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FINAL PROJECT REPORT

Solar+: Enabling Clean Energy in Disadvantaged Communities With Integrated Photovoltaics and Storage

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Solar+: Enabling Clean Energy in Disadvantaged Communities w/ Integrated PV + Storage is the final report for this project (EPC 16-068) conducted by The Electric Power Research Institute. Information from this project contributes to the Energy Research and Development Division's EPIC program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

This project identified scalable community models that maximize the economic and environmental benefits of solar photovoltaic (PV) energy systems for low-income multi-family customers. The systems tested included advanced solar technologies, batteries, direct-current distribution and appliances, advanced controls, and behavioral demand-response strategies. This resource integration project evaluated how these technologies benefit owners and residents of a typical Southern California affordable multi-family housing property, especially important as Californians transition to time-of-use rates that increase electric-grid flexibility and reduce greenhouse gas emissions, which together benefit both utilities and their customers.

Keywords: solar, storage, affordable housing, direct current, time-of-use, TOU, DC, controls, behavioral, demand response, DR

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Introduction

This project, EPC 16-068, *Solar+: Enabling Clean Energy in Disadvantaged Communities With Integrated PV + Storage* is a clean-energy resource and control demonstration at an affordable housing property in a low-income, disadvantaged neighborhood in Compton, California. The property was constructed in 2017 and incorporates several decarbonization measures (for example, mini-split heat pumps, EnergyStar* appliances, LED lighting). EPRI followed suit by installing a combination of solar photovoltaic (PV), energy storage, and load management technologies that were chosen based on their potential to further unlock decarbonization opportunity within a low-income multifamily property.

Project Purpose

EPRI conceived of this project at a significant moment in California history marked by the confluence of policy initiatives advancing decarbonization, zero net energy and equitable access to energy innovations.[1] The context also included a major shift of all customers in California to time-of-use (TOU) rates by 2021. There was concern that variable rates would lead to greater overall bills, especially during peak summer times for low-income customers. A study released by the California Public Utilities Commission (CPUC) at about the time the project was completed found that affordable-rate customers in hot climates would likely experience a $20-$40 average monthly bill increase and be unable to offset a significant portion of those increases

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[1] This project was designed to demonstrate a pathway for some of these important policy initiatives:

- Greenhouse gas reduction landmark bill Assembly Bill (AB) 32 (Fabian Nunez, Fran Pavley, Chapter 488, Statutes of 2006) and Senate Bill (SB) 32 (Fran Pavley, Chapter 249, Statues of 2016), 100 (Kevin de León, Chapter 18, Statues of 1999) and 350 (Kevin de León Eduardo Garcia, Das Williams, Chapter 547, Statues of 2015). To achieve carbon neutrality by 2045 will require replacement of fossil fuel use in buildings with renewable generation and techniques.
- The Long-Term Energy Efficiency Strategic Plan, which set the “Big Bold Goal” that all new homes in California be zero-net energy (ZNE) by 2020. Extending these goals, the State committed to making all new public buildings ZNE by 2020, and all new commercial buildings ZNE by 2030, and to reduce energy use in existing buildings by 50 percent by 2030 (SB 350).
- Title 24 code: New models for community-installed solar were necessary since it is difficult to establish enough properly oriented roof space in new home communities. The Title 24 development team was engaged with this work which directly informed development of the 2019 Title 24 code, that was aimed at achieving ZNE in residential communities.
- AB 693 (R. Fernandez Perea, Chapter 611, Statutes of 2013): This project provided technologies and implementation strategies in low income multifamily housing to address two major technical constraints for including solar in affordable housing– site fit and the business models. This project sought to address both of these constraints as California increases solar in multifamily affordable housing to 300 Megawatt (MW).
- 2022 State Energy Code: This project provides critical learnings in anticipation of the CEC’s proposed requirement that new multifamily buildings be equipped with solar PV and energy storage.
- Enabling Self-Generation Incentive Program (SGIP): This project sought to bridge the gap through load shaping with loads and storage that will make implementing energy storage more effective and enable SGIP installations to be better open to distribution systems.
- AB 2514 (Skinner, Chapter 469, Statutes of 2010): With Southern California Edison (SCE) as an engaged partner and co-funder, the team addressed business models to enable utilities to implement their targets for energy storage.

by load shifting. The need to manage electricity use and reduce the energy burden of low-income customers during this transition was imperative. The ultimate purpose of this project was to demonstrate project pathways within a low-income multifamily setting that maximize the benefits of solar PV and decarbonization for a vulnerable population, while simultaneously enabling grid flexibility and environmental benefits that extend to the entire rate base.

Project Approach

The host site was a Leadership in Energy and Environmental Design (LEED) Silver-certified property designed with transit-oriented development principles in a disadvantaged community in Southern California. It provides 61 affordable housing units, of which 31 are reserved for homeless residents. One hundred percent of the residents qualify for affordable electricity rates and would transition as part of the larger statewide shift from flat, fixed rates to time-of-use (TOU) by 2021.

EPRI designed and installed two nearly identical 60 kW bifacial solar photovoltaic (PV) arrays and 60 kW/120 kWh lithium-ion batteries at each housing building. The project incorporated battery controls and a behavioral demand response (DR) strategy that included a TOU energy management mechanism for residents. It also featured a DC distribution and appliance mini-grid for efficient utilization of local solar production for common-area loads.

The project purpose directly informed the control strategies by:

1. Futureproofing against rate changes for vulnerable populations without tools to manage TOU and demand rates.
2. Local load balancing with solar PV, readying the grid for impending electrification of buildings while avoiding upgrades of distribution transformers and secondaries.
3. Managing storage to reduce greenhouse gas emissions (GHG) from the California electricity grid.
4. Managing bulk-system capacity through residential participation in the Demand Response Auction Market.

Project Results

The project achieved around a 9-percent reduction in total electricity use from behavioral energy management alone during the 4-9 pm peak hours in the summer of 2021 when compared with the summer of 2020. The net savings are expected to be even higher since the battery was also discharged during the 4-9 pm peak hours. In the fall, the energy storage system was profiled to reduce energy drawn from the grid during times of peak grid marginal carbon content (which is not coincident with peak TOU hours) to further contribute to decarbonization. The collective set of measures demonstrated significant decarbonization potential for this community, demonstrated in reduced Scope 1 and Scope 2 emissions.

Evaluated New Solar Technologies

This project evaluated new solar technologies that address space constraints through higher efficiencies to assist multifamily buildings with roof-area constraints to meet ZNE goals.

This project demonstrated, however, that unless there is sufficient space on reflective flat roofs, dua-sided PV cannot deliver its full benefit on sloped roofs. The site had a mix of flat white reflective roofs and sloped dark asphalt roofs, resulting in mismatch in tilts and azimuths and ground reflected irradiance with only four total maximum power-point tracking channels. As a result, the array performed at 84 percent of modeled direct current (DC) production and 78 percent of modeled alternating current (AC) production.

Demonstrated Integration of Solar and Storage with Smart Inverters

Demonstrated integration of solar and storage with smart inverters with segmentation of storage for meeting various needs: peak demand management, utility-controlled distribution grid flexibility, and so on.

The controls strategy was guided by the objectives of minimizing use of grid power during TOU peak pricing periods, shaving electric vehicle charging system peaks, balancing solar to avoid distribution upgrades, reducing GHG from the California electric system and, finally, managing bulk system capacity through demand response. Levers for implementing the controls strategy were the battery controller and a Willowbrook-specific behavioral DR program using gamification and monetary rewards to encourage residents to consistently reduce energy upon demand, especially during TOU peak periods.

Improved Near-Term Grid Flexibility and Reliability

Improved near-term grid flexibility and reliability connected distributed energy resources (DER) with DR capability.

EPRI evaluated three controls scenarios at the host site. The first two employed a bottom-up approach with one addressing control objectives year-round with the second addressing them in a targeted fashion seasonally, i.e., discharging the battery during strategic periods in the winter when emissions from the electric system are at their highest (due to the operation of natural gas peaker plants) and again in the summer when system peaks and high pricing are in effect. Scenario 3 used a top-down approach with a priority of 10 percent peak load reduction while addressing other control objectives secondarily. Scenario 3 bore the highest financial returns of all the scenarios evaluated as part of this project and also met other control objectives 97 percent of the year.

EPRI worked with a demand aggregator to enroll residents into a customized behavioral DR program that incorporated time of use-related messaging and behavioral energy savings tips into its day-ahead and day-of notifications. Roughly one-third of Willowbrook residents successfully enrolled in the behavioral time-of-use DR program. Performance data suggests that residents actively engaged, and that monetary and gamification mechanisms were motivating factors for participation. Sampled residents participated in at least 50 percent of DR events and saved up to 50 percent compared with historic baselines. Energy consumption in 2021 during the 4-9 pm time of use window fell compared to the previous year by approximately 15 percent. Not only did customers save on their utility bills; they also earned cash from improving their baselines. This aspect of the project proved that behavioral methods using gamification and/or cash-earning mechanisms can be highly effective at inducing targeted reductions of energy use.

Integration of DC Mini Grids

Integration of DC mini grids will eliminate conversion losses for solar PV to heating, ventilation and air conditioning (HVAC), and lighting loads.

HVAC

On the DC HVAC side, unfortunately, EPRI experienced persistent technical difficulty with the selected system, which was the only commercially available DC-enabled heat pump system that EPRI could find at the time. Due to lack of compatibility between the inverter and variable refrigerant flow, the unit had to be connected directly to the solar, bypassing the inverter as originally planned. An automatic transfer switch was installed to enable remote switching from AC to DC modes of operation. Ultimately, EPRI was not able to operate the unit in DC mode, directly supplied by solar PV, for any extended period of time, a feature that was advertised by the manufacturer. EPRI worked directly with the manufacturer to troubleshoot, which informed its product revisions for future generations of the product.

Lighting

Replacement of existing LED AC lighting fixtures with DC lighting resulted in a slight efficiency gain (3.6 percent) in terms of lumens per watt. Controls furthered efficiency though those compatible with DC lighting with UL listings were not readily available. EPRI embarked on a UL 2108 Low Voltage Lighting System field evaluation to comply with the local permitting authority's conditions for use of non-UL-listed compatible controls. Low-voltage cable losses were mitigated with a 250VDC lighting driver located as close as possible to the light fixtures. Increased availability of 380VDC (or higher) voltage DC lighting, as well as UL-listed DC lighting controls and updates to the National Electric Code to allow for general utilization of higher DC voltages, are needed for optimal efficiency to further unlock the DC lighting market.

Evaluated Various Business Models Around Community-Scale Solar and Storage

EPRI evaluated various business models around community-scale solar and storage and how they can create benefits such as economics and reliability while also providing grid benefits. The economics of solar + storage for low-income communities is nascent/non-existent with current rates. The Solar on Multifamily Housing incentive program and Virtual Net Energy Metering rate structure, which influenced the project design, effectively prevent the landlord from charging the tenants for the benefits of solar, which means that the property owners must justify the investment based on the common area usage. In many cases, common area usage is very limited (in this case just over 10,000 kWh per year), which means that property owners, if they are leasing solar, cannot cover the lease payments.

Because of the difficulties in monetizing grid services from energy storage, the cost-benefit analysis suggests that all scenarios without outside funding support would bear a negative net present value. Used to estimate the value of a future stream of payments, a positive number suggests an attractive investment with future cash flows. The net present value for the best performing scenario was -$312,619. This cost-benefit analysis only monetizes the utility bill savings to the property and excludes any financial benefit from greenhouse gas emissions, net peak load reductions or other distribution services, which could defer distribution upgrades from the DC distribution and appliance project scope that would benefit the property, utility, and rate base.

Technology Transfer

According to the California Department of Housing and Community Development, there are approximately 4.3 million multifamily units in California with approximately 480,000 that are qualified as affordable housing. EPRI focused on sharing research and results from this project to affordable multifamily housing owners and operators as well as program administrators, policy makers, and building trades. EPRI presented these results at conferences and provided publications to industry, government, and utility audiences using Willowbrook as a test case for implementing low-income multifamily solar + storage.

Examples of other additional technology transfer activities included:

- Southern California Edison (SCE), a project partner and co-funder, used the Willowbrook project as a case study for in-house engineering training in summer 2021. Utility representative Mark Martinez stated that the utility will be using the lessons from this and other EPRI projects in the utility's future DER forecasting and modeling work as well: *"These projects help identify opportunities for future models of DER programs… This and other projects will continue to help us understand how future customer solar and storage systems can provide local grid reliability, and what we can do to help our customers maximize their benefits."*
- EPRI and project partner OhmConnect, a DR aggregator, expanded the behavioral TOU energy management platform at other California low-income multifamily properties as the larger residential market shifts to TOU rates.
- Linc collaborated with EPRI on two virtual site visits to provide utilities, affordable housing owners, operators, engineers, and facility managers the ability to hear directly from the project team and staff and ask direct and pointed questions about the installed system.
- EPRI presented at numerous conferences, including but not limited to those hosted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the American Council for an Energy-Efficient Economy, Getting to Zero, and EPRI's Electrification and Utility Advisory conferences.

The lessons learned as part of this project reveal the gaps and barriers necessary to commercialize the technologies used. As part of the project's technology-transfer activities, examples included: the need to update the National Electric Code standards and building codes for general use at higher DC voltages, to provide more incentives to expand the availability of DC equipment, and to develop better monetization strategies to improve the return on investment of behind-the-meter storage where it aligns with state policy and rate-base requirements.

Benefits to California

As an integrated solution for low-income multifamily housing in California, the estimated project benefits are promising.

Lowered Costs: Extending the results of this project to California's affordable multifamily households shows the potential for bill reductions of $253 million for California's low-income households.

Increased Reliability: Reduced evening demand by 8.6 percent during TOU peak periods will contribute to increased grid reliability, ultimately benefiting all California ratepayers.

Economic Development: Job creation equivalent to eight person-years. This can also be scaled to major job growth if similar retrofit work is conducted statewide for the target sector. The reduction in energy bills and DR participation payments also leave tenants with greater disposable income, which is particularly impactful for low-income populations that make up nearly 20 percent of all California ratepayers.

Environmental Safety: Extending the results of this project to California's low-income multi-family households shows a potential statewide CO2 reduction of about 83,331 metric tons per year.

Public Health: This project improves public health by reducing pollution and GHG emissions. This project also tests a resilience strategy in disadvantaged communities through the DC distribution and appliance demonstration, which could help vulnerable populations in need of continuous power for medical devices during outages.

Consumer Appeal: This project enhances a sustainable, LEED certified urban in-fill, mixed use and transit-oriented property where people can live close to employment. This project also enhances the comfort and affordability of this housing to further consumers' interests.

Energy Security: Reducing energy use through energy efficiency and renewable measures provides energy security through greater self-reliance. Using renewable energy resources also avoids the need for more power plants. SCE and affordable housing developer Linc are using the results of this work to inform their future planning and development.

Chapter 1: Background

Overview

The primary objective of the project was to identify scalable community models that maximize the economic and environmental benefits of PV energy systems for low-income populations and affordable-housing facility operators. With Southern California Edison (SCE) as a key partner and local utility, this resource integration project also evaluated how to further scale and enable grid flexibility, reliability, and greenhouse gas emission reductions that benefit the entire rate base.

The technology innovations were selected based on their potential to align with California policies targeting the low-income multifamily sector. Emphasis was placed on business models that supported the economic and environmental advancement of low-income residents as California utilities transition all residential customers, including those on affordable discount rates, to time-of-use (TOU) rates, with time differentiation and peak pricing that benefit both utilities and the larger rate base (including solar) to avoid distribution upgrades and shave peaks, reduce GHG from the California electric system, and manage bulk-system capacity through demand response (DR).

The Electric Power Research Institute (EPRI) is the prime researcher and lead on this research and demonstration project. The California Energy Commission (CEC) and SCE are funders for EPRI's specific deliverables and expected outcomes. Other team members include Linc, a California-based affordable housing developer, project site host and manager of Gridscape, the solar + storage technology integrator. Staten is the licensed contractor and installer of solar + storage as well as the designer and installer of the direct current (DC) distribution and appliance demonstration. Primus is the construction manager, representing Linc's interests and managing on-site activities and construction. OhmConnect manages the behavioral DR program deployed among the host site's residents. Finally, Kliewer & Associates is a consultant to SCE, providing technical support and representing SCE's research interests in the project. The project partners are shown in Figure 1.

Figure 1: Project Team

Prime Recipient

EPRI
ELECTRIC POWER
RESEARCH INSTITUTE

Project Manager: Agatha Kazdan, Senior Technical Leader
Principal Investigator: Ram Narayanamurthy, Technical Executive

Funding Agencies

STATE OF CALIFORNIA
ENERGY COMMISSION

Liet Le, Agreement Manager

SOUTHERN CALIFORNIA
EDISON®
An *EDISON INTERNATIONAL*® Company

Mark Martinez, Mgr of Emerging Markets and Technology &
Nav Pillay, Project Engineer

Site Owner & Operator

LINC Housing
CORPORATION

Russell Foster

Systems Integrator

GRIDSCAPE

Vipul Gore, CEO

Demand Response Aggregator

ohmconnect

Elliot Marks, Director

SCE Rep & Technical Support

KA
Building Science©

Ron Kliewer, Pres. &
Christie Kjellman, Senior Engineer

Construction Management

primus
BUILDING SOLUTIONS

Tania Boysen, President

Engineering, Procurement, Construction

STATEN

Javier Palma, Project Manager

Source: EPRI

The Customer Story

SCE transitioned all of its residential electric customers to TOU rates by 2021. During the project term in the lead-up to that transition, all residents at both Willowbrook and the majority of the low-income residents at properties owned by Linc (a California non-profit affordable housing owner and developer) were on fixed discounted electric rates and do not have time-differentiated rates, but rather tiered rates. For the first time, they would face different energy rates by the season and the time of day. While they would still have their rates discounted under the CARE program, variable rates can still lead to greater overall bills, especially during peak summer periods.

In a 2017 pilot program to understand TOU impacts, the California Public Utilities Commission (CPUC) found that all Pacific Gas and Electric Company (PG&E) and SCE CARE customers in hot climates experienced higher total annual electricity costs under TOU pricing, ranging from $20 - $40 in average monthly bill increases. SCE CARE customers were also generally found to be unable to offset a significant portion of the bill increases by load shifting.[2] Table 1 highlights current and predicted rates for Willowbrook residents.

Table 1: SCE CARE-Current and Predicted CARE TOU Rates ($/kWh)

Current Rates ($/kWh)	Time of Day	TOU Rates – Summer*	TOU Rates – Winter*
$ 0.12305	Peak	$0.3134	N/A
$ 0.12305	Mid-Peak	$0.1849	$0.1317
$ 0.12305	Off-Peak	$0.1218	$0.1152
$ 0.12305	Super Off-Peak	N/A	$0.0934

***Applies a 30 percent discount to rates to estimate impact of CARE discounts for residents only.**

Source: Southern California Edison, 2020

EPRI approached Linc with a project to pay for the about $1.1 million in development costs for the installation of a solar PV and battery storage demonstration project at Willowbrook, with both funding and in-kind labor and equipment support. The project would feature advanced solar technologies, batteries, DC distribution, appliances, controls, and behavioral DR strategies to effectively reduce the community's energy costs and carbon footprint. Linc's board of directors agreed to EPRI's proposal to use Willowbrook as a showcase of early stage technologies based on its potential to effectively counter bill increases from the TOU rate transition. Staff highlighted the boost in yield from the bifacial solar PV and battery storage as particularly helpful during peak and mid-peak periods. When utility-provided electricity is at its most expensive, the battery would transmit stored electricity to the property.

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[2] Hawiger, Marcel. Hayley Goodson. Opening Brief of the Utility Reform Network Concerning Compliance with Section 745 Requirements for the Implementation of Default Residential Time of Use Rates. 2017. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M191/K054/191054131.PDF. The Utility Reform Network.

The following project benefits were presented[3] to the Linc governance and board by staff to seek approval before proceeding:

- Cost savings for the common area and tenants: the solar system is designed to supply 100 percent of common-area electricity use and 66 percent of tenant electricity use. It would discount the electricity rate by 10 percent for tenants, as compared with current SCE rates, in Year 1. With TOU rates, the battery storage would draw and store electricity during off-peak times (daytime). This would make cheaper electricity available for the property during peak times (evening).
- Provide greater cost stability for the common area and for tenants: solar would provide electricity on a low 2.5 percent escalation rate for both the common area and tenants for the next 20 years.

