SETBACK FROM
STREET WALL
COMPOSITE SECTION DRAWING
6'-0"
FDNY
DOUBLE DOOR TO
5TH FL CORRIDOR
6'-0" REQUIRED
SETBACK FROM
STREET WALL
PARAPET
134'-6" (97'-10")
BLKHD ROOF DECK
129'-6" (92'-10")
PARAPET
122'-6" (85'-10")
ROOF DECK
117'-6" (80'-10")
PARAPET
99'-8" (63'-0")
5TH FL
95'-6" (58'-10")



BEAMS CAN BE REMOVED TO ALLOW CRANE ACCESS TO AHU-2
NO PV PANELS OVER CHILLER
ZONING HEIGHT LIMIT 6' ABOVE BULKHEAD ROOF
5.00°
3'-5"
8'-0"
6'-7"
3'-6"
6'-0" FDNY
9'-0"
15'-2"
TEF-2
AHU-4
CHILLER
AHU-2
AHU-3
BOILER FLUES
3'-6"
6'-0" ZONING SETBACK FROM STREET WALL
5'-8"
ZONING HEIGHT LIMIT 15' ABOVE ROOF
15°
6'-0" FDNY
9'-0"
18'-5"
11'-2"
9'-0"
4'-2"
28'-10"



1 SOLAR CANOPY FRAMING PLAN

SCALE: 1/8"=1'-0"

1 SOLAR CANOPY FRAMING PLAN

SCALE: 1/8"=1'-0"

N

NOTES:

1. THIS DRAWING IS NOT FOR CONSTRUCTION OR PRICING.
2. ELEVATIONS SHOWN THUS: (+#'-##") ARE RELATIVE TO PROJECT DATUM (+0'-0").
3. TOP OF STEEL BEAMS AND POSTS (+0'-0"), U.O.N.
4. ALL STEEL TO BE G90 GALVANIZED, U.O.N.
5. W-SHAPE STEEL MEMBERS TO BE COMPRISED OF ASTM A992 (Fy=50ksi) STEEL, HSS MEMBERS TO BE ASTM A500 GRADE C (Fy=50ksi), MISC. STEEL INCL. PLATES TO BE ASTM A36 (Fy=36ksi). BOLTS TO BE ASTM F3125 GRADE A325 U.O.N. (BOLTED SHEAR CONNECTION DESIGN CONSIDERS THREADS INCLUDED.)
6. ALL PV CANOPY POSTS ARE LOCATED AT BUILDING MAIN COLUMNS, CONTINUOUS TO BUILDING FOUNDATION, U.O.N. SEE KEYNOTES.
7. FILLER BEAMS (NOT AT COLUMN GRID LINES) TO BE SPACED EVENLY. COORDINATE POST LOCATIONS WITH ORIGINAL BUILDING DESIGN DRAWINGS BY SBLM ARCHITECTS, SILMAN STRUCTURAL ENGINEERS, AND OTHERS.

SYMBOLS:

(#) INDICATES POST DOWN (SUPPORTING PV CANOPY), SEE SCHEDULE FOR SIZE MATCHING #

POST # SCHEDULE							
#	1	2	3	4	5	6	7
HSS	8x8x3/8	10x8x3/8	10x10x5/16	10x10x3/8	10x10x1/2	12x10x3/8	12x12x3/8

B# INDICATES 45° KNEE-BRACE MOMENT CONNECTION, SEE SCHEDULE AND SEE ALSO TYPICAL KNEE-BRACE CONNECTION DETAIL.

45° KNEE BRACE SCHEDULE				
B#	1	2	3	4
ECCENTRICITY 'e' [DIST.]	2'-9"	2'-9"	2'-9"	4'-0"
BRACE ∠ [NOMINAL]	4x4x3/8	4x4x3/8	5x5x3/8	6x6x3/8
3/4"ø A325 BOLTS [#]	2	3	4	4

(N*) BEAMS MARKED THUS REQUIRE SINGLE-PLATE CONNECTION AT EACH END W/ N 3/4"ø ASTM A325 BOLTS. ALL BEAMS REQUIRE SINGLE-PLATE CONNECTIONS AT SUPPORTING BEAMS OR HSS POSTS. TYPICAL CONNECTIONS REQUIRE 2 3/4"ø ASTM A325 BOLTS UNLESS OTHERWISE NOTED IN PLAN.