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[3] Clarke, Rebecca, "Solar and Storage at Mosaic Gardens at Willowbrook." Memorandum to the Linc Board of Directors. November 26, 2018.

Chapter 2: Project Purpose

EPRI conceived of this project at a key moment in California's energy history marked by the confluence of policy initiatives advancing decarbonization, zero net energy and equitable access to energy innovations. The driving purpose of this project was to maximize the benefits of solar PV and decarbonization for a vulnerable population while enabling grid flexibility and environmental benefits for the entire rate base. The context was importantly a major shift of all customers in California to TOU, causing concern that variable rates would lead to greater overall bills, especially during peak times and especially for low-income customers.

The project team used the demonstration project at Willowbrook to address several larger research questions within the context of a California low-income multifamily, including:

- What are the economics of community-scale solar + storage?
- How does it fit within the state's energy policy goals?
- What are the early-stage technologies that overcome barriers of solar + storage in the field?
- What are some business models for IOUs to adopt for customer and grid benefits?

The team also chose building technologies and approaches that addressed some of these research questions and presented potential for unlocking decarbonization potential within multifamily buildings to:

- Evaluate new solar technologies that can address space constraints through higher efficiencies. Manufacturers claim dual-sided or bifacial PV boost a 23 percent efficiency rating and offer substantial assistance to commercial and multifamily buildings with roof-area constraints to meet ZNE goals.
- Demonstrate solar and storage integration with smart inverters that segment storage to meet various needs such as peak demand management and utility-controlled distribution grid flexibility. Address challenges of late evening energy peaks using storage and loads to better match solar production.
- Demonstrate a system platform that can manage loads and is both customer-responsive and automated enough to bid into the California Independent System Operator, Demand Response Auction Market, or some other energy market.
- Integrate direct DC mini grids that eliminate conversion losses for solar PV to heating, ventilation, air conditioning (HVAC) and lighting loads, which together offer greater efficiencies to the customer in local solar PV utilization.
- Evaluate various business models around community-scale solar and storage and how they can provide economic benefits and reliability while providing grid benefits. Develop models to establish social equity using renewable generation, working with a low-income community serving formerly homeless residents.

Chapter 3: Project Approach

Project and Site Description

Willowbrook is an affordable multifamily housing property in Compton, California, a disadvantaged community in Southern California. It was constructed in 2017 by Linc, achieving LEED Silver certification and incorporating transit-oriented development concepts. Today, Willowbrook provides 61 housing units to low-income families with 31 units reserved for individuals or families transitioning from homelessness. The site was selected because it represented the target market of affordable multifamily housing, and the owner was motivated to investigate the benefits of solar + storage for its larger portfolio. While EPRI, Linc, and its partners started development of the project shortly after Willowbrook's construction completion in 2017, construction of the solar + storage project scope only officially began in Fall 2020 once all necessary approvals were secured. The site layout is shown in Figure 2.

Figure 2: Willowbrook Site Layout

Source: EPRI

Technology Description

As depicted in Figure 3, two near-identical solar PV + storage systems were set up at each housing building (buildings 1 and 2) at Willowbrook. A DC distribution and appliance technology demonstration was also installed at Building 2.

Figure 3: Project System Configuration

Source: EPRI

The full technology demonstration scope was comprised of:

- Two (2) battery cells 60 kW/2-hour, provided by EnergPort.
- Two (2) 60-kW bifacial solar PV arrays, provided by Canadian Solar.
- A DC-coupled PV and storage system, with inverter provided by CE+T.
- Inverters that meet California Rule 21 mandates grid-supportive functions.
- A local controller coordinating PV, battery, and inverter, provided by GridScape.
- A level-up Open Demand Side Resources Integration Platform (OpenDSRIP), developed by EPRI and funded through another CEC grant (EPC 15-075) that coordinated overall system controls.
- This project used Virtual Net Energy Metering (VNEM). The production and operation of the PV and battery were distributed (allocated) across each of the residential unit meters and the common building meter.
- The project included certain DC loads at Building 2, directly coupled with the battery system, including common-area lighting and air conditioning.

Project Innovations

The team incorporated several key innovations into the scope, described here in more detail.

High-Efficiency Bifacial Solar PV

Bifacial PV models are designed to optimize limited roof space, such as in commercial and multifamily applications where roof space can be relatively sparse, by collecting energy from the top and the back of the modules to increase yield. This project used 170 Canadian Solar CS3U 355-watt bifacial panels. Figure 4 shows a portion of the bifacial solar PV installation at the project site. Target efficiency for the panels was 23 percent. The project team paired the bifacial solar PV with two 60 kW, 2-hour batteries manufactured by EnergPort (Model L3060), as shown in Figure 5.

Figure 4: Bifacial Solar Installation at Project Site

Figure 5: L3060 EnergPort Battery Installation at Project Site

Source: EPRI

DC-Coupled Bi-Directional Smart Inverter

A DC-coupled PV and storage system with a Stabiliti 30C3 bi-directional inverter manufactured by CE+T (formerly Ideal Power) was selected partially because it fulfills California Rule 21 Phase 1 mandates for grid supportive functions, which govern required “autonomous” functions that DER with inverter-based interfaces must possess for utility interconnection, including:

- Anti-Islanding: Trip off under extended anomalous conditions.
- Low/High Voltage Ride-Through: Ride through voltage excursions beyond normal limits.

- Low/High Frequency Ride-Through: Ride through frequency excursions beyond normal limits.
- Volt-Amps Reactive (VAR): Dynamic reactive power injection through autonomous responses to local voltage measurements.
- Ramp Rate: Define default and emergency ramp rates as well as high and low limits.
- Fixed Power Factor: Provide reactive power by a fixed power factor.
- Soft Reconnect: Provide "soft-start" methods.

The Stabiliti 30C3 is a multi-port and DC-coupled inverter with three bi-directional ports (2 alternating current (AC) and 1 DC), including:

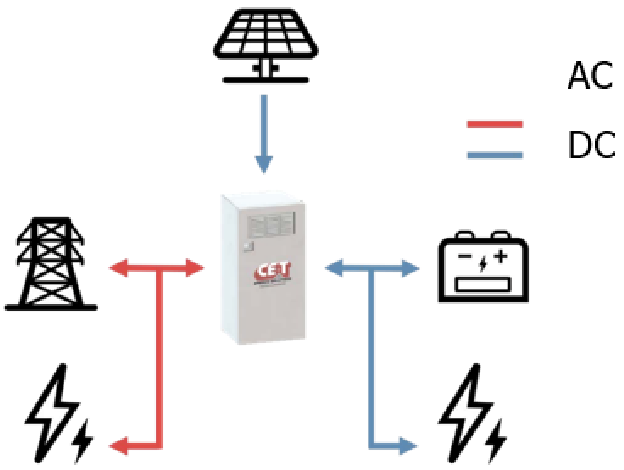
a. AC port for utility grid connection.
b. DC port for PV modules.
c. DC port for battery energy storage.

An inverter, such as this one, allows individual control of both storage and PV modules. It also saves conversion losses between solar PV and battery system charging without converting to AC. The roundtrip efficiency is 97 percent. Figure 6 shows one of the bi-directional inverters installed in the field. Figure 7 shows a schematic bi-direction inverter diagram setup.

Figure 6: Installed CE+T Stabiliti 30C3 Inverter Units (Left) and Enclosed EnergPort L3060 Batteries (Right)

Source: EPRI

Figure 7: Bi-Directional Inverter Diagram



Red Line is AC, Blue Line is DC.

Source: CE+T (Right)

Energy Efficient DC Distribution and Appliances (Minigrid)

Use of AC power, which is the standard mode of electricity distributed to customers today, is primarily a legacy of the 20th Century, when the only way to step voltage up or down was through transformers requiring AC. Use of DC electricity may potentially reduce distribution losses by reducing the number of conversions between generation and distribution.

Because solar PV, storage, and DC loads are naturally compatible, the team demonstrated a DC distribution and appliance system to compare their energy use to a traditional AC distribution system with compounding energy losses estimated to be as high as 33 percent. This is noteworthy considering residential applications have particularly high potential as one-third of U.S. residential loads are native DC (and could be higher with electric vehicles).[4]

The appliances used in this project include a DC-enabled Gree GMV-Y36WL/A-T(U) Variable Refrigerant Flow (VRF), a variable speed mini-split heat pump that can work in 100-380 voltage direct current (VDC) as well as AC mode, as shown in Figure 8. The VRF features a permanent magnetic brushless DC compressor and fan motors, 2-stage high-efficiency motors, and DC electronics able to accept a broad voltage range. Figure 9 also shows the 24VDC Lamar lighting that was installed along exterior hallways in common areas; 18 24VDC lighting was installed. The DC mini grid also included 24VDC Lamar lighting, Amatis bridge, sensors and switches, and two Nextek power hubs.

This project proved more complex than originally conceived. Some of the components proved incompatible, specifically the Stabiliti 20C3 bi-directional inverter and VRF. While the manufacturer's commitment and interest in such systems may eventually resolve these issues with future product revisions, the team addressed this issue at the project level by connecting the

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[4] Pantano, Stephen. Peter May-Ostendorp, Katherine Dayem, Demand DC: Adoption Paths for DC Power Distribution in Homes. 2016. https://www.aceee.org/files/proceedings/2016/data/papers/1_156.pdf. American Council on Energy Efficiency.

solar directly to the VRF, rather than via the DC port of the multiport inverter. Some of the components were also hard to find; for example, high-voltage DC breakers and DC lighting controls. The local permitting authority required as a condition of approval hiring an NRTL to conduct a UL2108 Low Voltage Lighting Systems field evaluation of the Amatis sensors and switches. Installation and testing results are described in further detail in Chapter 4.

Figure 8: Gree VRF GMV-Y36WL/A-T(U)

Source: Gree

Figure 9: Lamar 24V DC Lighting

Source: Lamar

Controls Description

EPRI designated four primary control objectives for the project:

1. Futureproofing against rate changes for vulnerable populations without the tools to manage TOU and demand rates.
2. Local load balancing with solar PV, to prepare for electrification of buildings, while avoiding upgrades of distribution transformers and secondaries.
3. Managing storage to reduce GHG emissions from the California electric grid.
4. Methods to manage bulk-system capacity using demand-response based on participation in the demand response auction mechanism (DRAM).

As shown in Table 2, the controls strategies employ the battery system controller, Gridscape Energyscope Application Programming Interface (API), and customer notifications through an online behavioral DR platform (Ohmconnect’s #OhmHour messaging platform).

Table 2: Controls Strategies

Control Objective	Use Case	Strategies	Levers
TOU Management & EV Peak Shaving	Increase customer awareness of TOU	Inform customers periodically about high-rate periods.	#OhmHour messaging based notification

Control Objective	Use Case	Strategies	Levers
TOU Management & EV Peak Shaving	Customer sided load management	Call to action for customers to reduce energy use	#OhmHour messaging with call to action
TOU Management & EV Peak Shaving	Use battery during high TOU periods	Discharge batteries to defray high TOU energy costs and system-wide EV peak charging	Gridscape Energyscope API based battery control.
Solar Balancing	Use batteries to soak up solar	Charge batteries during periods of high solar output	Gridscape Energyscope API based battery control.
GHG Emissions Reduction	Use batteries to reduce source carbon footprint	Discharge batteries during high marginal carbon emissions time (based on ISO emissions data)	Gridscape Energyscope API based battery control.
Demand Response	Customer participation in DRAM	Enroll customers for DRAM participation	OhmConnect #OhmHour platform

Source: EPRI, 2020

Hardware and Software Architecture

The hardware and software control architectures are summarized in the following sections.

Hardware Control Architecture Summary

- The primary hardware for providing controls for customer and grid services in Willowbrook is the mini-split HVAC systems installed in living units, and two lithium-ion energy storage systems installed in common-area locations in the community.
- Controls for living-unit level controllable loads were enabled via a DR messaging platform that provides a "gamified" mechanism to influence customer behavior toward energy-efficient behaviors, especially during high TOU periods.
- Controls for energy storage systems are enabled through a combination of cloud-based high-level controls (through a battery-profile setting interface) and an on-premises local controller (for low-level charge and discharge control and SGIP compliance).

Figure 10 illustrates DER technologies within the project scope and the communication interfaces in the hardware control architecture.

Software Control Architecture Summary

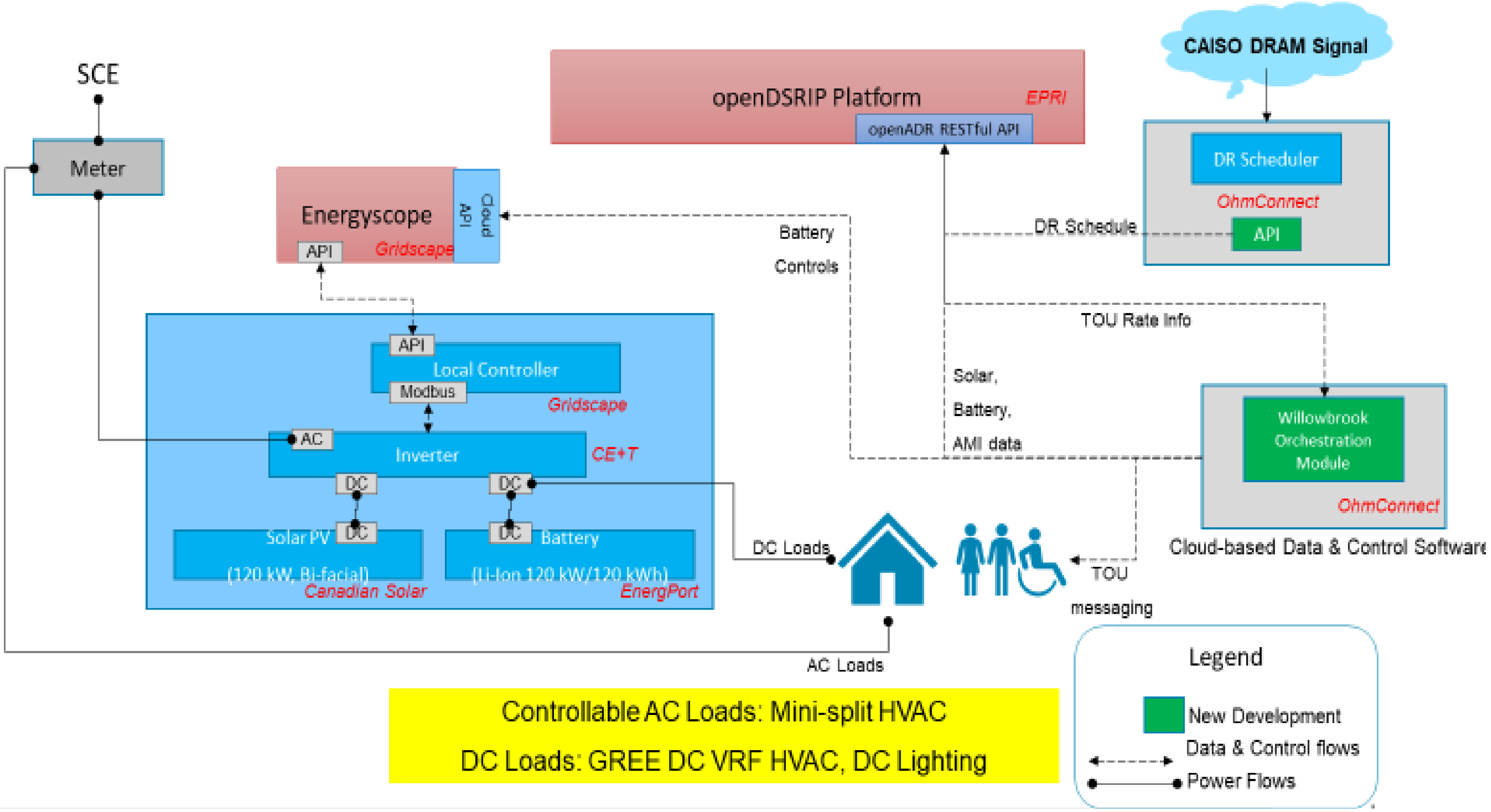
The Willowbrook Orchestration Module (WOM) acts as a data aggregation and control platform. All data is backhauled to the Open Demand Side Resource Integration Platform (openDSRIP) for measurement and verification (M&V) and evaluation of project performance. The main controls are implemented via battery profiles enabled through the system controller (EnergyScope) cloud-based interface. The controls are implemented in a distributed manner between the openDSRIP control module that provides control actions for the Solar+Storage at the community level and the WOM, which provides control actions for the flexible load.

The software control architecture, shown in Figure 11, involves various software or virtual components housed either in the cloud or locally (depending upon the specific hardware, connectivity, and performance requirements).

Measurement and Verification

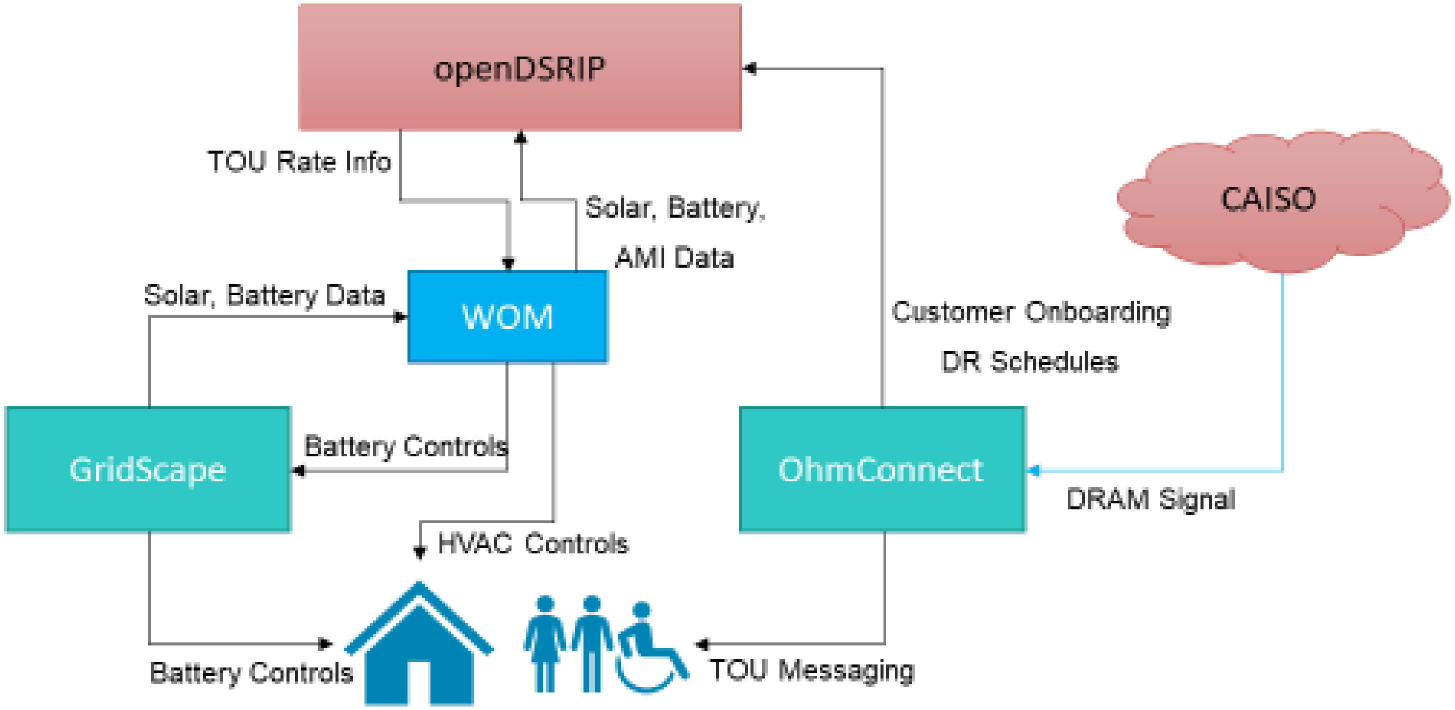
The M&V plan was developed in accordance with project objectives to verify that the systems demonstrated were operating as expected.