KEYNOTES:

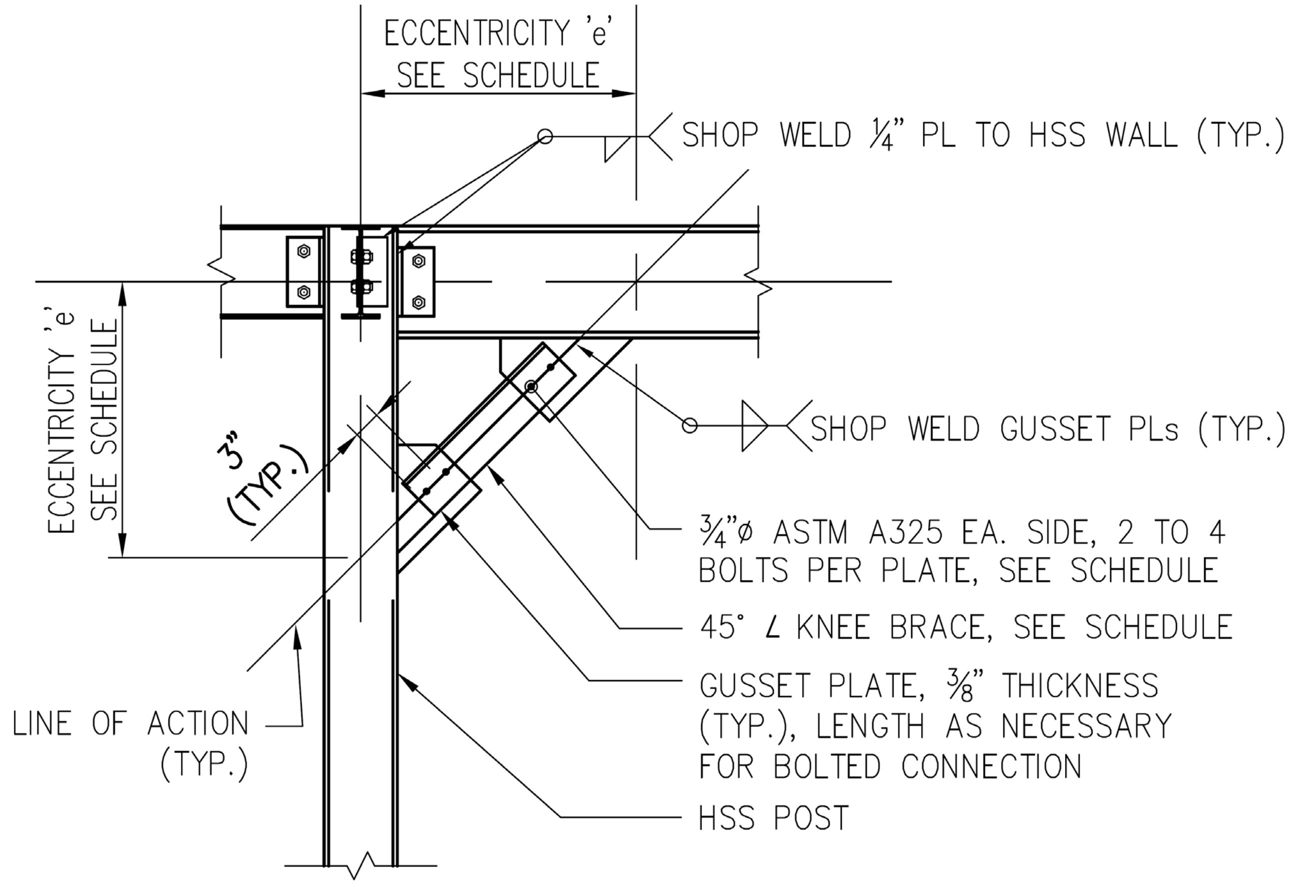
(1) INDICATED PV CANOPY POSTS (2 TOTAL) ARE LOCATED TO AVOID IMPEDING ON AHU DUNNAGE. BUILDING STRUCTURAL ENGINEER TO ANALYZE/REDESIGN RAISED SLAB AND TRANSFER BEAM STRUCTURE AT THE 5th FLOOR, AS NECESSARY FOR LOADS IMPOSED BY PV CANOPY.

(2) INDICATED PV CANOPY POSTS (4 TOTAL) LOCATED AT COLUMN GRID LINE No. 5 ARE NOT SUPPORTED BY COLUMNS BETWEEN 5th FLOOR AND ROOF SLAB LEVELS. BUILDING STRUCTURAL ENGINEER TO ANALYZE/REDESIGN SUPPORTING BEAMS AT THE ROOF LEVEL AS NECESSARY.

(3) INDICATED PV CANOPY POSTS (6 TOTAL) ARE SUPPORTED BY DUNNAGE POST BELOW, TERMINATING AT 5th FLOOR SLAB (NO ADDITIONAL SUPPORT/REINFORCEMENT). BUILDING STRUCTURAL ENGINEER TO ANALYZE, REDESIGN, OR REINFORCE AS NECESSARY.

(4) LOW CANOPY BEAMS ARE SUPPORTED BY COLLECTOR BEAMS ALONG BUILDING FACE. BUILDING STRUCTURAL ENGINEER TO PROVIDE BRACKET DETAIL AT COLUMN LINE #2 (AND BETWEEN 5th FLOOR AND ROOF SLAB LEVELS) SUPPORTING THIS DIRECT ATTACHMENT AS NECESSARY.

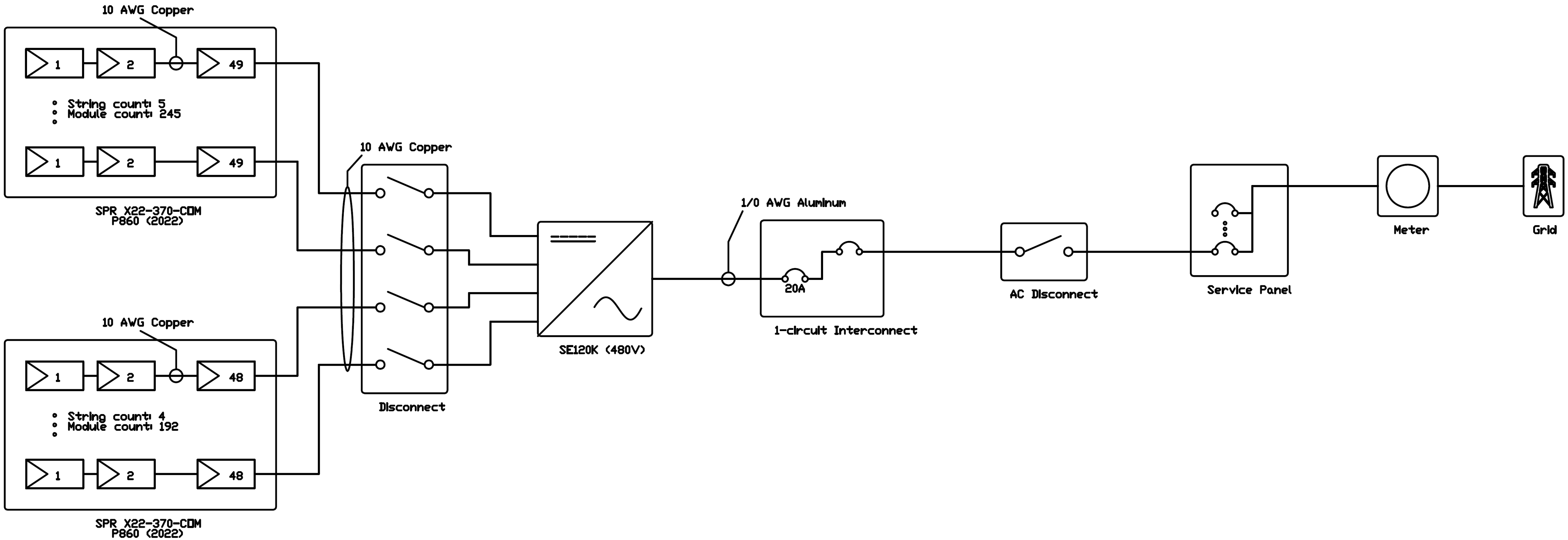
(5) INDICATED PV CANOPY POSTS (4 TOTAL) ARE NOT SUPPORTED BY COLUMN LINE BELOW. BUILDING STRUCTURAL ENGINEER TO ANALYZE, REDESIGN, OR REINFORCE TWO-WAY FLAT SLAB AS NECESSARY.