Figure 10: Hardware Control Architecture



Source: EPRI

Figure 11: Software Control Architecture



WOM – Willowbrook Orchestration Module

Source: EPRI

PV Array Conversion Efficiency

Solar PV efficiency determination required precise measurements of inputs (sunlight and local environmental conditions) and outputs (electricity and energy), including:

- Irradiance, measured using secondary standard calibrated thermopile pyranometers, enclosed in an active ventilation housing to minimize the effects of self-heating and moisture build-up on the lens. Irradiance was sampled at least once every 10 seconds (1-second preferred) to capture varying conditions due to cloud movement. Typical daily insolation uncertainty was less than 2 percent (1.5 percent preferred).
- PV module back-surface temperatures were measured using either surface-mount thermocouples or thermistors with appropriate adhesion and thermal conductivity. Measurement uncertainty should be less than 2 C (1 C preferred).

Integrating Solar and Storage with Smart Inverters and Mini DC Grids

Measurement of DC power flowed across key buses, from the solar array, to and from the batteries, and to DC loads. This was accomplished by measuring DC current and DC voltage, then calculating DC power and integrating it over time to determine DC energy:

- DC voltage was measured with uncertainty less than 0.5 percent and sampled at least once per second.
- DC current was measured with uncertainty less than 0.5 percent and sampled at least once per second.
- Temperature measurements were taken for both surface and air temperature either surrounding the batteries or inside battery cabinets.

Integration and Segmentation of Storage for Various Needs

Isolating and capturing electrical parameters for the PV/energy storage inverter, in the context of overall power flow within the site, required the measurement of power flows to and from the utility grid to tenant loads, and to and from the PV-battery inverter.

- Power quality (PQ) metering supported additional data capture of harmonics and flicker levels, and triggered waveform events as the PV-battery inverter provided verification of successful grid-support functions.

Building and Unit Measurement Requirements

The detailed measurement of building- and unit-level parameters allowed accurate disaggregation of overall energy consumption and a comparison of pre-treatment and post-treatment performance at the individual energy-efficiency level. Building- and unit-level measurements were split into the following components:

- Advanced Metering Infrastructure (AMI): 15-minute interval data, resident data, and owner common area accounts instead of circuit-level monitoring.
- PV + Storage control parameters: Parameters used by Gridscape for control of PV + storage at the community level.

Monitoring Equipment and Instrumentation

EPRI procured, assembled, and configured data acquisition equipment prior to delivering the equipment to the field site. Hardware included instruments listed in Table 3 and additional components including but not limited to enclosures, cellular data plans, wired and wireless networking devices, data loggers, input modules, and power supplies. Configuration included data-point definitions, calibration checks, network routing, and security. Quantities shown in Table 3 are based on a site layout that contains two separate buildings. Each building had one energy storage system and one PV array. Building 2 included DC loads.

Table 3: M&V Instrumentation List

Item	Manufacturer/Model	Quantity
Irradiance sensor	Kipp & Zonen / SMP10	6
PV module temperature sensor	Kipp & Zonen / RT1	3
DC voltage sensor	Flex-core / VT7-014D-24	10
DC current transformer	Flex-core / DT1-010-24D-BD-SP Flex-core / DT0-010-24U-U-FL	10 2
AC power quality meter (bidirectional)	Schweitzer Engineering Labs / SEL-735	2
AC current transformers	SEL	4
Thermocouples	Vaisalia / HMP3 Humidity and Temperature Probe	2
AC power meter	Resident AMI data, Gridscape EnergyScope API	62
Battery temperature sensor	Gridscape EnergyScope API	0
Cell modem	Cradlepoint / COR IBR600C	5
Data logger	Obvius A8810-0	5
Din rail-mounted 8-port industrial switch	Advantech EKI-2525 5FE Unmanaged Ethernet Switch	5
A/D converters	Advantech Adam 6024e - confirmed by vendor	5
Power supply	MEAN WELL RD-35B AC-DC Power Supply Dual Output 5V 24V 4 Amp 1.3 Amp 35W	5
Enclosure	Altelix 14x12x6 Fiberglass Weatherproof NEMA Enclosure with 120 VAC Power Outlets and Aluminum Equipment Mounting Plate	5
Wiring	GS Power 18 Gauge 200’ Red /200' Black (400 feet Total) Bonded Zip Cord	1
Screw terminal strips blocks	MILAPEAK 8 Positions Dual Row 600V 15A Screw Terminal Strip Blocks with Cover + 400V 15A 8 Positions Pre-Insulated Terminals Barrier Strip (Black & Red) by MILAPEAK	5

Item	Manufacturer/Model	Quantity
Wire cable glands	TUPARKA 32 Pcs Cable Gland Waterproof Adjustable Joints with Gaskets 3-16mm PG7 PG9 PG11 PG13.5 PG16 PG19	2
DIN Rail Block Kit and rail terminal	Dinkle DIN Rail Block Kit #2 DIN Rail Terminal Block Kit Dinkle 20 DK4N	5

Source: EPRI

EPRI provided installation schematics for the monitoring system, measurement points, specification sheets, and installation procedures for contractors. Monitoring equipment was installed in various locations on the site including near the utility service entrance, rooftop, near DC loads, and at energy storage systems. The M&V layout that was ultimately installed is shown in figures 12 and 13. As a high-level summary, PQ meters monitor and record the output and performance of the inverters and controller as they manage the solar PV, batteries, and DC loads. Rooftop instruments monitor and record the amount of solar irradiance experienced by the solar PV and its effect on panel temperatures.

Data collection parameters are shown below:

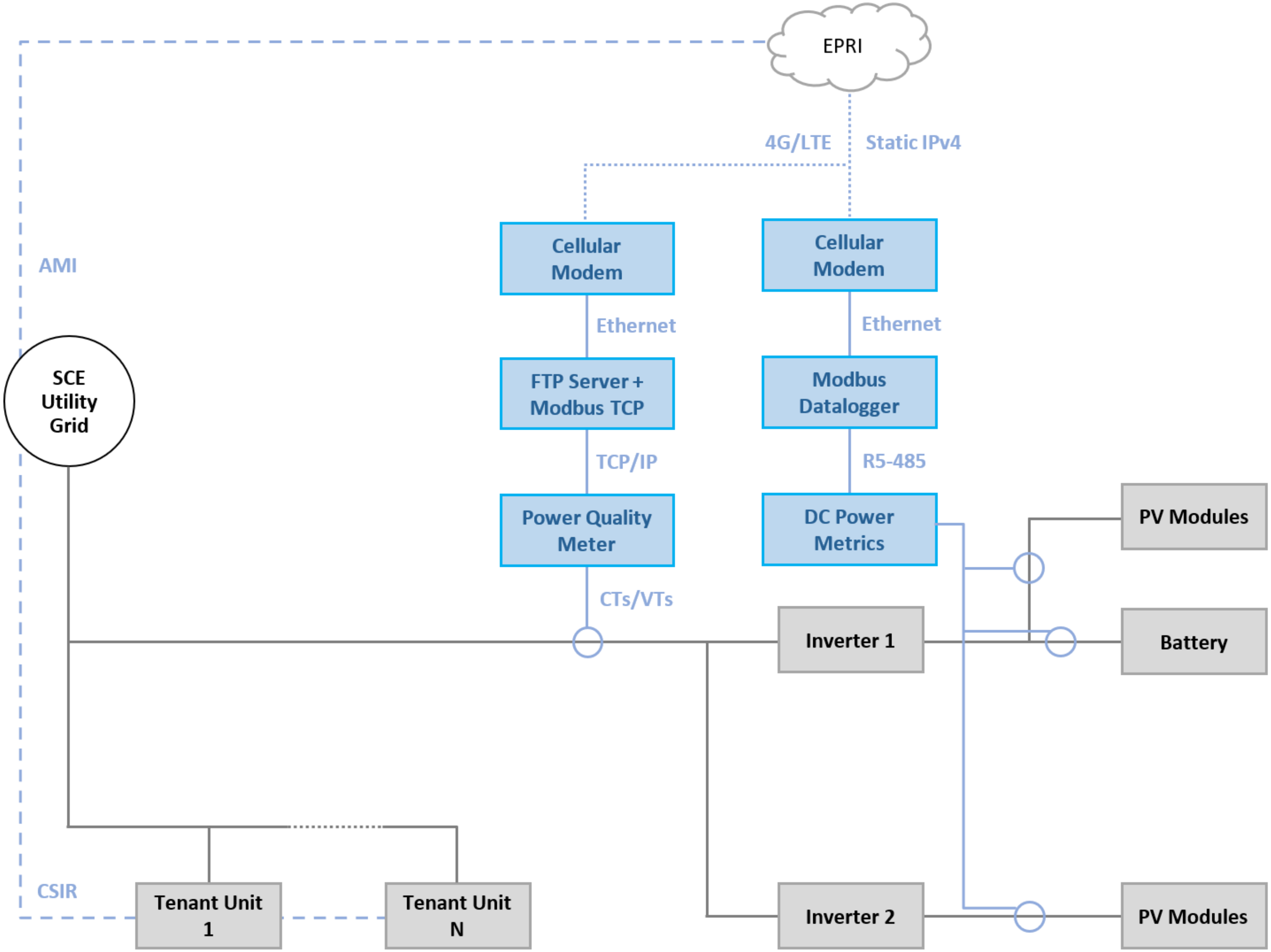
Main Service Entrance (Buildings 1 and 2)

- Voltage (V), per phase: 1-second resolution
- Current (A), per phase: 1-second resolution
- Active power (kW): 1-second resolution
- Reactive power (kVAR): 1-second resolution
- Active energy (kWh), delivered and received: 1-minute resolution
- Reactive energy (kWh), delivered and received: 1-minute resolution

Inverter AC Grid Interface (Buildings 1 and 2)

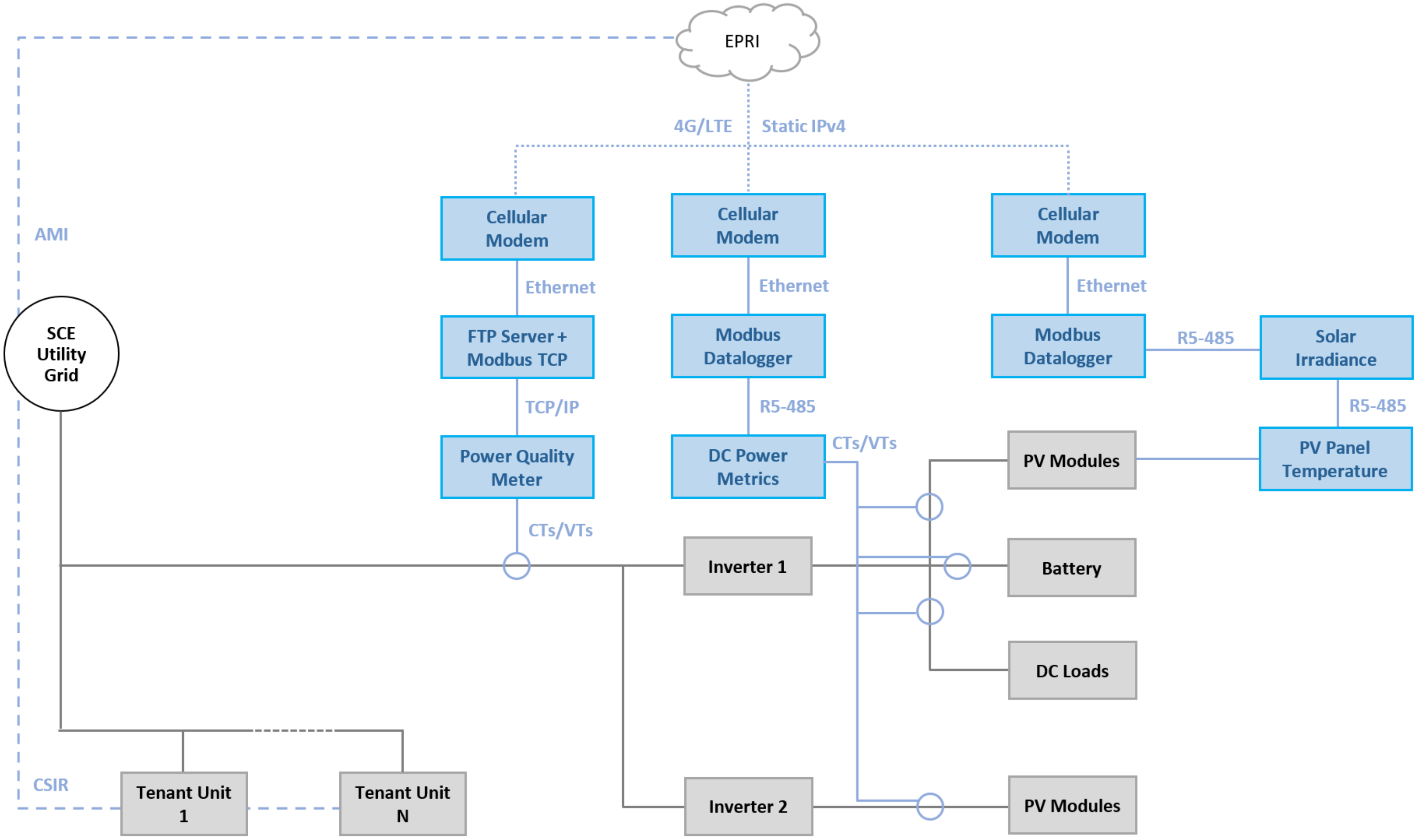
- Voltage (V), per phase: 1-second resolution
- Current (A), per phase: 1-second resolution
- Active power (kW): 1-second resolution
- Reactive power (kVAR): 1-second resolution
- Frequency (Hz): 1-second resolution
- Power factor, displacement and true: 1-second resolution
- Active energy (kWh), delivered and received: 1-minute resolution
- Reactive energy (kWh), delivered and received: 1-minute resolution
- Flicker, short-term (PST) and long-term (PLT): 10-minute and 2-hour resolutions
- Total harmonic distortion, voltage and current per phase (percent): 10-minute resolution
- Selected fundamental magnitudes, phase angles, and harmonic quantities: (as needed)
- Voltage and current waveforms, event triggered: 128 samples per cycle, 2-second window

Figure 12: M&V Schematic for Building 1



Source: EPRI

Figure 13: M&V Schematic for Building 2



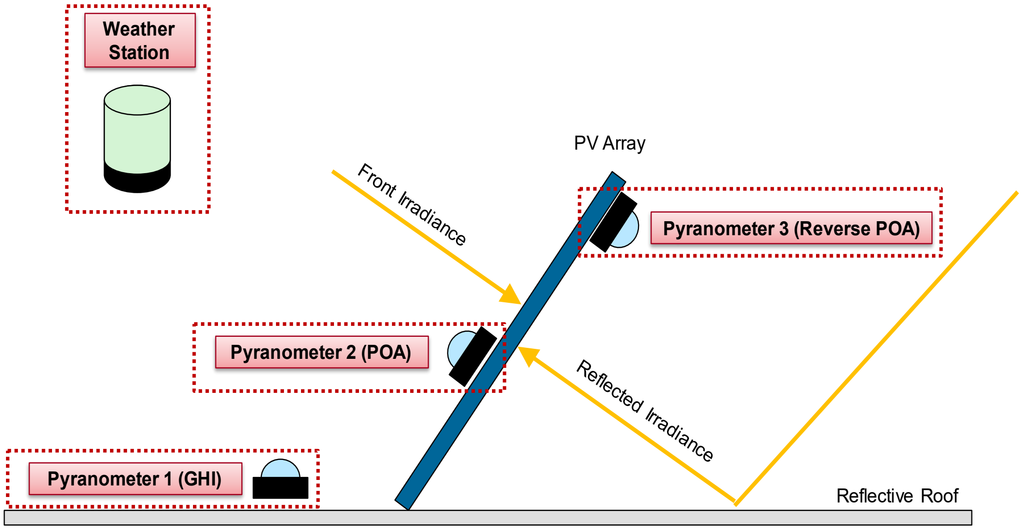
Source: EPRI

PV Array (Buildings 1 and 2)

- Plane-of-array (POA) irradiance (W/m^2): 1-second resolution, quantity 2
- Reverse plane-of-array (R-POA) irradiance (W/m^2): 1-second resolution, quantity 2
- Global horizontal irradiance (GHI) (W/m^2): 1-second resolution
- PV module back-surface temperature (°F) (°C): 1-minute resolution, up to quantity 8
- DC voltage (V) and current (A) at inverter solar input terminal: 1-second resolution

Figure 14 depicts a diagram of the bifacial solar PV irradiance sensor placement.

Figure 14: Bifacial Solar PV Irradiance Sensor Placement



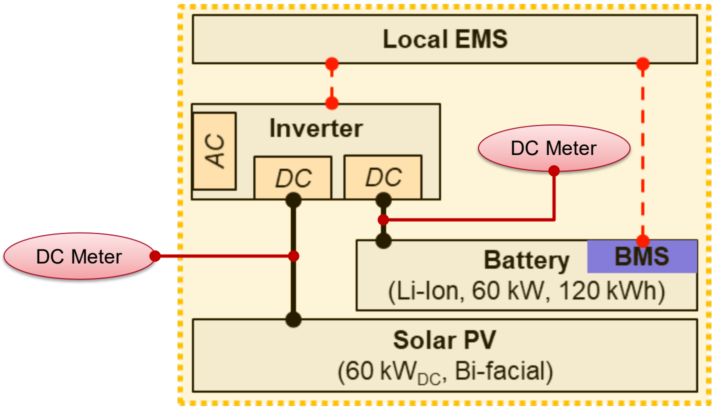
Source: EPRI

Battery (Buildings 1 and 2)

- DC voltage (V) and current (A) at inverter's battery bus: 1-second resolution
- Battery module and/or cabinet temperature (°F) (°C): 1-minute resolution, up to quantity 8
- State of charge (percent), operating mode, and other parameters if available via the inverter's communication interface: 1-minute resolution.

The DC monitoring points for energy storage and PV systems for both buildings are shown in Figure 15.

Figure 15: DC Monitoring Points for Energy Storage and PV Systems



Source: EPRI

Direct Current Loads (Building 2)

- Common area lighting: voltage (V), current (A): 1-second resolution
- HVAC: voltage (V), current (A): 1-second resolution
- HVAC: thermocouples, air-flow sensors

Data Collection and Analysis

EPRI verified data collection (for example, acquisition, system, logging) at 1-second, 1-minute, or 15-minute intervals (depending on the metric and sensor device) and reported back to EPRI's server to be imported to a SQL database in order to be properly warehoused and secure.

EPRI collected data from the M&V systems described above to provide technical support for deployed systems and to conduct the analysis required, using a measurements-based, statistical approach:

- Functionality: Validate successful operations of battery and PV systems. This included confirming inverters were operating properly; determining if inverters change operating mode when commanded; and quantifying how accurately inverters implement advanced functions based on inputted parameters, such as volt-var curves or fixed power-factor settings.
- Solar Energy Performance: Determine how much solar energy is generated from use of bifacial PV array. This includes computing performance-based metrics to compare solar generation relative to localized environmental conditions, which compensates for incident solar radiation and PV module temperature throughout the day. Measured performance was correlated with modeled performance of a non-bifacial PV array to determine the efficiency gain in using bifacial technology.
- PQ Implications: Study of common PQ factors–harmonics, flicker, and momentary voltage events–in relation to the inverters' operations. This is intended to identify how much advanced inverters contribute to overall PQ within the site and interaction with the utility grid.

- Comparison of energy utilization pre- versus post-treatment: Using data collected before energy efficiency measures were put in place to establish a baseline of energy utilization, a detailed comparison of the energy utilization post treatment will be conducted. This analysis provided quantitative indicators of the efficacy of the energy-efficiency retrofits in improving energy utilization.
- Load Shed DR performance: Using a set of control strategies that are applied at the PV plus Storage, the efficacy of the controls and behavioral DR in providing short-term grid performance and reliability enhancements will be analyzed.

More specific M&V method details are discussed in Chapter 4.

Chapter 4: Project Results

This section highlights the demonstration results, organized by objective:

1. Bifacial PV Conversion Efficiency
2. Integration and Segmentation of Storage for Meeting Various Needs
3. Building/Unit Level Measurement Requirements
4. Project Performance
    a. Solar, Storage, and Load
    b. Energy Efficiency
5. Distribution System Analysis
6. Cost Benefit Analysis
7. Customer Value Proposition
8. Integration of Solar and Storage with Smart Inverters and Mini DC Grids

Bifacial PV Conversion Efficiency

Background

Bifacial solar modules have received substantial interest from stakeholders seeking to boost available energy yield from solar installations. Land costs, development costs, and roof space all drive interest in more solar yield from less space. Bifacial modules are increasing in popularity for larger ground-mount tracking solar systems for this reason. Especially in multi-family housing, rooftop space for solar is often insufficient to produce enough solar energy with conventional solar modules to cover the electrical loads of the building. Figure 16 shows a bifacial module, and Figure 17 shows a mono-facial module of the same nameplate wattage from the same manufacturer.

Figure 16: Bifacial Module Back Sheet

Source: EPRI

Figure 17: Mono-Facial Module Back Sheet

Source: EPRI

Conventional mono-facial solar modules collect solar energy only from the front side of the module. The back of mono-facial modules is covered with an opaque plastic back sheet material and the cells are only made to collect energy through one side. Mono-facial modules can collect direct normal or diffuse irradiance but cannot collect reflected irradiance. While these modules have the same nameplate rating, the bifacial module can potentially harvest reflected irradiance from the surface below and therefore has potentially higher efficiency.

GRI[5] or albedo is light that has been reflected from the ground, roof, or other material. Bifacial modules are configured with cells that can collect irradiance from both sides, as the name implies. Bifacial modules typically use a glass back sheet instead of the opaque plastic used on mono facial modules. The additional glass adds weight and cost to bifacial modules, as does the additional cell processing. However, the additional solar collector area on the back of bifacial modules can improve the output and solar conversion efficiency without making the modules or solar array larger.

As with mono-facial modules, the energy output from the back of a bifacial module is directly related to the irradiance received. Reflected irradiance at any given point on an array or even across a single module is very sensitive to shading, color, and reflectivity of the roof or ground and numerous other factors. Because of this, developers using bifacial modules often design arrays, racking, and background materials to maximize uniform reflected irradiance received by the modules. These design choices can involve solar trackers, racking with increased height and spacing between modules, light-colored background materials, module level power electronics, and other factors.

Where the site is not designed specifically to maximize uniform reflected irradiance, a reduction in energy boost from bifacial modules may occur. In fact, the bifacial boost can be negative under certain circumstances. This reduction occurs where mismatch between modules or substrings within modules exists; mismatch is most often created by non-uniform irradiance. Sandia National Lab conducted a study on module-level power electronics and found that gains are available by mitigating mismatch with power electronics.[6]

Willowbrook Test Site

The CEC expressed an interest in implementing innovative solar technologies that can increase the solar energy yield from constrained rooftop spaces, such as those found on multifamily housing buildings. EPRI worked with Linc housing to implement a test installation of bifacial solar at Willowbrook. This installation was done in conjunction with multi-port DC-coupled bi-directional inverters and energy storage. Staten Solar installed 60kW or (170) 355W Canadian Solar Bifacial modules per building. These modules were coupled to two 30kW CE+T three-port bi-directional inverters on each building. Each inverter has a single maximum power point tracker, and module strings were connected to rapid shutdown devices and string combiners. Each inverter has five solar strings connected. The solar designs with various tilts and azimuths are depicted in Figures 18 and 19.

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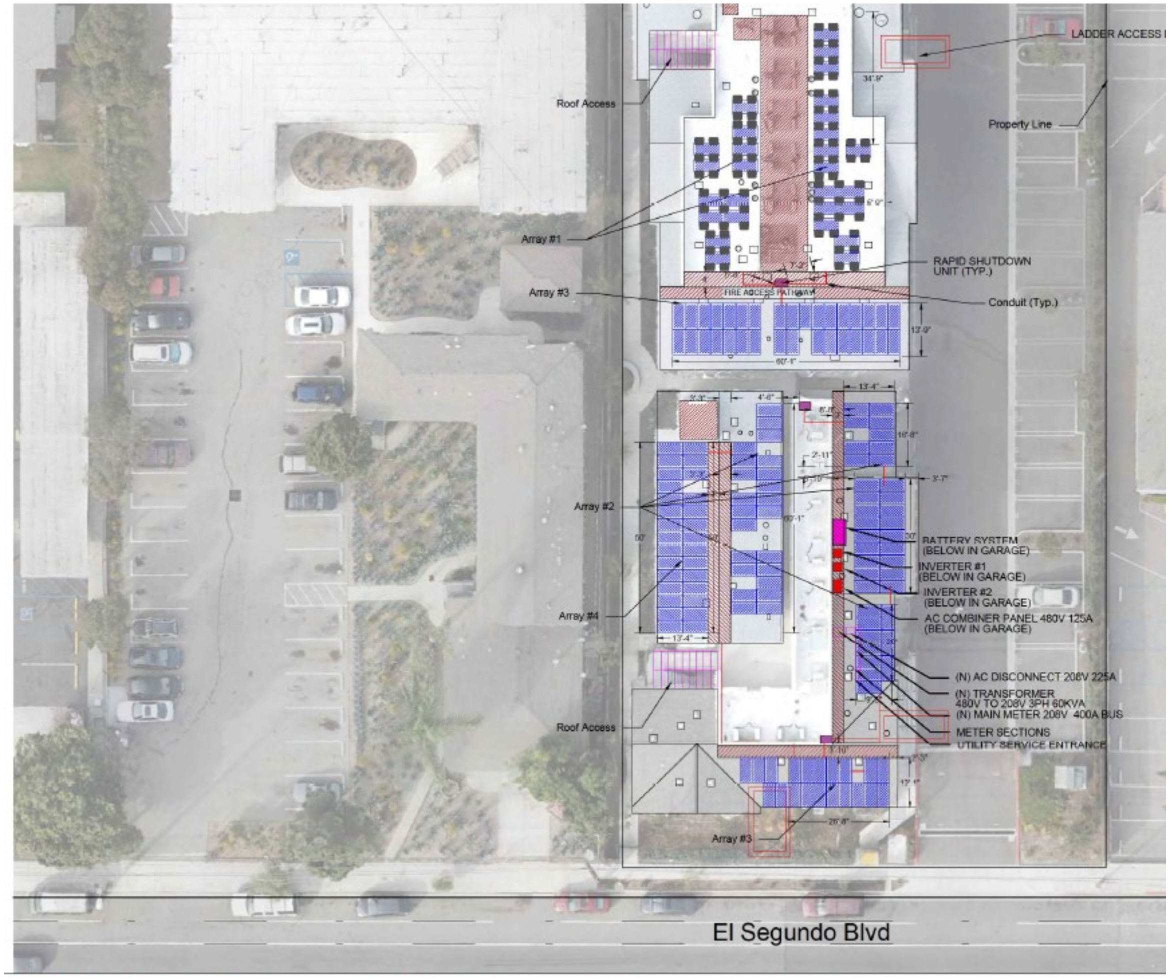
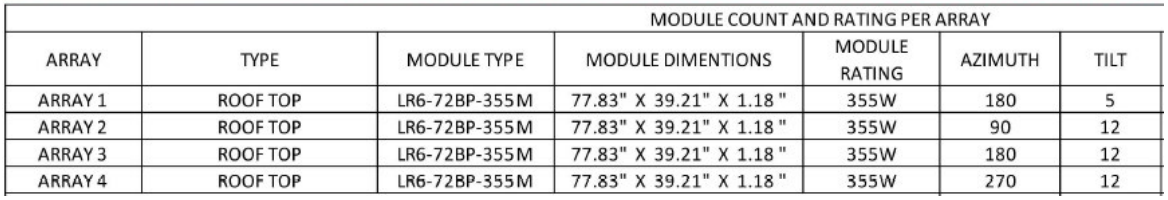
[5] Sun, Xingshu, Khan, Mohammad Ryyan, Deline, Chris, and Alam, Muhammad Ashraful. Optimization and performance of bifacial solar modules: A global perspective. United States: N. p., 2018. Web. https://doi.org/10.1016/j.apenergy.2017.12.041. National Renewable Energy Lab (NREL).

[6] Riley, Daniel. Joshua Stein, Craig Carmignani. SAND2018-8627C Performance of Bifacial PV Modules with MLPE vs. String Inverters. https://www.osti.gov/servlets/purl/1581914. Sandia National Laboratories.

Figure 18: Building 1 Solar PV Array As-Builts With Tilt and Azimuth

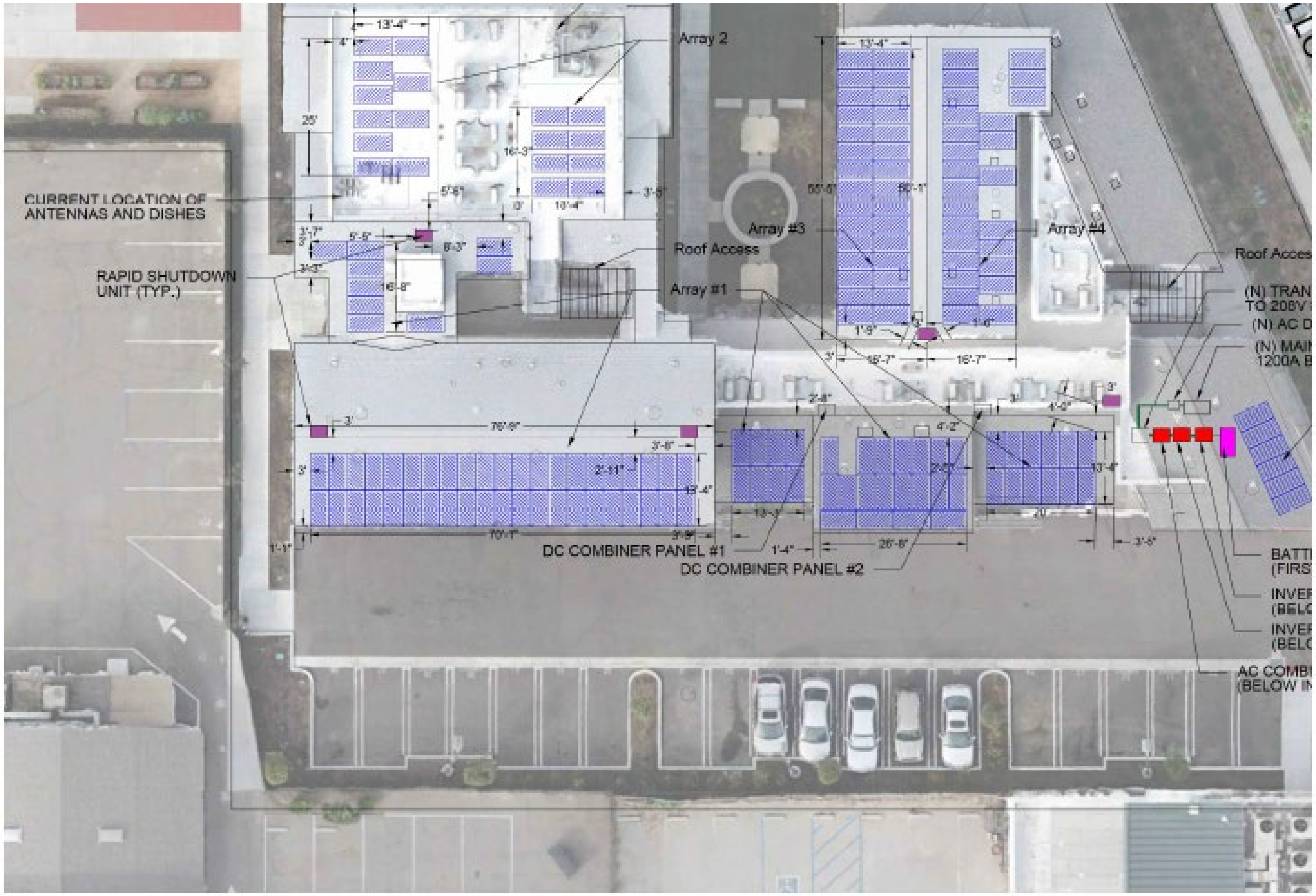




			MODULE COUNT AND RATING PER ARRAY			
ARRAY	TYPE	MODULE TYPE	MODULE DIMENTIONS	MODULE RATING	AZIMUTH	TILT
ARRAY 1	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	180	5
ARRAY 2	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	90	12
ARRAY 3	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	180	12
ARRAY 4	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	270	12

Source: As-Builts by Staten Solar

Figure 19: Building 2 Solar PV Array As-Builts With Tilt and Azimuth



MODULE COUNT AND RATING PER ARRAY						
ARRAY	TYPE	MODULE TYPE	MODULE DIMENTIONS	MODULE RATING	AZIMUTH	TILT
ARRAY 1	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	180	12
ARRAY 2	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	180	5
ARRAY 3	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	270	12
ARRAY 4	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	90	12
ARRAY 5	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	75	12

Source: As-Builts by Staten Solar

The buildings at Willowbrook were not optimized for rooftop solar exposure and have several different roof exposures, angles, and azimuths. The roofs are however coated in light colored materials, which can increase available ground reflected irradiance (GRI). This project required a DC-coupled architecture for solar and storage. Unfortunately, module-level power electronics (MLPE) options for commercial-scale DC coupled solar and storage systems are very limited and were unavailable at the time of procurement for this project. Because of this, four sets of five strings, twenty strings in total, of solar modules were connected to four inverters with only one maximum power-point tracking channel per inverter.

Boost from bifacial modules requires GRI received by the modules to be maximized and uniform. Tilt, azimuth, and elevation should be optimized to take advantage of benefits available from bifacial modules.[7] Where numerous solar strings are connected in parallel, any underperforming string(s) create mismatch losses by pulling the operating parameters away from the maximum power point. This effectively reduces the output of all collective strings. The magnitude of this reduction can be challenging to model, but a reduction to other string outputs is likely when just one of several parallel strings is underperforming.

The solar contractor provided modelling for the solar installations conducted in PVSyst, a solar PV modeling tool. The basic results are shown in tables 4, 5, and 6. Column "EArray," provides the DC energy forecast before the inverters, while "E_Grid" forecasts the production exported through the generation meters monthly. The modeling assumes a mono-facial nameplate module conversion efficiency of 17.7 percent, so does not presume gain from bifacial. The PVSyst modeling also assumed only a 0.1 percent production loss due to mixed module orientations, though various orientations are noted in the document.

Table 4: Building 1 Inverter 1 PV System Model

COM 221_2
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	89.4	82.5	2.441	2.277	0.797
February	95.5	41.70	14.23	99.7	92.7	2.739	2.442	0.766
March	147.5	57.69	14.56	150.7	141.1	4.133	3.710	0.771
April	177.1	68.02	15.77	176.6	166.2	4.816	4.511	0.799
May	197.4	87.05	16.97	195.4	183.8	5.317	4.983	0.798
June	213.9	86.58	18.19	209.1	197.2	5.657	5.305	0.794
July	226.5	77.08	19.86	224.2	211.9	6.024	5.327	0.744
August	208.3	75.64	20.05	207.9	196.0	5.605	5.257	0.791
September	163.0	57.29	19.81	163.1	153.1	4.385	4.108	0.788
October	129.4	47.80	18.14	133.2	124.2	3.606	3.375	0.793

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[7] https://www.osti.gov/pages/servlets/purl/1423188 Optimization and Performance of Bifacial Solar Modules: A Global Perspective Xingshu Sun,1 Mohammad Ryyan Khan, 1 Chris Deline, 2 and Muhammad Ashraful Alam1,

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR
November	97.5	35.06	16.24	103.6	95.6	2.808	2.622	0.792
December	84.2	33.29	14.32	90.2	82.8	2.451	2.286	0.793
Year	1824.6	703.64	16.84	1843.2	1727.0	49.982	46.202	0.785

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr, for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Source: PVSyst Model Results, EPRI

Table 5: Building 1 Inverter 2 PV System Model

COM 221_2
Balances and main results

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	90.5	83.5	2.194	2.042	0.794
February	95.5	41.70	14.23	99.9	93.0	2.431	2.161	0.762
March	147.5	57.69	14.56	152.6	143.0	3.708	3.332	0.769
April	177.1	68.02	15.77	181.4	170.9	4.391	4.114	0.799
May	197.4	87.05	16.97	199.2	187.5	4.818	4.516	0.798
June	213.9	86.58	18.19	216.5	204.6	5.214	4.893	0.796
July	226.5	77.08	19.86	228.3	216.1	5.458	4.834	0.745
August	208.3	75.64	20.05	211.6	199.6	5.069	4.758	0.792
September	163.0	57.29	19.81	169.9	159.9	4.067	3.812	0.790
October	129.4	47.80	18.14	136.6	127.6	3.291	3.079	0.793
November	97.5	35.06	16.24	105.1	97.1	2.533	2.362	0.791
December	84.2	33.29	14.32	92.1	84.6	2.227	2.073	0.793
Year	1824.6	703.64	16.84	1883.6	1767.4	45.402	41.976	0.785

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr, for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Source: PVSyst Model Results, EPRI

Table 6: Building 2 PV System Model (Both Inverters)

COM 221_2
Balances and main results

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	91.7	84.7	4.73	4.76	0.801
February	95.5	41.70	14.23	101.3	94.2	5.24	4.52	0.740
March	147.5	57.69	14.56	153.0	143.3	7.91	7.43	0.805

	GlobHor kWh/m²	**DiffHor** kWh/m²	**T_Amb** ⁰C	**GlobInc** kWh/m²	**GlobEff** kWh/m²	**EArray** MWh	**E_Grid** MWh	**PR**
April	177.1	68.02	15.77	179.7	169.1	9.24	7.95	0.733
May	197.4	87.05	16.97	197.4	185.7	10.13	9.51	0.798
June	213.9	86.58	18.19	212.5	200.6	10.85	10.20	0.795
July	226.5	77.08	19.86	226.4	214.1	11.47	10.79	0.789
August	208.3	75.64	20.05	210.5	198.3	10.69	10.05	0.791
September	163.0	57.29	19.81	167.5	157.3	8.49	7.98	0.789
October	129.4	47.80	18.14	136.5	127.5	6.97	5.95	0.722
November	97.5	35.06	16.24	106.3	98.3	5.43	5.10	0.794
December	84.2	33.29	14.32	93.1	85.6	4.77	4.47	0.796
Year	1824.6	703.64	16.84	1876.0	1758.8	95.92	88.38	0.781

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr, for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Source: PVSyst Model Results, EPRI

Measurement and Verification

The site was outfitted with two SEL 735 V4 PQ meters. These meters are positioned to measure the cumulative power flows of two inverters to and from the facility and grid. No loads are connected to the meters, only inverters. Therefore, the SEL 735 meters are positioned similarly to measure only the inverter output, like a generation meter. The storage and controls vendor, Gridscape, is also monitoring solar input to the inverters, which can be compared to "EArray" from tables 4, 5, and 6. Several Kipp and Zonen CMP 11 pyranometers are positioned across the array in addition to several corresponding module temperature sensors. One CMP 11 is positioned to capture GHI (global horizontal irradiance); another faced vertically down at the roof to capture GRI. Other units are placed to capture plane of array (POA) irradiance at the various array angles, as well as GRI 180° to POA.

A sample month of data was collected from these meters, and sensors were captured and compared with the models for a period beginning in late July 2021. During this period, the inverters on Building 1 were off due to ground faults for much of the test period. Therefore, data comparisons are based solely on the operable system on Building 2. Compared with the forecast for August 2021, August 2021 production was less than the PVSyst model, which did not incorporate bifacial gains. Table 7 depicts the forecast and actual output at both buildings. DC Production was 84 percent of modeled production, and AC generation was 78 percent of modeled production. Performance ratio (PR) was calculated separately based on actual irradiance, temperature, and measured power values. When corrected for measured GRI, production was 68 percent of forecast. No contribution from the bifacial component of the modules is evident in the output data.