1

TYPICAL 45° KNEE-BRACE DETAIL

SCALE: 1/2"=1'-0"



Module Specifications	
437x SunPower SPR X22-370-COM	
STC Rating	370 W
Vmp	59.1 V
Imp	6.26 A
Voc	69.5 V
Isc	6.66 A

Inverter Specifications	
1x SolarEdge SE120K (480V)	
Max AC Power Rating	120 kW
Max Input Voltage	1,000 V
Min AC Power Rating	0 W
Min Input Voltage	680 V

Wire Schedule		
Tier	Wire	Length
AC Branch	1x 1/0 AWG	182ft
String	9x 10 AWG	1030ft

PV Canopy Structural Considerations and Calculations

Design of the PV canopy structure was based on the geometry of the base building structural design drawings. Design of structural steel was in accordance with the NYCBC 2014 edition, the Steel Construction Manual and Specification AISC 360-05. In keeping with NYCBC 2014 provision 2205.2.1, the design and detailing of the lateral force resisting system was guided by the Seismic Provisions for Structural Steel Buildings AISC 341-16. Steel grades are typical for each shape. All steel is intended for a hot-dip galvanized finish. The primary structural members are W-section beams and rectangular HSS columns; both are typical choices for exposed, rectilinear plan steel frames like rooftop mechanical dunnage framing. Load determinations were performed in accordance with the NYCBC 2014 edition, which modifies reference standard ASCE 7-10, in general, but wind load determination draws on the earlier ASCE 7-05 edition. Analysis and design considered the LRFD load combinations as given in NYCBC 1605.2. Final element sizing aimed for an elastic design with about 30% excess strength with respect to controlling load effects (including interaction), or about 75% structural utilization.

The lateral force resisting system of the Test Case School PV Canopy is an ordinary sway moment frame with knee braced moment connections at select locations. AISC 341-16 commentary provides the following description of OMF knee-brace systems: "Knee-brace systems use an axial brace from the beam to the column to form a moment connection. Resistance to lateral loads is by flexure of the beam and column. … The knee brace carries axial force only, while the beam-to-column connection carries both axial force and shear" (p. 9.1-215). The "sway" frame distinction refers to the relatively high lateral displacement the frame would display under design loading, the role of column bending in the frame's lateral resistance, and the dominance of bending demand in the column design. The design obeys the stipulation of AISC 341-16 that the knee brace connections should exceed the plastic strength of the connected elements for ductility.

The decision to utilize knee brace connections in the moment frame was motivated largely by ease of installation (no field welds, and minimal steel grinding/refinishing after hot-dip galvanization) and ease of *dis*assembly. The design is intended to be partially deconstructed at bolted connections and then temporarily shored, to allow for replacement of mechanical units on dunnage platforms beneath the canopy level. The beam-column, beam-brace, and column-brace connections in the frame are all facilitated by shop-welding gusset plates on the HSS walls and beam flanges. The avoidance of required field welding should provide relatively low construction labor costs and a reliable construction process.

Knee brace connections on PV canopies can create a friction point between architectural and structural designers in practice, just as concentric bracing does in building design. Prior to design, it was noted that case studies of other PV canopies in NYC opted for knee brace connections, and these connections are frequently used in rooftop mechanical dunnage framing design. Although double-angles ("2Ls," one steel angle at each side of the gusset plate) are a typical choice for knee brace elements, the design ultimately used *single* angles, as the demand in the connections would have required twice as many bolts with double-angle detailing placing the bolts in double shear.

Demonstration Results

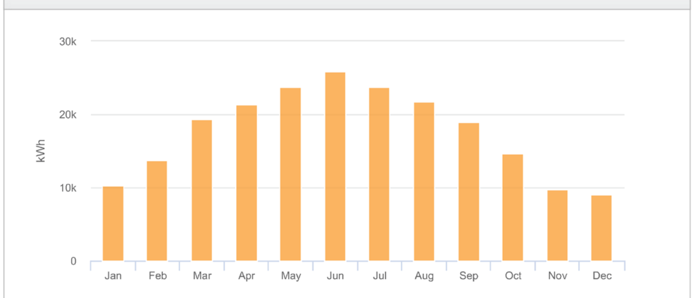
Renewable Energy Calculation

The Helioscope analysis for the selected PV canopy system (Scheme 4) is provided below.