Probable causes for losses include:

1. Mixed-string orientations connected to single maximum power point tracking.
2. Modules not located to maximize received GRI.
3. String mismatch due to mixed orientations and variable GRI.
4. Soiling

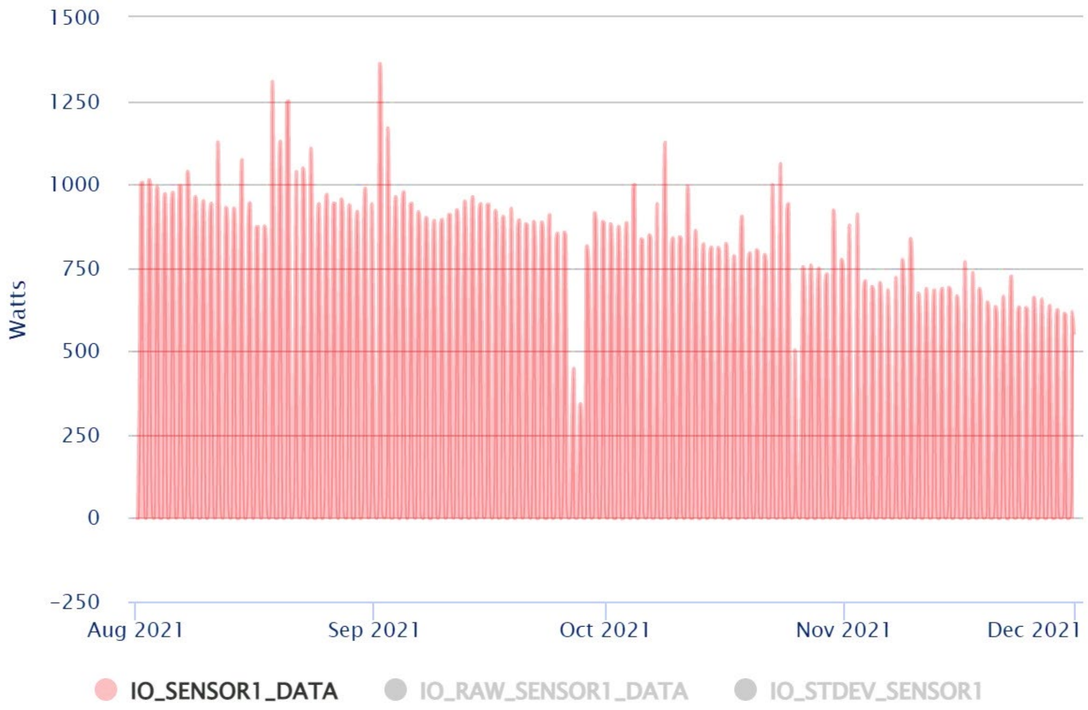
Table 7: Forecast and Actual Output

	Willowbrook DC	Building 1 DC	Willowbrook AC
PV Syst Model August	10,690 kWh	9,700 kWh	10,005 kWh
Actual Output	8,973 kWh	1,368 kWh	7,745 kWh
Performance Ratio W/O GRI	83.94 percent	14.10 percent	78.36 percent
Performance Ratio W/GRI	67.96 percent	10.36 percent	

Source: EPRI

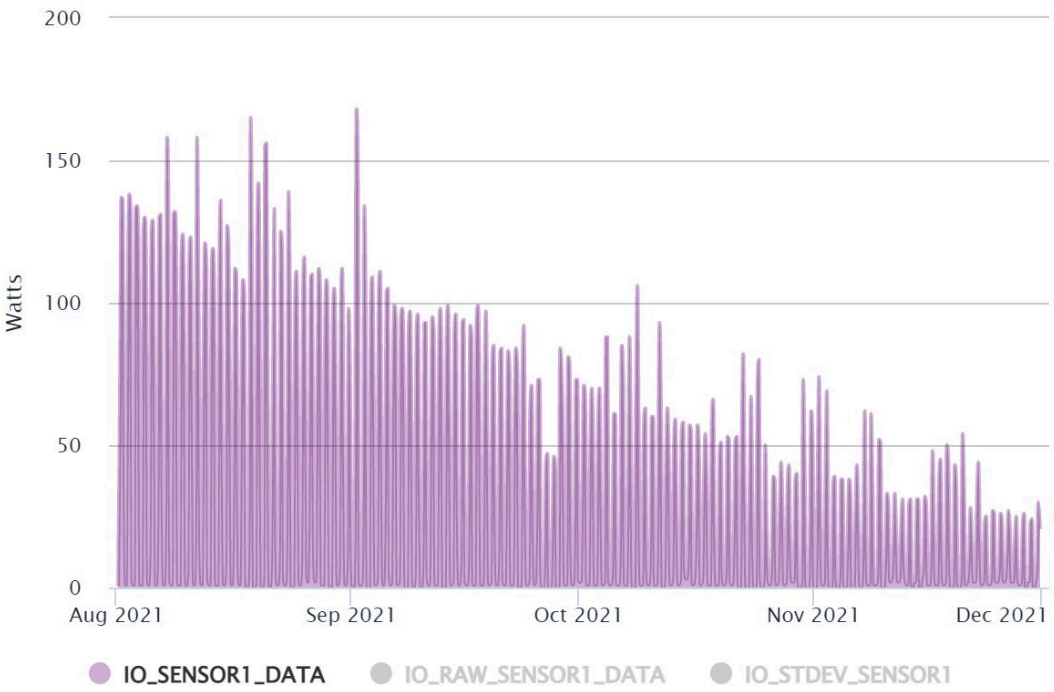
Since these measurements were taken, PV output has continuously remained significantly lower than PVSyst forecasts would suggest. The shortfall is not likely due to any unusual prevalence of cloudy conditions or otherwise low irradiance. Figure 20 and Figure 21 depict the POA and albedo captured by CMP-11 sensors, recording irradiance as expected for a 15° tilt during this time.

Figure 20: Plane of Array Irradiance



Source: EPRI

Figure 21: Plane



Source: EPRI

While much of the PV output shortfall is due to limited actual DC yield from the arrays, part is due to conversion and battery efficiency. Table 8 compares predicted solar array DC kWh versus actual, as well as energy to the grid (yield) predicted by PVSyst to actual yield from SEL 735 meters.

Table 8: Forecast and Actual Output

	September	October	November	Average
Willowbrook PV Syst DC	8490	6970	5430	
Willowbrook DC	7331	6037	2686	
% of Expected DC	**86%**	**87%**	**49%**	**74%**
Willowbrook PV Syst Yield	7980	5950	5100	
Willowbrook AC	6680	4360	1940	
% of Expected AC	**84%**	**73%**	**38%**	**65%**
El Segundo PV Syst DC	8452	6897	5341	
El Segundo DC	6269	5588	3334	
% of Expected DC	**74%**	**81%**	**62%**	**73%**
El Segundo PV Syst DC	7920	6454	5254	
El Segundo AC	5110	4540	2300	
% of Expected AC	**65%**	**70%**	**44%**	**60%**

Source: EPRI

The PVSyst DC predictions assumed standard efficiency for the modules and did not consider any bifacial boost. Yet, DC production is always substantially lower than predicted. Curve tracing was conducted; however, results were uniform and did not suggest failed modules or wiring. Therefore, the reduced output observed is presumed to be due to mismatch losses. These mismatch losses have two general causes: the modules are installed at many different angles and azimuths with only four total MPPT channels, and GRI mismatch due to variable mounting arrangements. As noted by Sandia, bifacial modules may produce less electricity than equivalent mono facial modules where mismatch is present and granular MPPT is not available.[8]

Conversion efficiency was also lower than predicted, with a 9 and 13 percent loss beyond the predicted difference between DC and AC. This is in part because the PVSyst models did not anticipate power diversion through a DC-coupled battery. DC HVAC was not operating due to a failed board during this data collection period, and both buildings exhibited similar losses, so these losses are not attributable to the DC minigrid. Based on DC measurements in October 2021, the Willowbrook battery round-trip efficiency was 68 percent on a total input of 586 kWh, or about 10 percent of the total system throughput. Inverter losses are also higher than anticipated in part because the model assumed that the inverter would operate at peak efficiency. This peak efficiency is possible at only one power level, with other power levels lower. At times when no power flows, the inverter still consumes idle power to maintain operation; at those times the efficiency is 0 percent. Solar-only projects often shut off the inverters to avoid these idle losses, but this is not feasible in a minigrid arrangement.

Conclusions

Rooftop systems are typically designed around an existing roof design rather than designing a roof specifically to optimize solar exposure. Bifacial solar modules may not improve performance where GRI cannot be maximized, and mismatch cannot be managed through careful and uniform array design. MLPE may be able to mitigate mismatch between modules and strings. Bifacial modules have been demonstrated to provide improved yield where these design issues can be addressed. However, they may not provide performance to justify the costs if the site design is not optimal. Incorporating DC-coupled storage costs due to round-trip efficiency losses are inherent to charging and discharging a battery, and while other benefits might be realized through energy time shifting, the efficiency losses negatively impact total solar yield.

Integration and Segmentation of Storage for Meeting Various Needs

Inverter DC Ports: Solar PV, Battery, Loads

Four DC-coupled inverters were installed at the sites, two per building (Figure 22). Each inverter receives and distributes solar power from the bifacial PV panels on the roof. One inverter at each building is connected to the batteries, which charge and discharge based on a schedule

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[8] Riley, Daniel. Joshua Stein, Craig Carmignani. SAND2018-8627C Performance of Bifacial PV Modules with MLPE vs. String Inverters. https://www.osti.gov/servlets/purl/1581914. Sandia National Laboratories.

set by the inverter and controller. At one of the buildings, a DC minigrid was installed and is used to power DC loads, specifically lighting and HVAC.

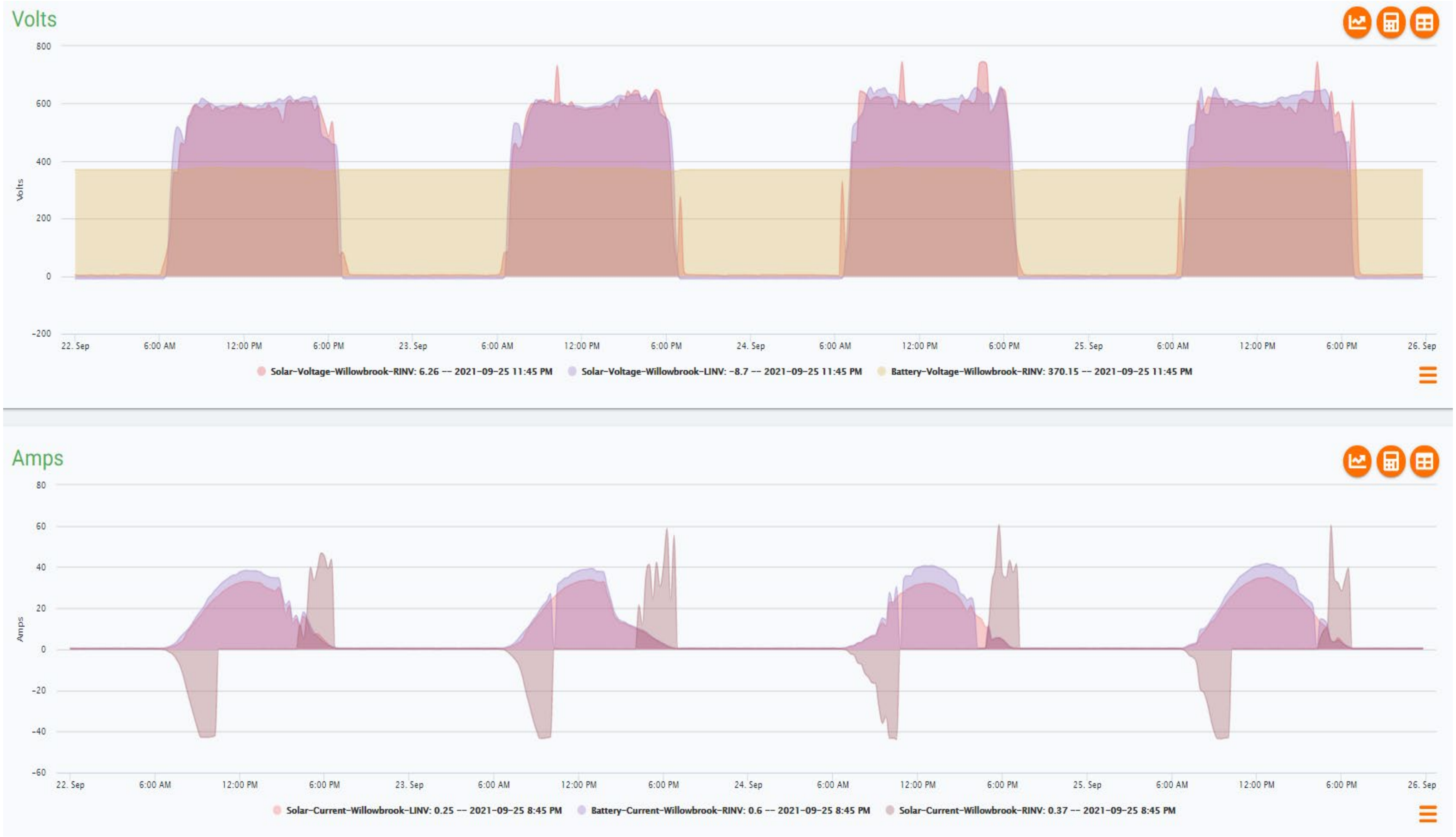
Figure 22: CE+T 30kW 3-Port Inverter

Source: EPRI

Monitoring equipment was installed to record the DC power flows in and around the system. Specifically, DC current transformers and DC voltage transducers were installed at each of the DC terminal ports of all four inverters. Altogether, this included four pairs of solar PV DC voltage and current measurements, two pairs of battery energy storage DC voltages and currents, and one pair of DC loads voltage and current.

As illustrated in Figure 23, data from these instruments quantify and verify the DC power flows of the system and allowed the research team to understand how solar and battery power were being generated, routed, and consumed. The data shows how the multiple converter stages of the DC-coupled inverter allow independent management of battery charging as well as solar maximum power point tracking, depending on the amount of sunlight reaching the panels.

Figure 23: Power Flow Data



Source: EPRI

PQ Meter Data: Inverter Output at the Transformer

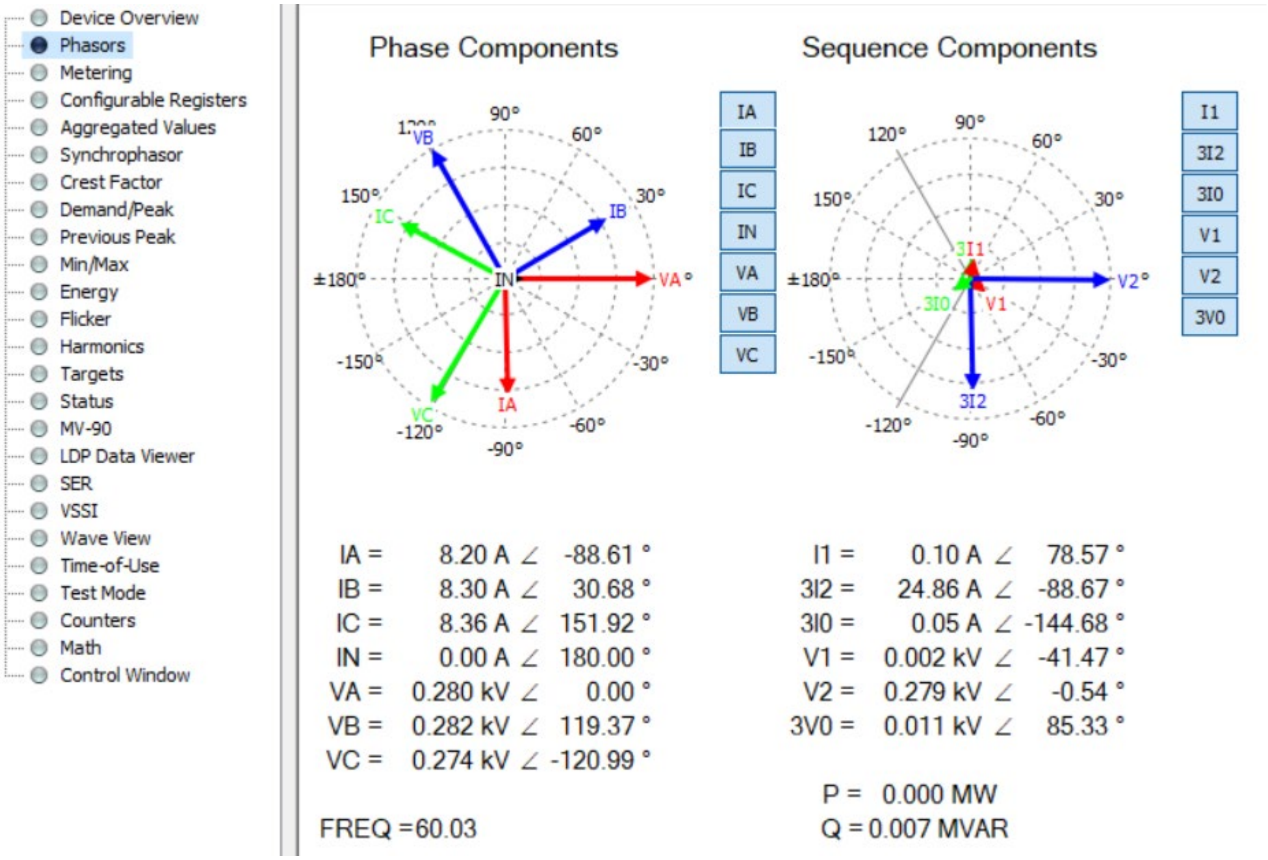
Two power quality (PQ) meters were installed, one at each building, to measure and record the combined output of the inverters to the grid (Figure 24). The location of these meters allowed accounting of the cumulative generation of the bifacial solar PV panels and battery energy storage systems, as well as providing detailed PQ data.

Figure 24: SEL 735 V4 PQ Meters

Source: EPRI

The meters record the PQ of the inverter output, including voltage and current magnitudes, harmonics, power factor, phase angle, real, reactive, and apparent power. As depicted in Figure 25, the voltage and current of each of the three phases of the immediate combined inverter output are monitored at the high side of the transformer.

Figure 25: Representative 735 SEL Human Machine Interface HMI Screen



IA = 8.20 A ∠ -88.61 °
IB = 8.30 A ∠ 30.68 °
IC = 8.36 A ∠ 151.92 °
IN = 0.00 A ∠ 180.00 °
VA = 0.280 kV ∠ 0.00 °
VB = 0.282 kV ∠ 119.37 °
VC = 0.274 kV ∠ -120.99 °

FREQ =60.03

I1 = 0.10 A ∠ 78.57 °
3I2 = 24.86 A ∠ -88.67 °
3I0 = 0.05 A ∠ -144.68 °
V1 = 0.002 kV ∠ -41.47 °
V2 = 0.279 kV ∠ -0.54 °
3V0 = 0.011 kV ∠ 85.33 °

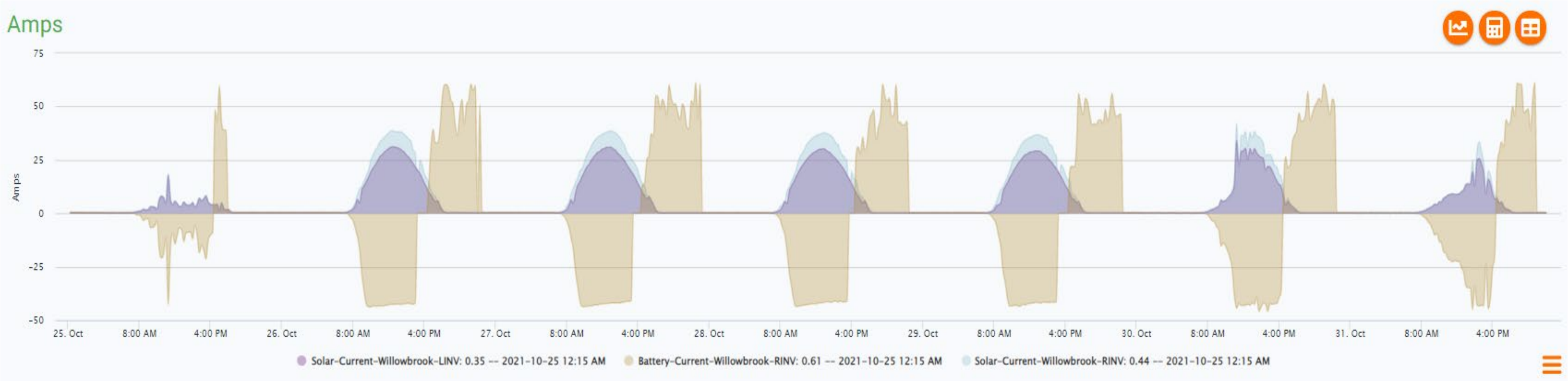
P = 0.000 MW
Q = 0.007 MVAR

Source: EPRI

Inverter Operation and Control on Solar PV Generation and Battery Dispatch

As shown in Figure 26, current data measured and recorded from the inverters' DC terminal ports for solar PV generation and battery dispatch show that the system charges the battery with solar power starting in the morning and continuing throughout the day.

Figure 26: SEL 735 V4 PQ Meters



Source: EPRI

On cloud-covered, low production days, all solar PV generation is used to charge the energy storage system, since the power generated is below the maximum charge current for the batteries. While it may seem good to have all solar power being used to charge the energy storage system, what this usually indicates is that the batteries are not being fully charged during the day. This is the case, evident by observations that the charge waveform matches the solar waveform and that the following discharge event is of considerably less duration than on other days depicted.

On sunny, normal production days, not all of the solar PV generation can be used to charge the energy storage system since the maximum charge current limit has been reached. This means that 1) some solar power is redirected to the grid and, more importantly, 2) that the energy storage system is likely to be fully charged from solar power generated only during the day. In most cases, the system seems well and properly sized since the energy storage stops charging just before the afternoon, when it begins discharging to offset energy charges during the mid- and on-peak TOU periods. This operational schedule and strategy align well with the dispatch modeled in the Distribution System Analysis section.

Building/Unit Level Measurement Requirements

Building-Level Analysis Requirements

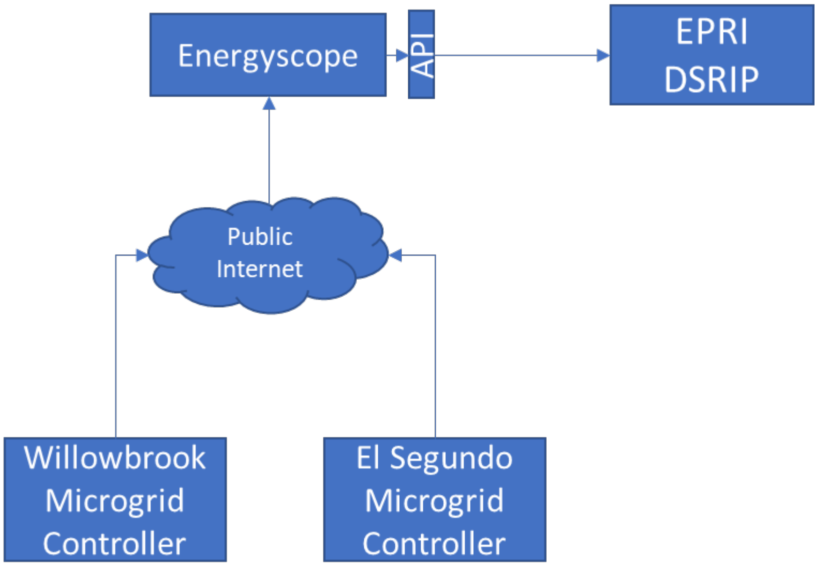
To evaluate the performance of the Willowbrook community, three types of energy performance analyses were conducted:

- Solar PV Profile Analysis
- Battery Profile Analysis
- Building-Level Load Characterization

Data Pipeline Requirements

The source of these analyses is the data collected from Gridscape's Energyscope API. Using Gridscape's Energyscope API, interval data on solar production measured on the DC side of the inverter is made available in real time. The data flow including Gridscape's EnergyScope API is shown in Figure 27. Data from solar production, battery, load monitors, and grid monitors at the installed system controller are backhauled to the Energyscope cloud instance via a dedicated broadband connection. Energyscope cloud instance provides a private API accessible to select third parties (including EPRI) for exposing solar, storage, load, and grid data. In addition, Energyscope provides a customer portal that may be used to visualize the solar, storage, load, and grid energy data and to help troubleshoot any data anomalies such as data loss.

Figure 27: Pipeline for Data Flow from Willowbrook and Building 1 Site Microgrid Controllers to EPRI DSRIP

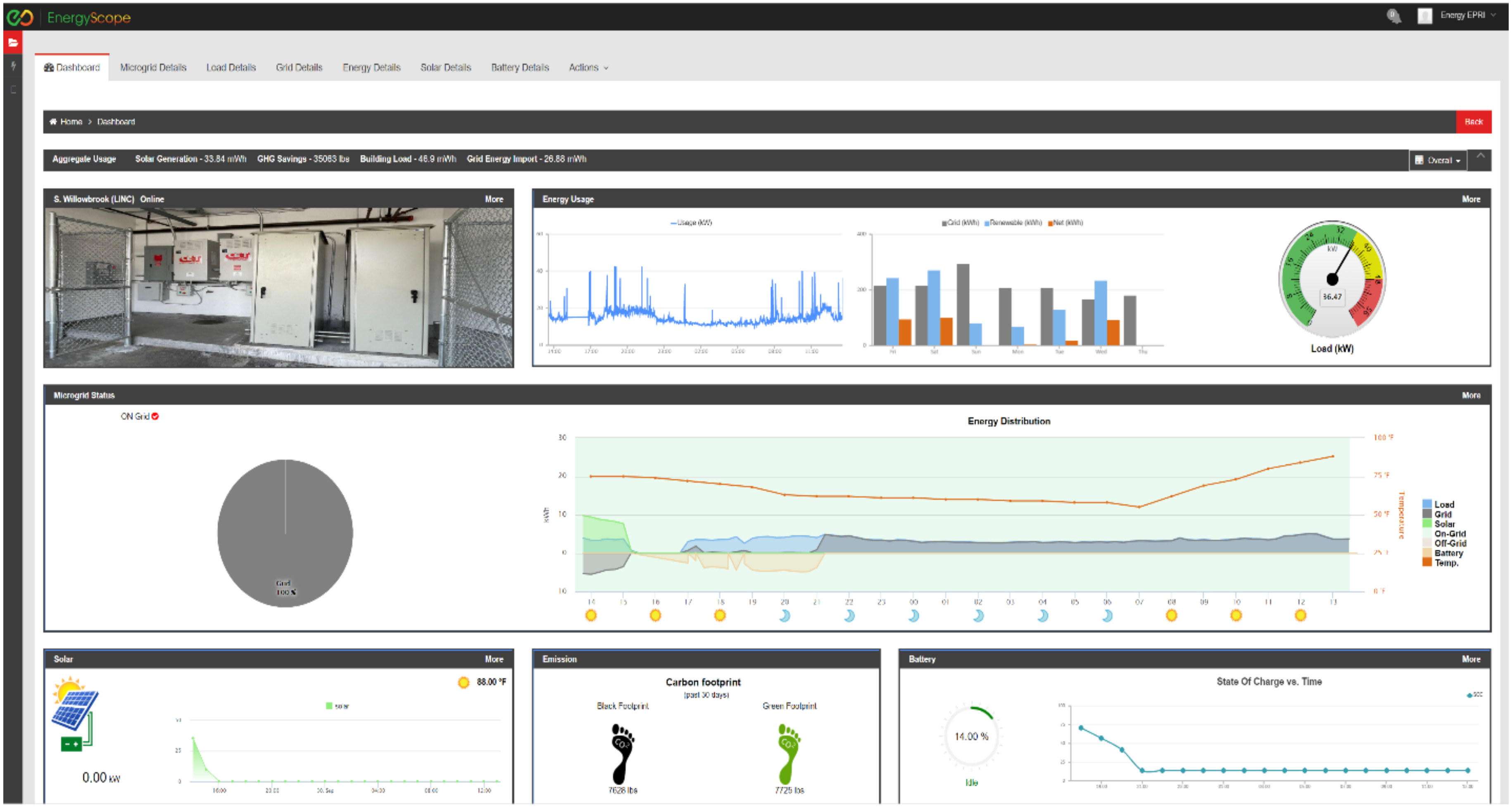


Source: EPRI

Data Availability and Quality

Data for this analysis are not directly measured from the source using a utility grade meter. The results of the analysis require an understanding of data availability and sufficiency. One of the challenges with the data pipeline from Energyscope API is the need to understand if a zero is a true-zero, or if it instead represents data unavailability. Some data reporting systems use notations such as “N/A” for representing data that is missing or unavailable, as opposed to reporting them as zero value. However, the data collected from Energyscope API are numerical quantities, and a heatmap is used to characterize data availability. The heatmap is based on solar production values, with clear distinctions between areas where a solar production value of zero is expected (such as after sunset) as opposed to lower than expected solar production (which could indicate data loss if it is zero). Figure 28 shows a screenshot of the EnergyScope customer portal dashboard, which visualizes data from solar, storage, and load.

Figure 28: EnergyScope Customer Portal Dashboard



Aggregate Usage Solar Generation - 33.84 mWh GHG Savings - 35063 lbs Building Load - 46.9 mWh Grid Energy Import - 26.88 mWh

Source: EPRI

Solar PV Profile Analysis

The Solar PV Profile Analysis is scoped differently compared with the PV Performance Analysis described in the above sections. In this analysis, the team examined how solar PV production contributes to the field control objectives by establishing hourly production patterns and peak production, then comparing how bifacial production compares to standard panels from a different PV installation in a different multifamily community in Southern California. The analysis requires an estimation of the hourly solar output from each building in the Willowbrook community.

Battery Profile Analysis

The Battery Profile Analysis is similar to the Solar PV Profile Analysis, except that the quantity being profiled is the battery's state of charge (SOC). This analysis is to understand how the battery's SOC varies during the day and if it would be conducive to energy management during periods of peak TOU rates. The profile would also reveal whether the battery is charging from renewable sources, consistent with California Rule 21. The field control trials surrounding the use case of GHG have the battery discharging to the grid between the hours of 3 a.m. and 8 a.m., and the profile helps identify if the battery is performing according to these profile expectations.

Building Load Performance

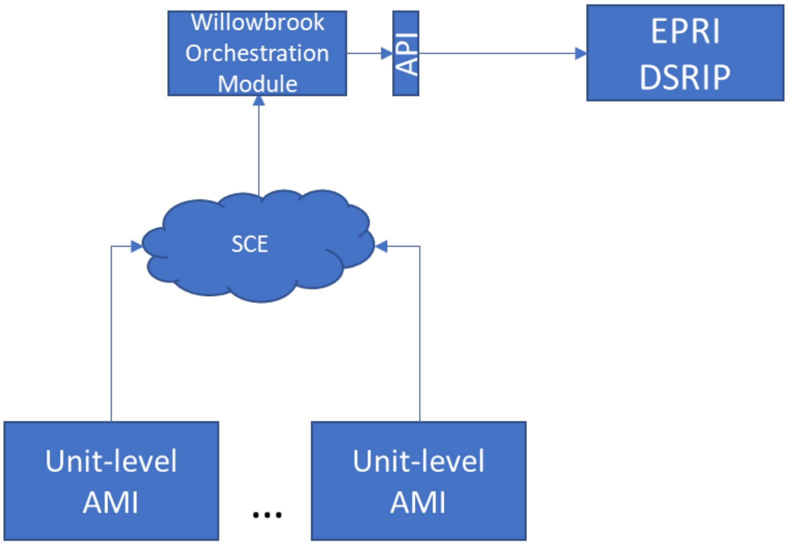
The third performance analysis is at the building level (living area plus common areas) to understand when electricity is consumed in the building. The load profile helps identify the average load levels at different times of the day, including when peaks occur. This analysis can also help identify how much energy is used by the building over several days (for example, seasonal energy performance identifies when and how much energy is used each season). Ultimately, the goal is to be able to compare the performance of the building post-installation of Solar+Storage package and when TOU messaging is used to nudge building occupants towards energy conservation behaviors, especially during TOU peak hours. The data from summer 2020 may be used to compare it with Summer 2021, with the caveat that the data must be weather normalized. Additionally, with potential data availability issues impacting 2021, it may be necessary to normalize for data loss as well.

Unit-Level Analysis Requirements

Data Pipeline Requirements

The source data for all unit-level analyses is the AMI data collected from the Willowbrook Orchestration Module (WOM). The WOM implements an API that delivers data to OpenDSRIP daily. The data flow, including WOM, is shown in Figure 29. Data from customers' smart meters are backhauled to SCE through its normal AMI data collection process. This data is then shared with OhmConnect via the Green Button link. OhmConnect uses the AMI data for DR settlement and sends the data to EPRI's DSRIP on a daily batch-data drop.

Figure 29: Pipeline for Data Flow from Willowbrook and Building 1 Site System Controllers to EPRI DSRIP



Source: EPRI

Unit-Level Load Performance

This analysis is performed to better understand when and how much energy is being used at the unit level. The load profile helps identify average load levels at different times of the day, including when peaks occur. Ultimately, the goal is to be able to compare performance at the unit-level, post-installation of the Solar+Storage package, and when TOU messaging is used to nudge occupants toward greater energy conservation, especially during TOU peak hours. The data from Summer 2020 may be used to compare with Summer 2021, with the caveat that the data must be weather normalized. Unlike the building level analysis, given that 2020 and 2021 data are based on AMI data collected via the Green Button process, there are no major data loss issues to contend with at the unit level.

Project Performance

- Solar, Storage, and Load
- Energy Efficiency

Data Availability and Quality

Before discussing the results of solar PV, battery, and load profiles, it is necessary to understand the availability and quality of data that is the source for the analysis. The analyses and the accompanying data are defined in Table 9.

Table 9: Analyses and Data Sources

Analysis	Data Needs
Building Level Solar PV Profile	• Solar PV production data from Energyscope
Building Level Battery Profile	• Battery State data from EnergyScope

Analysis	Data Needs

Building Level Load Profile	- Building level Load data from EnergyScope
	- Baseline Data (2020)
	  ○ AMI data from individual units
	  ○ Common Area AMI data
	  ○ Weather data (Cooling Degree Days)

Unit Level Load Profile	- AMI data from OhmConnect developed WOM

A set of heat maps is used to visualize the availability and quality of data from Energyscope API. Figure 30 through Figure 41 shows the data availability. The color coding is done to show (in black) all instances of 0 solar PV production; when this happens in the middle of the day it is attributed to data loss, as opposed to other factors such as shade and cloud cover. The red color indicates a median point in the range of daily production, and green indicates better than the 75th percentile.

Figure 30 through Figure 41 show that:

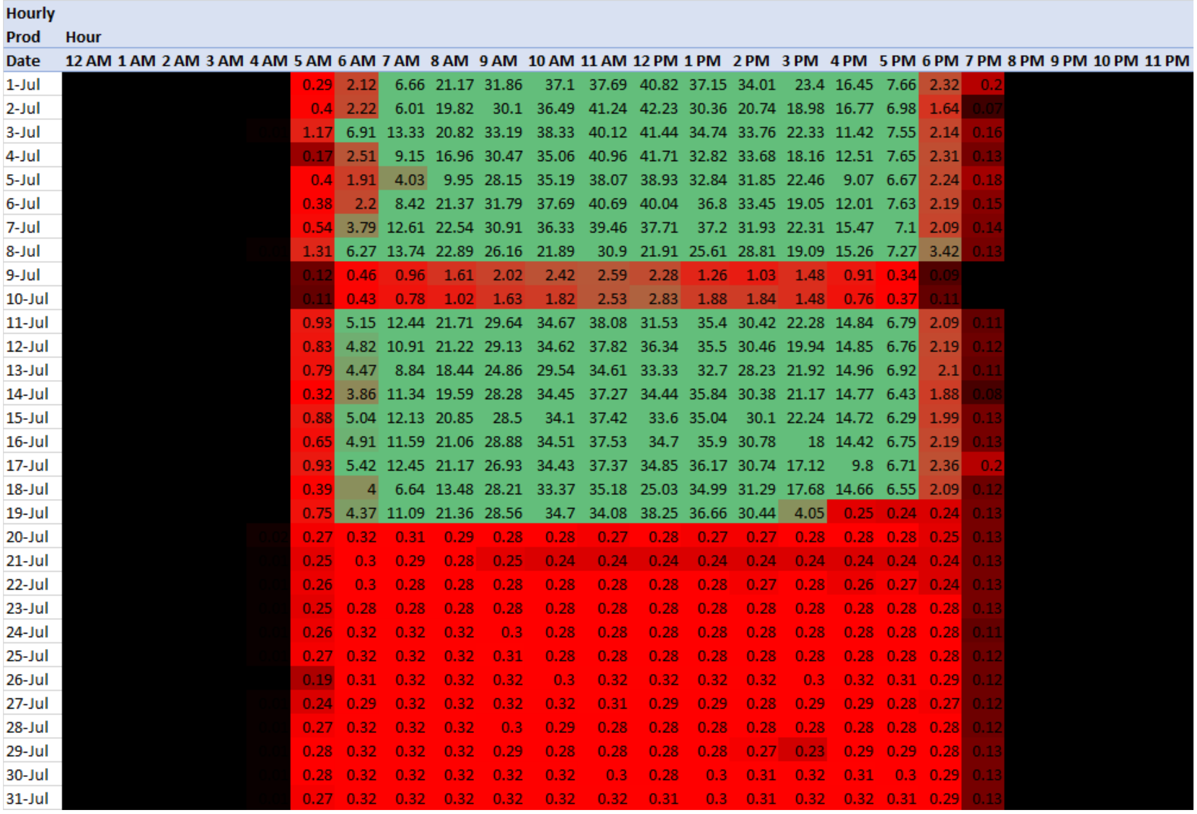
1. Building 1 and Building 2 have very different failure modes. Independent causes of data failures impacted both sites.
2. In general, the Building 2 site has better data availability compared with the Building 1 site even though the relative solar PV capacity on the respective inverters was about the same.
3. After a few days of data loss in early June, Building 2 returned to high data availability.
4. The Building 1 site had a major data outage in Aug 2021 that lasted 23 days.
5. The data flow in Building 1 recovered in the fall months (September through November).