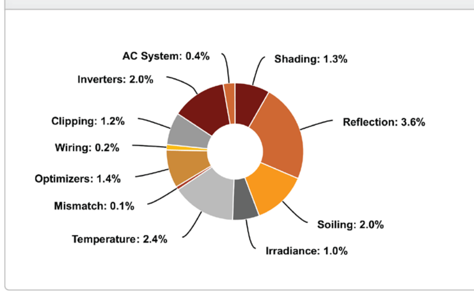
System Metrics

Design	Design 1 (copy)
Module DC Nameplate	161.7 kW
Inverter AC Nameplate	120.0 kW Load Ratio: 1.35
Annual Production	212.0 MWh
Performance Ratio	85.4%
kWh/kWp	1,311.4
Weather Dataset	TMY, 10km grid (40.85,-73.95), NREL (prospector)
Simulator Version	e5c63dbf40-2863ab4c71-16aaed79f5-e4285b7d40

Monthly Production



Sources of System Loss



Components

Component	Name	Count
Inverters	SE120K (480V) (SolarEdge)	1 (120.0 kW)
AC Home Runs	1/0 AWG (Aluminum)	1 (181.9 ft)
Strings	10 AWG (Copper)	9 (1,030.3 ft)
Optimizers	P860 (2022) (SolarEdge)	221 (190.1 kW)
Module	SunPower, SPR X22-370-COM (370W)	437 (161.7 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	-	48-49	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	7°	206°	1.1 ft	1x1	364	346	128.0 kW
Field Segment 2	Flush Mount	Landscape (Horizontal)	15°	206°	0.0 ft	1x1	91	91	33.7 kW

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,443.9	
	POA Irradiance	1,535.5	6.3%
	Shaded Irradiance	1,515.8	-1.3%
	Irradiance after Reflection	1,460.9	-3.6%
	Irradiance after Soiling	1,431.7	-2.0%
	Total Collector Irradiance	**1,431.9**	**0.0%**
Energy (kWh)	Nameplate	231,490.2	
	Output at Irradiance Levels	229,201.9	-1.0%
	Output at Cell Temperature Derate	223,815.3	-2.4%
	Output After Mismatch	223,550.0	-0.1%
	Optimizer Output	220,415.0	-1.4%
	Optimal DC Output	219,975.8	-0.2%
	Constrained DC Output	217,350.7	-1.2%
	Inverter Output	212,967.3	-2.0%
	Energy to Grid	**212,046.8**	**-0.4%**
Temperature Metrics			
	Avg. Operating Ambient Temp		14.4 °C
	Avg. Operating Cell Temp		23.0 °C
Simulation Metrics			
	Operating Hours		4686
	Solved Hours		4686

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km grid (40.85,-73.95), NREL (prospector)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model
Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Module Characterizations

Module	Uploaded By	Characterization
SPR X22-370-COM (SunPower)	HelioScope	Sunpower_SPR_X22_370_COM.pan, PAN

Component Characterizations

Device	Uploaded By	Characterization

Detailed Layout

Shading Heatmap

Shading by Field Segment

Description	Tilt	Azimuth	Modules	Nameplate	Shaded Irradiance	AC Energy	TOF[2]	Solar Access	Avg TSRF [2]
Field Segment 1	7.0°	206.0°	346	128.0 kWp	1,514.6kWh/m^2	169.1 MWh[1]	89.7%	99.4%	89.1%
Field Segment 2	15.0°	206.0°	91	33.7 kWp	1,520.2kWh/m^2	43.0 MWh[1]	93.1%	96.1%	89.5%
Totals, weighted by kWp			**437**	**161.7 kWp**	**1,515.8kWh/m^2**	**212.0 MWh**	**90.4%**	**98.7%**	**89.2%**

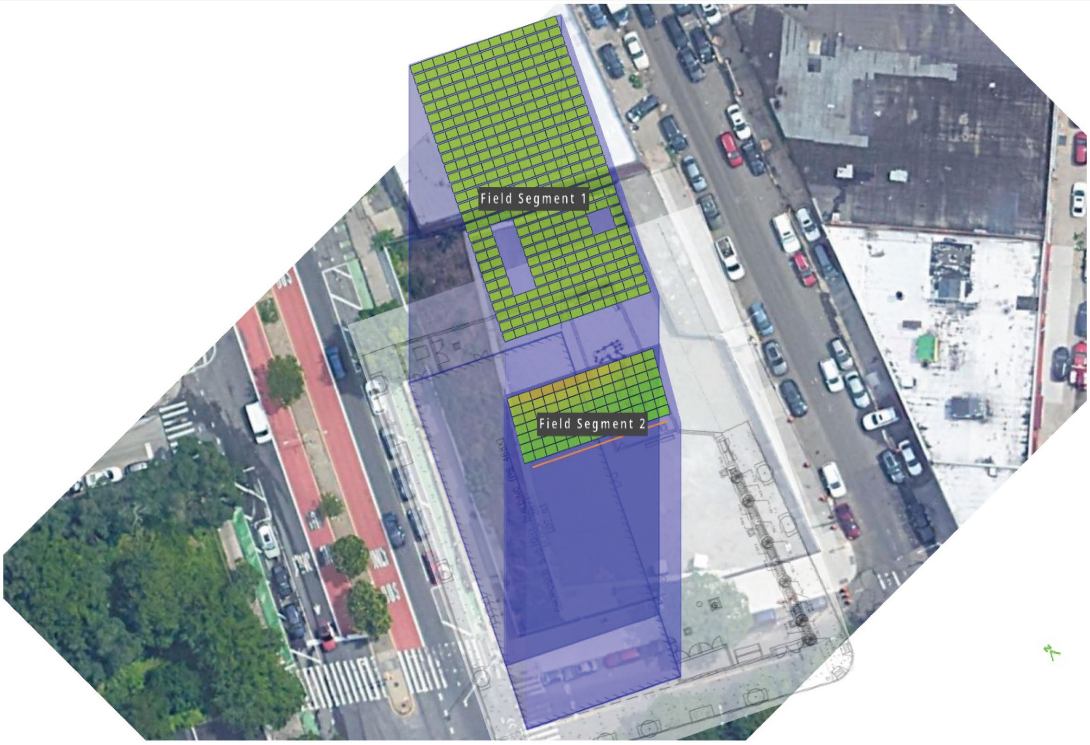
[1] approximate, varies based on inverter performance