Figure 30: Solar Data Availability for Building 1 in June 2021

Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jun						0.16	1.54	3.71	8.96	16.01	20.44	22.43	21.79	20.16	16.11	9.27	4.86	3.16	0.92					
2-Jun						0.19	1.31	2.6	4.62	11.51	20.06	22.87	22.02	20.13	16.83	10.75	6.73	3.11	0.81					
3-Jun						0.17	1.59	4.47	13.33	18.83	21.17	21.67	22.19	20	16.43	10.18	6.42	3.08	0.65					
4-Jun						0.78	4.53	7.78	14.72	18.54	32.7	40.05	39.29	37.3	31.65	18.59	14.45	6.01	1.69	0.05				
5-Jun						0.29	2.6	7.24	17.5	24.33	37.97	38.85	38.69	38.15	31.85	15.47	9.39	6.52	1.7	0.07				
6-Jun						0.43	3.09	7.51	18.55	30.97	38.46	41.53	39.17	37.41	32.8	17.95	9.81	7.46	1.98	0.07				
7-Jun						0.18	1.5	2.68	4.48	5.82	7.16	9.83	20.72	11.82	19.3	22.19	0.63	0.33	0.08					
8-Jun						1.26	6.17	16.33	13.38	24.02	29.84	41.9	40.39	35.83	32.29	16.28	10.13	6.16	1.89	0.05				
9-Jun						1.7	4.66	8.23	12.56	27.9	35.29	38.64	38.96	35.17	33.15	18.91	10.17	6.84	1.81	0.09				
10-Jun						1.31	6.09	14.89	24.48	31.97	37.69	41.58	39.3	38.72	33.01	16.93	8.6	5.97	1.76	0.11				
11-Jun						1.29	6.59	12.3	24.27	31.99	37.02	39.91	36.55	38.22	32.66	17.84	8.66	6.68	1.78	0.09				
12-Jun						1.29	6.67	14.44	24.19	31.78	36.84	36.16	40.13	37.81	32.4	16.79	8.81	6.89	1.92	0.08				
13-Jun						0.6	4.11	14.23	23.96	29.98	29.44	38.03	40.45	38	32.71	17.18	10.17	6.73	1.76	0.12				
14-Jun						1.24	6.36	13.87	23.46	29.84	36.19	36.68	38.05	37.15	31.69	18.63	11.55	6.48	1.82	0.08				
15-Jun						1.39	6.41	11.51	17.21	18.73	33.68	38.64	30.43	28.21	24.1	15.05	14.07	4.4	1.86	0.05				
16-Jun						1.06	6.26	12.61	21.96	30.61	33.98	37.78	37.11	29.71	25.47	18.85	13.38	6.71	2.45	0.1				
17-Jun						0.97	5.87	12.57	11.18	13.41	31.46	38.88	24.9	35.39	31.07	17.77	11.25	7.62	2.52	0.17				
18-Jun						0.2	3.21	3.59	5.85	21.82	25.35	33.11	32.93	26.73	16.36	23.97	16.35	7.58	2.41	0.16				
19-Jun						0.69	4.63	9.74	22.85	32.27	38	41.4	41.85	37.06	33.75	18.53	10.53	7.87	2.3	0.15				
20-Jun						0.31	2.25	6.04	15.44	25.4	36.03	38.89	39.16	35.12	31.82	18.11	12.55	7.85	2.43	0.15				
21-Jun						0.3	2.96	16.17	25.37	32.88	38.13	41.72	40.12	39.54	34.16	18.47	10.61	7.91	2.25	0.2				
22-Jun						1.04	6.15	13.21	25.46	33.71	39.45	42.69	40.66	40.08	36.51	17.02	8.24	5.11	2.15	0.12				
23-Jun						1.33	5.36	11.88	23.57	32.11	37.38	41.08	38.58	34.93	34.78	15.15	9.77	7.67	2.22	0.18				
24-Jun						1.03	3.51	9.39	25.29	2.59								18.05	2.21	0.21				
25-Jun						1.2	6.76	15.4	25.74	33.64	39.26	41.94	43.4	40.76	31.07	21.67	9.96	7.72	2.25	0.22				
26-Jun						1.26	6.62	14.84	24.71	32.24	38.18	37.26	41.75	39.25	33.84	21.99	14	7.6	2.3	0.15				
27-Jun						1.06	3.43	10.48	21.61	30.71	37.6	40.95	41.08	34.72	32.91	17.38	16.15	7.65	2.29	0.14				
28-Jun						1.02	5.09	14.23	24.05	31.83	37.69	40.76	39.55	35.89	32.61	18.47	12.32	5.62	2.98	0.22				
29-Jun						0.32	3.25	9.77	18.34	20.42	26.03	35.63	29.53	33.21	36.04	16.88	11.12	5.48	2.1	0.16				
30-Jun						0.21	1.42	4.17	9.48	28.35	38.11	40.44	40.3	36	32.8	19.65	15.81	7.43	2.25	0.16				

Source: EPRI

Figure 31: Solar Data Availability for Building 1 in July 2021



Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jul						0.29	2.12	6.66	21.17	31.86	37.1	37.69	40.82	37.15	34.01	23.4	16.45	7.66	2.32	0.2				
2-Jul						0.4	2.22	6.01	19.82	30.1	36.49	41.24	42.23	30.36	20.74	18.98	16.77	6.98	1.64	0.07				
3-Jul					0.01	1.17	6.91	13.33	20.82	33.19	38.33	40.12	41.44	34.74	33.76	22.33	11.42	7.55	2.14	0.16				
4-Jul						0.17	2.51	9.15	16.96	30.47	35.06	40.96	41.71	32.82	33.68	18.16	12.51	7.65	2.31	0.13				
5-Jul						0.4	1.91	4.03	9.95	28.15	35.19	38.07	38.93	32.84	31.85	22.46	9.07	6.67	2.24	0.18				
6-Jul						0.38	2.2	8.42	21.37	31.79	37.69	40.69	40.04	36.8	33.45	19.05	12.01	7.63	2.19	0.15				
7-Jul						0.54	3.79	12.61	22.54	30.91	36.33	39.46	37.71	37.2	31.93	22.31	15.47	7.1	2.09	0.14				
8-Jul					0.01	1.31	6.27	13.74	22.89	26.16	21.89	30.9	21.91	25.61	28.81	19.09	15.26	7.27	3.42	0.13				
9-Jul						0.12	0.46	0.96	1.61	2.02	2.42	2.59	2.28	1.26	1.03	1.48	0.91	0.34	0.09					
10-Jul						0.11	0.43	0.78	1.02	1.63	1.82	2.53	2.83	1.88	1.84	1.48	0.76	0.37	0.11					
11-Jul						0.93	5.15	12.44	21.71	29.64	34.67	38.08	31.53	35.4	30.42	22.28	14.84	6.79	2.09	0.11				
12-Jul						0.83	4.82	10.91	21.22	29.13	34.62	37.82	36.34	35.5	30.46	19.94	14.85	6.76	2.19	0.12				
13-Jul						0.79	4.47	8.84	18.44	24.86	29.54	34.61	33.33	32.7	28.23	21.92	14.96	6.92	2.1	0.11				
14-Jul						0.32	3.86	11.34	19.59	28.28	34.45	37.27	34.44	35.84	30.38	21.17	14.77	6.43	1.88	0.08				
15-Jul						0.88	5.04	12.13	20.85	28.5	34.1	37.42	33.6	35.04	30.1	22.24	14.72	6.29	1.99	0.13				
16-Jul						0.65	4.91	11.59	21.06	28.88	34.51	37.53	34.7	35.9	30.78	18	14.42	6.75	2.19	0.13				
17-Jul						0.93	5.42	12.45	21.17	26.93	34.43	37.37	34.85	36.17	30.74	17.12	9.8	6.71	2.36	0.2				
18-Jul						0.39	4	6.64	13.48	28.21	33.37	35.18	25.03	34.99	31.29	17.68	14.66	6.55	2.09	0.12				
19-Jul						0.75	4.37	11.09	21.36	28.56	34.7	34.08	38.25	36.66	30.44	4.05	0.25	0.24	0.24	0.13				
20-Jul					0.02	0.27	0.32	0.31	0.29	0.28	0.28	0.27	0.28	0.27	0.27	0.28	0.28	0.28	0.25	0.13				
21-Jul					0.01	0.25	0.3	0.29	0.28	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.13				
22-Jul					0.01	0.26	0.3	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.28	0.26	0.27	0.24	0.13				
23-Jul					0.01	0.25	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.13				
24-Jul					0.01	0.26	0.32	0.32	0.32	0.3	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.11				
25-Jul					0.01	0.27	0.32	0.32	0.32	0.31	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.12				
26-Jul						0.19	0.31	0.32	0.32	0.32	0.3	0.32	0.32	0.32	0.32	0.3	0.32	0.31	0.29	0.12				
27-Jul					0.01	0.24	0.29	0.32	0.32	0.32	0.32	0.31	0.29	0.29	0.28	0.29	0.29	0.28	0.27	0.12				
28-Jul					0.01	0.27	0.32	0.32	0.32	0.3	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.12				
29-Jul					0.01	0.28	0.32	0.32	0.32	0.29	0.28	0.28	0.28	0.28	0.27	0.23	0.29	0.29	0.28	0.13				
30-Jul					0.01	0.28	0.32	0.32	0.32	0.32	0.32	0.3	0.28	0.3	0.31	0.32	0.31	0.3	0.29	0.13				
31-Jul					0.01	0.27	0.32	0.32	0.32	0.32	0.32	0.32	0.31	0.3	0.31	0.32	0.32	0.31	0.29	0.13				

Source: EPRI

Figure 32: Solar Data Availability for Building 1 for August 2021

Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Aug						0.01	0.28	0.32	0.32	0.32	0.32	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.11			
2-Aug						0.01	0.28	0.34	0.32	0.32	0.3	0.06		9.16	40.81	34.64	19	17.06	7.29	1.89	0.06			
3-Aug							0.43	4.92	13.73	24.37	32.93	38.33	41.23	41.94	39.53	32.95	20.29	12.55	6.62	1.81	0.03			
4-Aug							0.37	4.68	13.22	23.44	31.96	37.81	40.7	41.92	38.87	31.22	17.82	12.75	6.66	1.68	0.04			
5-Aug							0.07	0.36	0.95	1.72	2.24	2.59	2.79	2.79	2.54	2.1	1.36	0.9	0.35	0.07				
6-Aug							0.15	2.62	9.14	22.7	29.68	36.76	42.94	39.16	39.79	30.14	24.73	16.16	0.28					
7-Aug							0.1	1.69	5.82	10.38	27.34	38.53	41.75	41.79	38.49	32.85	17.65	16.11	6.55	1.64	0.01			
8-Aug																								
9-Aug																								
10-Aug																								
11-Aug																								
12-Aug																								
13-Aug																								
14-Aug																								
15-Aug																								
16-Aug																								
17-Aug																								
18-Aug																								
19-Aug																								
20-Aug																								
21-Aug																								
22-Aug																								
23-Aug																								
24-Aug																								
25-Aug																								
26-Aug																								
27-Aug																								
28-Aug																								
29-Aug																								
30-Aug																								
31-Aug															4.21	17.05	13.46	4.85	2.45	0.28				

Source: EPRI

Figure 33: Solar Data Availability for Building 1 for September 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Sep							0.05	1.78	5.31	3.54	5.78		8.48	10.08	18.84	17.28	18.44	11.21	5.19	0.49				
2-Sep							0.02	0.54	2.24	5.17	7.52	10.58	18.41	28.47	36.66	30.98	22.28	11.86	4.02	0.41				
3-Sep							0.03	1.09	4.71	12.44	27.31	36.54	40.60	33.39	37.44	31.66	17.61	11.18	3.72	0.39				
4-Sep							0.07	3.00	11.48	21.84	29.19	31.23	40.25	40.81	37.71	31.63	21.63	12.04	3.92	0.41				
5-Sep							0.08	3.02	10.95	21.69	28.38	29.62	35.84	36.21	34.63	30.00	20.23	10.58	3.22	0.29				
6-Sep							0.06	1.95	8.55	20.73	28.13	31.62	38.06	38.29	35.21	29.00	19.02	9.32	3.21	0.27				
7-Sep							0.06	2.66	7.58	15.34	29.06	30.32	37.35	37.23	33.70	27.75	17.26	10.07	3.41	0.28				
8-Sep							0.04	2.32	8.72	8.57	19.41	33.45	33.01	36.91	33.66	28.36	16.59	10.05	3.03	0.23				
9-Sep							0.06	2.58	9.97	20.00	28.75	32.26	36.59	36.13	32.95	26.19	17.17	9.59	3.52	0.44				
10-Sep							0.03	1.65	5.85	8.33	28.05	31.07	36.13	36.68	34.79	28.94	19.05	9.93	3.17	0.17				
11-Sep							0.05	2.57	10.34	19.43	29.96	35.36	38.76	38.82	35.67	29.37	19.22	9.84	3.15	0.23				
12-Sep							0.05	2.75	11.10	19.76	29.42	34.17	37.27	37.11	34.13	28.13	16.37	9.54	2.92	0.18				
13-Sep							0.02	1.11	6.68	20.84	29.55	37.08	40.26	40.29	36.80	30.46	25.96	13.45	3.40	0.16				
14-Sep						0.02	1.49	11.89	20.61	30.19	36.82	39.39	39.11	35.79	29.52	18.99	9.92	2.82	0.16					
15-Sep						0.01	0.80	4.32	13.71	29.76	35.81	24.07	18.77	30.65	29.72	15.35	6.32	2.43	0.08					
16-Sep						0.01	0.57	3.51	11.98	30.50	35.86	33.71	17.98	28.43	26.43	13.41	6.31	2.35	0.11					
17-Sep						0.01	1.06	5.78	11.00	15.20	34.65	37.25	26.76	18.27	13.90	12.85	5.99	2.06	0.11					
18-Sep						0.03	0.68	3.17	6.95	10.86	27.97	38.67	36.75	29.73	22.45	10.56	6.42	2.18	0.10					
19-Sep						0.05	1.49	4.05	10.94	25.90	32.55	31.40	19.83	16.46	13.76	13.25	5.64	1.94	0.08					
20-Sep						0.06	1.53	7.91	7.19	23.24	33.93	36.71	25.68	15.89	13.60	12.18	5.20	1.67	0.08					
21-Sep						0.03	1.47	9.07	19.49	25.98	30.74	32.40	32.81	30.20	24.48	13.63	6.24	1.73	0.02					
22-Sep						0.02	2.09	9.11	10.64	11.39	14.12	16.35	16.78	15.66	12.25	14.51	7.56	2.00	0.02					
23-Sep						0.01	2.11	9.13	19.52	26.89	33.97	36.81	36.83	25.69	14.25	10.14	5.96	1.48	0.01					
24-Sep						0.01	1.01	4.76	11.99	26.45	30.54	35.25	34.97	30.97	24.87	9.44	5.73	2.66	0.02					
25-Sep						0.01	1.19	8.42	17.87	25.43	32.73	35.70	35.18	31.46	25.38	13.73	5.31	1.57	0.03					
26-Sep							0.21	1.21	2.80	4.59	8.28	8.81	10.99	12.00	12.37	8.49	4.64	0.90	0.01					
27-Sep							0.20	1.56	3.19	7.26	7.80	7.93	7.65	8.79	10.31	5.21	2.82	0.61	0.01					
28-Sep						0.01	1.21	6.02	11.05	17.26	10.48	9.35	11.41	14.37	17.37	11.46	6.34	1.68	0.02					
29-Sep						0.01	1.56	8.00	16.58	23.80	28.40	30.68	32.57	29.76	22.49	12.91	6.39	1.36	0.02					
30-Sep						0.01	2.02	8.75	18.80	26.02	32.30	20.47	19.07	10.45	5.79	13.74	5.90	1.28						

Source: EPRI

Figure 34: Solar Data Availability for Building 1 for October 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Oct						0.01	1.94	4.39	1.12	27.37	6.91	5.50	32.66	30.39	24.02	14.99	6.24	1.45	0.01					
2-Oct						0.01	1.94	8.47	18.66	25.66	32.00	34.58	34.15	30.37	23.89	14.79	6.10	1.26	0.01					
3-Oct						0.01	1.77	7.79	17.61	24.88	31.69	31.97	32.19	28.91	22.89	14.02	5.79	1.15						
4-Oct						0.01	1.78	4.33	8.66	16.20	23.59	25.70	32.31	20.81	17.63	1.74	0.04	0.26						
5-Oct						0.01	1.65	8.27	18.53	27.92	33.17	35.58	35.71	31.46	23.12	14.78	5.95	1.16						
6-Oct							0.31	2.22	5.92	4.97	6.53	16.83	22.14	21.06	23.17	13.69	6.14	0.96						
7-Oct							0.48	5.28	9.16	14.06	9.51	11.74	13.94	7.20	6.93	7.13	2.07	0.54						
8-Oct							0.45	5.20	14.18	14.80	12.22	16.21	31.16	23.63	23.84	12.26	5.87	0.94						
9-Oct						0.01	1.27	8.34	18.78	27.33	33.67	35.02	35.93	31.74	24.39	14.58	5.47	0.92						
10-Oct							1.24	8.25	19.10	28.24	33.61	34.12	35.05	30.97	24.08	14.31	5.29	0.83						
11-Oct							0.87	5.86	12.01	22.01	20.67	9.77	13.48	26.84	21.39	13.94	4.92	0.68						
12-Oct							1.10	7.20	19.36	29.41	35.48	36.27	35.68	31.70	24.25	13.95	5.11	0.74						
13-Oct							1.37	7.76	18.21	25.55	31.35	35.24	32.86	30.52	23.26	13.43	4.78	0.67						
14-Oct							1.34	7.68	17.79	26.87	32.16	34.56	30.26	29.02	22.07	12.83	4.68	0.63						
15-Oct							1.16	7.34	17.65	26.56	31.79	32.23	32.32	28.32	21.37	12.15	1.67							
16-Oct							1.17	7.42	17.73	26.67	32.01	34.08	31.23	28.78	21.89	12.38	4.40	0.56						
17-Oct							1.05	7.13	16.97	24.61	29.32	29.64	30.75	27.22	20.13	11.57	4.20	0.47						
18-Oct							0.50	4.27	14.24	19.23	29.79	36.29	35.02	28.66	22.17	12.41	4.30	0.48						
19-Oct							1.08	7.27	17.49	25.23	30.23	32.25	31.54	28.54	21.34	12.02	4.18	0.45						
20-Oct							0.90	6.95	17.00	25.74	31.60	33.64	31.67	29.21	21.63	9.24	5.48	0.54						
21-Oct							1.01	7.20	16.10	24.94	31.15	31.63	32.20	28.73	21.61	12.17	4.07	0.39						
22-Oct							0.23	1.38	6.55	20.09	32.04	27.24	29.98	26.34	19.28	10.60	3.46	0.26						
23-Oct							0.47	2.15	0.72															
24-Oct							0.69	5.54	14.10	16.54	21.98	13.77	22.09	26.84	18.11	10.68	3.49	0.29						
25-Oct							0.19	1.03	2.16	6.31	9.46	4.13	4.03	4.93	6.55	3.58	2.17	0.29						
26-Oct							0.63	6.12	16.72	25.93	31.51	33.49	32.63	28.37	19.78	10.85	3.46	0.25						
27-Oct							0.58	5.82	14.03	24.14	30.56	32.53	29.55	26.39	19.60	10.42	3.44	0.22						
28-Oct							0.72	5.66	13.38	22.44	29.45	31.60	28.64	26.46	19.36	10.14	3.34	0.18						
29-Oct							0.60	5.91	15.31	24.02	29.26	31.20	28.63	25.86	18.76	9.77	3.24	0.17						
30-Oct							0.09	1.38	4.80	9.77	26.49	31.75	30.66	23.92	19.36	9.16	3.26	0.14						
31-Oct							0.09	1.22	3.93	7.10	9.20	11.03	15.12	23.71	15.52	6.15								

Source: EPRI

Figure 35: Solar Data Availability for Building 1 for November 2021

Hour/Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Nov							0.21	5.50	10.54	13.58	11.38	13.70	12.91	9.56	8.97	7.26	3.39	0.29						
2-Nov							0.11	1.51	3.87	7.39	12.03	21.84	29.18	25.02	18.24	8.84	2.76	0.11						
3-Nov							0.12	1.65	8.70	22.14	28.03	30.36	29.54	23.76	18.07	9.24	2.35	0.07						
4-Nov							0.07	1.52	5.65	20.05	27.51	29.55	28.74	23.18	17.39	8.77	2.54	0.10						
5-Nov							0.10	1.60	7.03	21.11	28.27	30.31	28.23	22.16	17.54	8.80	2.52	0.08						
6-Nov							0.04	1.25	3.74	9.21	18.39	28.85	28.09	22.76	17.03	8.86	2.55	0.08						
7-Nov							0.04	1.06	3.24	6.40	6.32	17.93	25.44	23.23	15.71	8.38	2.48	0.07						
8-Nov							0.04	1.57	5.27	10.09	28.15	29.93	28.70	22.44	16.47	8.40	2.26	0.06						
9-Nov							0.22	3.45	7.87	21.31	22.64	24.90	25.76	21.15	15.94	8.33	2.14	0.06						
10-Nov							0.18	2.04	8.47	16.18	16.54	16.22	27.26	22.77	16.22	8.03	2.19	0.05						
11-Nov							0.25	3.88	7.61	13.44	16.12	16.18	3.16	1.68	12.81	2.42	2.07	0.04						
12-Nov							0.21	1.69	8.47	17.46	26.13	28.30	27.14	22.84	15.89	7.82	1.92	0.03						
13-Nov							0.16	2.69	8.60	13.13	15.62	12.16	24.09	21.67	5.23									
14-Nov							0.14	3.87	8.94	20.50	26.32	28.39	18.06	5.57	15.86	7.92	2.03	0.03						
15-Nov							0.16	1.40	7.46	12.39	17.08	24.80	16.73	21.30	4.64	2.15	1.95	0.01						
16-Nov							0.06	0.89	3.41	5.57	17.68	21.29	21.44	20.92	14.10	4.84	2.44	0.01						
17-Nov							0.07	1.52	3.52	6.05	8.41	12.52	18.46	14.21	9.98	7.38	1.69	0.01						
18-Nov							0.07	0.86	3.53	6.28	19.67	10.43	19.89	17.41	11.61	3.32	1.58	0.01						
19-Nov							0.02	0.68	2.53	6.20	7.87	13.83	12.03	10.07	5.39	5.19	1.77	0.01						
20-Nov							0.03	0.66	3.11	6.65	14.57	14.09	13.22	9.10	5.75	4.20	1.26	0.01						
21-Nov							0.06	2.89	7.67	12.42	13.66	15.07	15.03	14.95	7.74	4.24	1.37	0.01						
22-Nov							0.08	2.51	7.50	13.07	14.36	15.26	14.14	13.32	12.50	6.94	1.42	0.01						
23-Nov										11.31	23.55	25.77	24.53	20.53	14.26	6.40	1.57	0.01						
24-Nov							0.09	1.11	7.02	11.12	6.79	0.56	0.41	6.70	10.58	2.63	1.61	0.01						
25-Nov							0.05	1.55	7.07	12.85	19.70	20.15	16.59	13.57	10.28	6.29	1.59	0.01						
26-Nov							0.04	2.28	8.70	11.76	14.40	14.93	19.22	20.12	3.77	3.47	1.37	0.01						
27-Nov							0.04	2.68	7.96	11.42	14.25	14.64	12.80	10.35	2.68	2.77	1.46	0.01						
28-Nov							0.03	2.86	7.90	10.99	13.65	14.28	13.08	10.37	4.96	2.62	1.40	0.01						
29-Nov							0.05	1.36	7.00	10.85	12.89	13.12	11.88	16.10	5.83	6.12	1.24	0.01						
30-Nov							0.05	0.63	2.63	5.18	10.57	28.30	11.80											