[2] based on location Optimal POA Irradiance of 1,699.3kWh/m^2 at 35.8° tilt and 181.2° azimuth

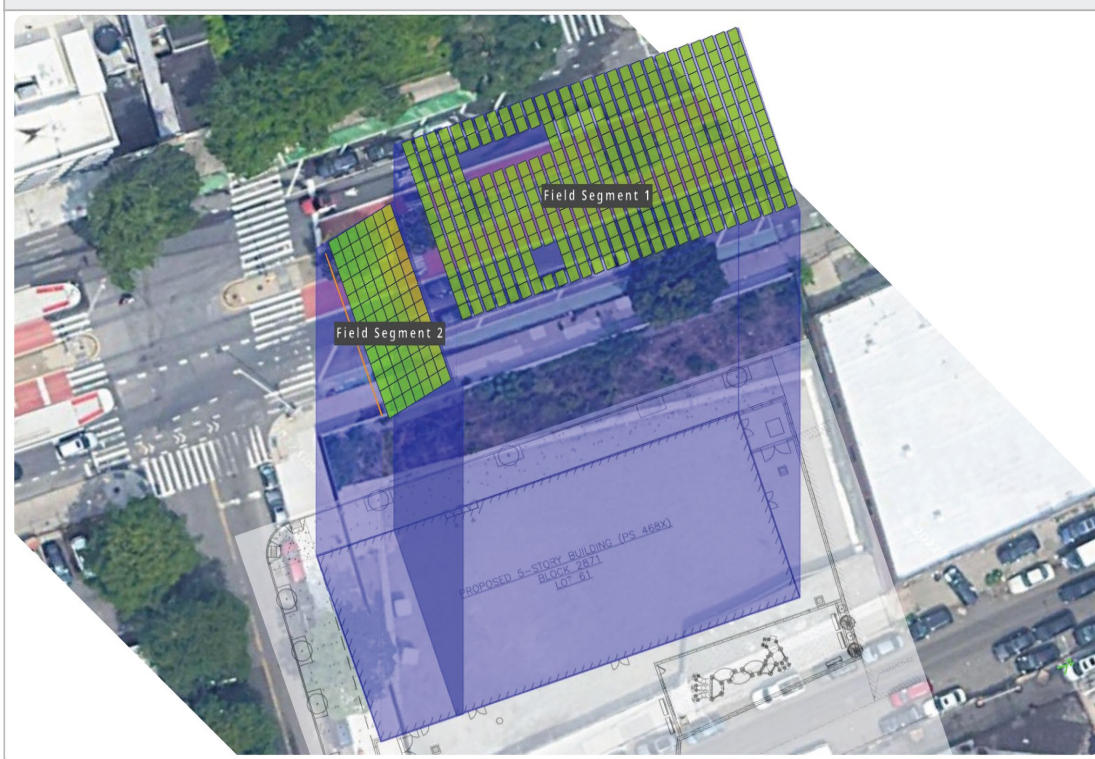
Solar Access by Month

Description	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Field Segment 1	98%	99%	100%	100%	100%	100%	100%	100%	100%	99%	99%	98%
Field Segment 2	97%	97%	97%	96%	95%	95%	95%	96%	97%	97%	97%	97%
Solar Access, weighted by kWp	**97.5%**	**98.6%**	**99.0%**	**99.0%**	**98.9%**	**98.8%**	**98.8%**	**99.0%**	**99.0%**	**98.7%**	**98.2%**	**97.6%**
AC Power (kWh)	**10,293.7**	**13,752.0**	**19,271.3**	**21,331.9**	**23,744.9**	**25,812.5**	**23,769.7**	**21,691.8**	**18,941.2**	**14,613.0**	**9,718.0**	**9,106.6**

Southwestern Angle



Southeastern Angle



Stormwater Management Calculation

The USWR compliance calculations, for both CSS and MS4 areas, for the selected rooftop stormwater management system (Scheme C) is provided below.

Total Site Area (sf):	*21,152*	Area of Land Disturbance (sf):	*21,152*
Percent Impervious Cover:	*67.1%*	Requires New Sewer Connnection?:	*YES*
Total Area of New Impervious Cover (sf):	*14,190*	Sewer Type:	*CSS*
		USWR Applies?:	*YES*

Step 1: SMP Volume Calculation

This section calculates the volume of stormwater managed by each stormwater management practice (SMP). Please fill in shaded cells.
** It should be noted that this calculator applies only for SMPs with simple geometry where the ponding surface is flat, the sides of the SMP are vertical, and voids created by internal structures are all located in the drainage layer. If an SMP does not satisfy the "simple geometry" criteria, calculate the volume of stormwater managed per Equation 4.1 in the NYC Stormwater Manual.*

SMP Number	SMP Type	SMP Area (sf)	Depth of Ponding (ft)	Depth of Soil Media Layer (ft)	Porosity of Soil Media Layer (cf/cf)	Depth of Drainage Media (ft)	Porosity of Drainage Media (cf/cf)	Volume of Voids Created (cf)	Total Volume Managed by SMP (cf)
1	Green Roof	6,962	0.00	0.5	0.2				696
2	Blue Roof	9,580	0.31						2,994
3									
4									
5									
		16,542				`			3,690

This section indicates the percent of each SMP volume which can be applied to individual USWR requirements (WQv, RRv, and Vv). Please fill in shaded cells in accordance with NYC Stormwater Manual - Appendix A.

SMP Number	SMP Type	Function Type	Percent of SMP Volume Applied to WQv	Percent of SMP Volume Applied to RRv	Percent of SMP Volume Applied to Vv
1	Green Roof	Evapotranspiration	100%	100%	0%
2	Blue Roof	Detention	100%	0%	100%
3					
4					
5					

Step 2: Water Quality Volume Calculation

This section calculates the Water Quality Volume (WQv) for the 90th percentile rain event. Please fill in shaded cells.
** It should be noted that the contributing area, runoff coefficient, and WQv must be determined for each individual practice – and, in total, the practices must manage the WQv across the entire site.*

Management Area			Contributing Area (sf)	Percent Impervious Cover (%)	Water Quality Volume Required, WQv (cf)	Water Quality Volume Provided (cf)	WQv Requirement Verification
		Total Site Area	21,152	67.1%	148.2	3,690.0	Requirement Met
SMP Number	**SMP Type**	**Contributes to WQv?**					
1	Green Roof	YES	10,820	36%	72.0	696.2	Requirement Met
2	Blue Roof	YES	10,820	11%	69.0	2,993.8	Requirement Met
3							
4							
5							

Step 3: Runoff Reduction Volume Calculation

This section calculates the Runoff Reduction Volume (RRv). *Please fill in shaded cells.*

Area of New Impervious Cover (sf)	Hydrologic Soil Group	Specific Reduction Factor	Runoff Reduction Volume, RRv (cf)	Runoff Reduction Volume Provided (cf)	RRv Requirement Verification
14,190	C	0.3	505.5	696.2	Requirement Met

Description	S
HSG-A	0.55
HSG-B	0.40
HSG-C	0.30
HSG-D	0.20

← *The specific reduction factor used to calculate RRv will depend on the hydrologic soil group (HSG) of soils underlying the project site. Designers may classify soils based on results of the geotechnical investigation or refer to the NRCS web soil survey for data on HSGs by location.*

Step 4: Sewer Operations Volume Calculation

This section calculates the Sewer Operations Volume (Vv) and Maximum Release Rate (Q-DRR) for the contributing area. *Please fill in shaded cells.*

This section calculates the Weighted Runoff Coefficient (Cw) for the project site.

Surface Description	Area of Surface Cover (sf)	Runoff Coefficient, C
Roof	3,858	0.95
Paved	10,332	0.85
Green Roof	6,962	0.70

Runoff Coefficient, C	Surface Description
0.95	Roof Area
0.85	Paved Areas
0.70	Green roof with 4 in. growing media
0.70	Porous asphalt/Porous Concrete*
0.70	Synthetic turf fields*
0.65	Gravel parking lot
0.30	Undeveloped areas
0.20	Grass, bio-swales, landscaped areas

← *This table contains runoff coefficient values for common surfaces.*

** Using a C value of 0.7 for the indicated surface types typically requires the use of an outlet pipe, with approval*

Weighted Runoff Coefficient	0.819

Contributing Area	Sewer Type	Rainfall Depth of 10YR Rainfall Event (in)	Sewer Operations Volume, Vv (cf)	Sewer Operations Volume Provided (cf)	Vv Requirement Verification
21,152	CSS	1.85	2,670.3	2,993.8	Requirement Met

Maximum Release Rate (q) (cfs/acre)	Maximum Release Rate, Q-DRR (cfs)	Calculated Release Rate (cfs)	Q-DRR Requirement Verification
0.1	0.049		Requirement Met

Total Site Area (sf):	*21,152*	Area of Land Disturbance (sf):	*21,152*
Percent Impervious Cover:	*67.1%*	Requires New Sewer Connnection?:	*YES*
Total Area of New Impervious Cover (sf):	*14,190*	Sewer Type:	*MS4*
		USWR Applies?:	*YES*

Step 1: SMP Volume Calculation

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SMP Number	SMP Type	SMP Area (sf)	Depth of Ponding (ft)	Depth of Soil Media Layer (ft)	Porosity of Soil Media Layer (cf/cf)	Depth of Drainage Media (ft)	Porosity of Drainage Media (cf/cf)	Volume of Voids Created (cf)	Total Volume Managed by SMP (cf)
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2	Blue Roof	Detention	0%	0%	100%
3					
4					
5					

Step 2: Water Quality Volume Calculation

This section calculates the Water Quality Volume (WQv) for the 90th percentile rain event. Please fill in shaded cells.

** It should be noted that the contributing area, runoff coefficient, and WQv must be determined for each individual practice – and, in total, the practices must manage the WQv across the entire site.*

Management Area			Contributing Area (sf)	Percent Impervious Cover (%)	Water Quality Volume Required, WQv (cf)	Water Quality Volume Provided (cf)	WQv Requirement Verification
		Total Site Area	21,152	67.1%	148.2	696.2	Requirement Met
SMP Number	**SMP Type**	**Contributes to WQv?**					
1	Green Roof	YES	10,820	36%	72.0	696.2	Requirement Met
2	Blue Roof	NO	10,820	11%			
3							
4							
5							

Step 3: Runoff Reduction Volume Calculation

This section calculates the Runoff Reduction Volume (RRv). *Please fill in shaded cells.*

Area of New Impervious Cover (sf)	Hydrologic Soil Group	Specific Reduction Factor	Runoff Reduction Volume, RRv (cf)	Runoff Reduction Volume Provided (cf)	RRv Requirement Verification
14,190	C	0.3	505.5	696.2	Requirement Met

Description	S
HSG-A	0.55
HSG-B	0.40
HSG-C	0.30
HSG-D	0.20

The specific reduction factor used to calculate RRv will depend on the hydrologic soil group (HSG) of soils underlying the project site. Designers may classify soils based on results of the geotechnical investigation or refer to the NRCS web soil survey for data on HSGs by location.

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This section calculates the Sewer Operations Volume (Vv) and Maximum Release Rate (Q-DRR) for the contributing area. *Please fill in shaded cells.*

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This table contains runoff coefficient values for common surfaces.

** Using a C value of 0.7 for the indicated surface types typically requires the use of an outlet pipe, with approval*

Weighted Runoff Coefficient	0.819

Contributing Area	Sewer Type	Rainfall Depth of 10YR Rainfall Event (in)	Sewer Operations Volume, Vv (cf)	Sewer Operations Volume Provided (cf)	Vv Requirement Verification
21,152	MS4	1.5	2,165.1	2,993.8	Requirement Met

Maximum Release Rate (q) (cfs/acre)	Maximum Release Rate, Q-DRR (cfs)	Calculated Release Rate (cfs)	Q-DRR Requirement Verification
1.0	0.486		Requirement Met