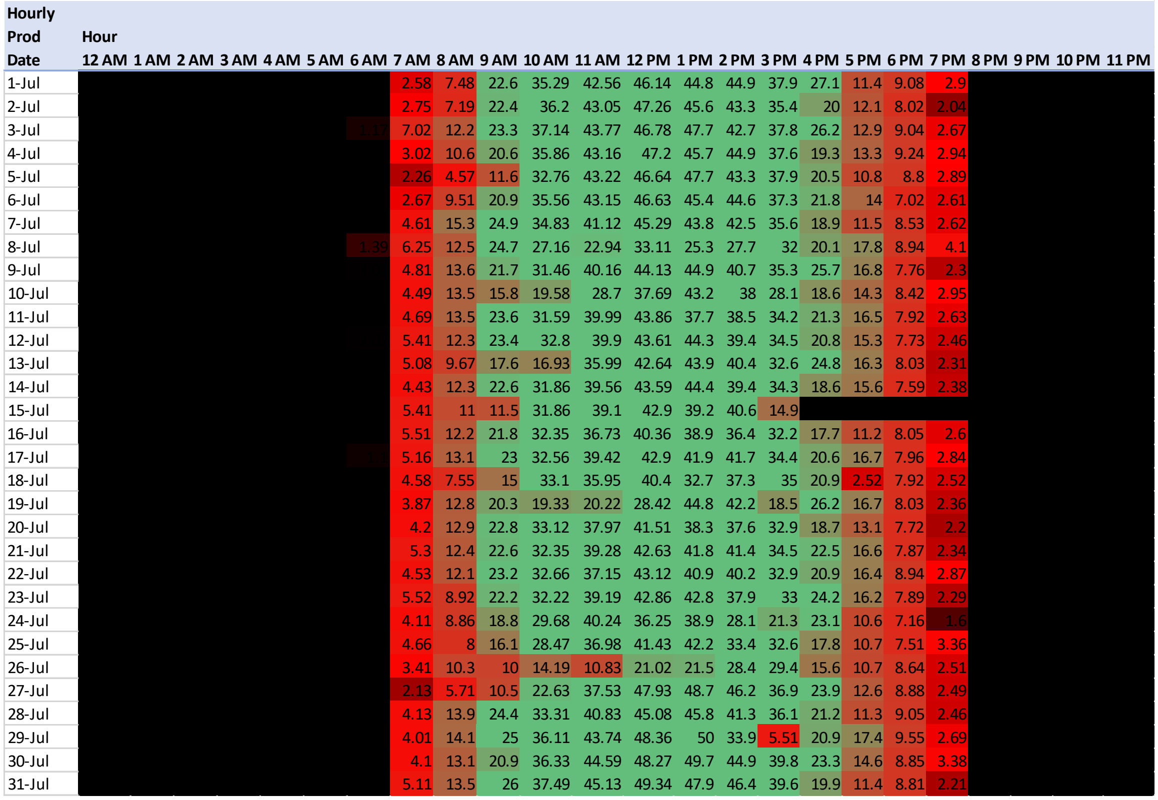
Source: EPRI

Figure 36: Solar Data Availability for Building 2 Site in June 2021

Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jun																								
2-Jun																								
3-Jun																								
4-Jun																								
5-Jun						0.03	0.58	3.18	7.02	19.6	35.53	42.98	41.58	46.5	43.3	35	16.9	12	7.93	2.17	0.09			
6-Jun						0.03	0.67	3.48	8.24	21.6	35.08	42.22	44.38	46.8	41.9	36	20.6	9.38	9.47	2.52	0.1			
7-Jun						0.02	0.4	2.23	3.5	5.26	6.61	8.22	11.07	22.1	12.5	21.5	17.5	12.1	7.45	1.83	0.05			
8-Jun						0.03	1.4	5.68	18.5	23.3	26.87	35.19	47.46	43.9	42.8	35.5	19.6	10.9	7.45	2.3	0.11			
9-Jun						0.03	1.75	4.97	8.91	20.1	35.19	40.84	47.01	45.2	43.2	36.5	18.7	10.7	8.4	2.38	0.11			
10-Jun						0.03	1.16	5.43	15.3	25.9	35.48	42.12	44.53	47.4	43.9	36.1	18.3	9.65	7.64	2.28	0.11			
11-Jun						0.03	1.22	5.67	15.4	25.2	35.77	42.02	45.21	44.2	43.4	36	20.1	9.67	8.28	2.36	0.11			
12-Jun						0.03	1.17	5.53	15.7	25.4	32.59	39.09	42.36	40.9	40.7	35.7	17.8	10.5	8.64	2.51	0.12			
13-Jun						0.03	0.94	5.17	14	26.4	35.88	42.53	43.02	46.3	43.4	36.1	22.2	10.6	8.32	2.17	0.09			
14-Jun						0.03	1.07	5.28	15.4	25.2	34.53	41.15	44.16	43.9	42.3	34.9	17.6	10.8	8.12	2.47	0.12			
15-Jun						0.03	1.39	5.97	14	22.2	29.81	36.13	41.13	34.3	30.3	25.1	15.7	14.8	4.78	3.7	0.12			
16-Jun						0.03	1.3	6.46	13.5	12.4	3.49	5.49	11.06	43.8	38.2	28	25.3	15.6	7.94	2.87	0.15			
17-Jun						0.02	1.28	5.59	13.2	12.3	20.36	42.69	43.17	47.6	34.8	18.2	11.9	8.96	4.33	0.88				
18-Jun						0.05	0.91	3.76	4.23	6.59	23.11	38.9	45.18	39.1	36.3	33.2	21.4	11.4	8.57	2.94	0.19			
19-Jun						0.03	0.9	5.1	14.3	26.8	36.55	43.37	47.16	45.7	44.7	37.7	20.5	13.1	9.24	2.98	0.17			
20-Jun						0.04	0.52	2.81	6.9	17.7	29.98	43.3	47.54	46.2	45.4	38	23.5	10.6	9.06	3.08	0.2			
21-Jun						0.04	0.52	3.51	17.1	26.7	32.68	43.14	45.07	48.3	45.3	38.1	25.2	11.9	9.54	2.9	0.2			
22-Jun						0.04	1.07	5.84	16.9	27.1	37.68	44.86	46.21	49.4	45.9	40.5	23.4	10.3	6.38	2.53	0.15			
23-Jun						0.04	1.26	5.03	10.4	25.5	36.11	43.41	47.47	46.1	45.7	39.3	17.4	10.3	8.69	2.98	0.19			
24-Jun						0.03	1.41	4.15	10.5	20.9	38.44	45.54	49.36	47.5	46.9	39.3	27.2	12.5	9.68	2.92	0.17			
25-Jun						0.03	1.08	5.46	16.8	27.6	37.79	44.55	48.89	47.6	46.8	38.9	23.1	10.7	8.55	2.83	0.19			
26-Jun						0.05	1.21	5.64	16.2	26.4	35.24	43.61	45.39	47.9	45.1	37.7	21.2	10.8	8.6	2.89	0.19			
27-Jun						0.03	1.32	3.98	12.1	25.7	36.27	43.01	44.36	47.2	44.4	36.8	18.8	12.3	8.99	2.74	0.17			
28-Jun						0.04	1.24	5.42	15.2	26	35.85	43.01	45.68	44.8	43.8	36.4	19.1	12.3	6.61	3.51	0.23			
29-Jun						0.02	0.47	3.72	10.9	20.1	19.25	29.83	42.04	35.7	38.4	40.7	21.1	10.3	6.28	2.52	0.21			
30-Jun						0.02	0.33	1.73	4.82	10.5	30.51	43.05	46.2	46.4	41.9	36.6	19.3	10.1	8.77	2.86	0.17			

Source: EPRI

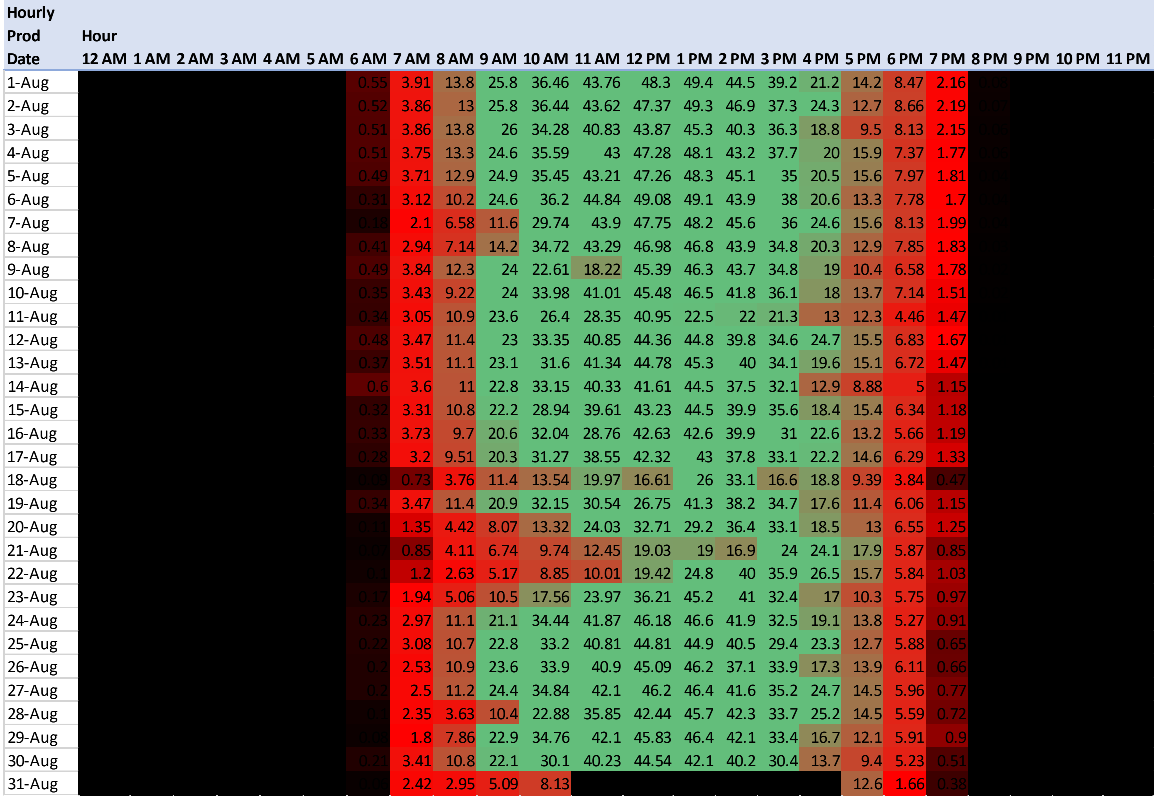
Figure 37: Solar Data Availability for Building 2 in July 2021



Hourly Prod Date	Hour																							
	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jul								2.58	7.48	22.6	35.29	42.56	46.14	44.8	44.9	37.9	27.1	11.4	9.08	2.9				
2-Jul								2.75	7.19	22.4	36.2	43.05	47.26	45.6	43.3	35.4	20	12.1	8.02	2.04				
3-Jul							1.17	7.02	12.2	23.3	37.14	43.77	46.78	47.7	42.7	37.8	26.2	12.9	9.04	2.67				
4-Jul								3.02	10.6	20.6	35.86	43.16	47.2	45.7	44.9	37.6	19.3	13.3	9.24	2.94				
5-Jul								2.26	4.57	11.6	32.76	43.22	46.64	47.7	43.3	37.9	20.5	10.8	8.8	2.89				
6-Jul								2.67	9.51	20.9	35.56	43.15	46.63	45.4	44.6	37.3	21.8	14	7.02	2.61				
7-Jul								4.61	15.3	24.9	34.83	41.12	45.29	43.8	42.5	35.6	18.9	11.5	8.53	2.62				
8-Jul							1.39	6.25	12.5	24.7	27.16	22.94	33.11	25.3	27.7	32	20.1	17.8	8.94	4.1				
9-Jul								4.81	13.6	21.7	31.46	40.16	44.13	44.9	40.7	35.3	25.7	16.8	7.76	2.3				
10-Jul								4.49	13.5	15.8	19.58	28.7	37.69	43.2	38	28.1	18.6	14.3	8.42	2.95				
11-Jul								4.69	13.5	23.6	31.59	39.99	43.86	37.7	38.5	34.2	21.3	16.5	7.92	2.63				
12-Jul								5.41	12.3	23.4	32.8	39.9	43.61	44.3	39.4	34.5	20.8	15.3	7.73	2.46				
13-Jul								5.08	9.67	17.6	16.93	35.99	42.64	43.9	40.4	32.6	24.8	16.3	8.03	2.31				
14-Jul								4.43	12.3	22.6	31.86	39.56	43.59	44.4	39.4	34.3	18.6	15.6	7.59	2.38				
15-Jul								5.41	11	11.5	31.86	39.1	42.9	39.2	40.6	14.9								
16-Jul								5.51	12.2	21.8	32.35	36.73	40.36	38.9	36.4	32.2	17.7	11.2	8.05	2.6				
17-Jul							1.1	5.16	13.1	23	32.56	39.42	42.9	41.9	41.7	34.4	20.6	16.7	7.96	2.84				
18-Jul								4.58	7.55	15	33.1	35.95	40.4	32.7	37.3	35	20.9	2.52	7.92	2.52				
19-Jul								3.87	12.8	20.3	19.33	20.22	28.42	44.8	42.2	18.5	26.2	16.7	8.03	2.36				
20-Jul								4.2	12.9	22.8	33.12	37.97	41.51	38.3	37.6	32.9	18.7	13.1	7.72	2.2				
21-Jul								5.3	12.4	22.6	32.35	39.28	42.63	41.8	41.4	34.5	22.5	16.6	7.87	2.34				
22-Jul								4.53	12.1	23.2	32.66	37.15	43.12	40.9	40.2	32.9	20.9	16.4	8.94	2.87				
23-Jul								5.52	8.92	22.2	32.22	39.19	42.86	42.8	37.9	33	24.2	16.2	7.89	2.29				
24-Jul								4.11	8.86	18.8	29.68	40.24	36.25	38.9	28.1	21.3	23.1	10.6	7.16	1.6				
25-Jul								4.66	8	16.1	28.47	36.98	41.43	42.2	33.4	32.6	17.8	10.7	7.51	3.36				
26-Jul								3.41	10.3	10	14.19	10.83	21.02	21.5	28.4	29.4	15.6	10.7	8.64	2.51				
27-Jul								2.13	5.71	10.5	22.63	37.53	47.93	48.7	46.2	36.9	23.9	12.6	8.88	2.49				
28-Jul								4.13	13.9	24.4	33.31	40.83	45.08	45.8	41.3	36.1	21.2	11.3	9.05	2.46				
29-Jul								4.01	14.1	25	36.11	43.74	48.36	50	33.9	5.51	20.9	17.4	9.55	2.69				
30-Jul								4.1	13.1	20.9	36.33	44.59	48.27	49.7	44.9	39.8	23.3	14.6	8.85	3.38				
31-Jul								5.11	13.5	26	37.49	45.13	49.34	47.9	46.4	39.6	19.9	11.4	8.81	2.21				

Source: EPRI

Figure 38: Solar Data Availability for Building 2 for August 2021



Hourly Prod Date	Hour																							
	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Aug							0.55	3.91	13.8	25.8	36.46	43.76	48.3	49.4	44.5	39.2	21.2	14.2	8.47	2.16	0.08			
2-Aug							0.52	3.86	13	25.8	36.44	43.62	47.37	49.3	46.9	37.3	24.3	12.7	8.66	2.19	0.07			
3-Aug							0.51	3.86	13.8	26	34.28	40.83	43.87	45.3	40.3	36.3	18.8	9.5	8.13	2.15	0.06			
4-Aug							0.51	3.75	13.3	24.6	35.59	43	47.28	48.1	43.2	37.7	20	15.9	7.37	1.77	0.06			
5-Aug							0.49	3.71	12.9	24.9	35.45	43.21	47.26	48.3	45.1	35	20.5	15.6	7.97	1.81	0.04			
6-Aug							0.31	3.12	10.2	24.6	36.2	44.84	49.08	49.1	43.9	38	20.6	13.3	7.78	1.7	0.04			
7-Aug							0.18	2.1	6.58	11.6	29.74	43.9	47.75	48.2	45.6	36	24.6	15.6	8.13	1.99	0.04			
8-Aug							0.41	2.94	7.14	14.2	34.72	43.29	46.98	46.8	43.9	34.8	20.3	12.9	7.85	1.83				
9-Aug							0.49	3.84	12.3	24	22.61	18.22	45.39	46.3	43.7	34.8	19	10.4	6.58	1.78				
10-Aug							0.35	3.43	9.22	24	33.98	41.01	45.48	46.5	41.8	36.1	18	13.7	7.14	1.51				
11-Aug							0.34	3.05	10.9	23.6	26.4	28.35	40.95	22.5	22	21.3	13	12.3	4.46	1.47				
12-Aug							0.48	3.47	11.4	23	33.35	40.85	44.36	44.8	39.8	34.6	24.7	15.5	6.83	1.67				
13-Aug							0.37	3.51	11.1	23.1	31.6	41.34	44.78	45.3	40	34.1	19.6	15.1	6.72	1.47				
14-Aug							0.6	3.6	11	22.8	33.15	40.33	41.61	44.5	37.5	32.1	12.9	8.88	5	1.15				
15-Aug							0.32	3.31	10.8	22.2	28.94	39.61	43.23	44.5	39.9	35.6	18.4	15.4	6.34	1.18				
16-Aug							0.33	3.73	9.7	20.6	32.04	28.76	42.63	42.6	39.9	31	22.6	13.2	5.66	1.19				
17-Aug							0.28	3.2	9.51	20.3	31.27	38.55	42.32	43	37.8	33.1	22.2	14.6	6.29	1.33				
18-Aug							0.09	0.73	3.76	11.4	13.54	19.97	16.61	26	33.1	16.6	18.8	9.39	3.84	0.47				
19-Aug							0.34	3.47	11.4	20.9	32.15	30.54	26.75	41.3	38.2	34.7	17.6	11.4	6.06	1.15				
20-Aug							0.11	1.35	4.42	8.07	13.32	24.03	32.71	29.2	36.4	33.1	18.5	13	6.55	1.25				
21-Aug							0.07	0.85	4.11	6.74	9.74	12.45	19.03	19	16.9	24	24.1	17.9	5.87	0.85				
22-Aug							0.1	1.2	2.63	5.17	8.85	10.01	19.42	24.8	40	35.9	26.5	15.7	5.84	1.03				
23-Aug							0.17	1.94	5.06	10.5	17.56	23.97	36.21	45.2	41	32.4	17	10.3	5.75	0.97				
24-Aug							0.23	2.97	11.1	21.1	34.44	41.87	46.18	46.6	41.9	32.5	19.1	13.8	5.27	0.91				
25-Aug							0.22	3.08	10.7	22.8	33.2	40.81	44.81	44.9	40.5	29.4	23.3	12.7	5.88	0.65				
26-Aug							0.2	2.53	10.9	23.6	33.9	40.9	45.09	46.2	37.1	33.9	17.3	13.9	6.11	0.66				
27-Aug							0.2	2.5	11.2	24.4	34.84	42.1	46.2	46.4	41.6	35.2	24.7	14.5	5.96	0.77				
28-Aug							0.1	2.35	3.63	10.4	22.88	35.85	42.44	45.7	42.3	33.7	25.2	14.5	5.59	0.72				
29-Aug							0.08	1.8	7.86	22.9	34.76	42.1	45.83	46.4	42.1	33.4	16.7	12.1	5.91	0.9				
30-Aug							0.21	3.41	10.8	22.1	30.1	40.23	44.54	42.1	40.2	30.4	13.7	9.4	5.23	0.51				
31-Aug							0.06	2.42	2.95	5.09	8.13							12.6	1.66	0.38				

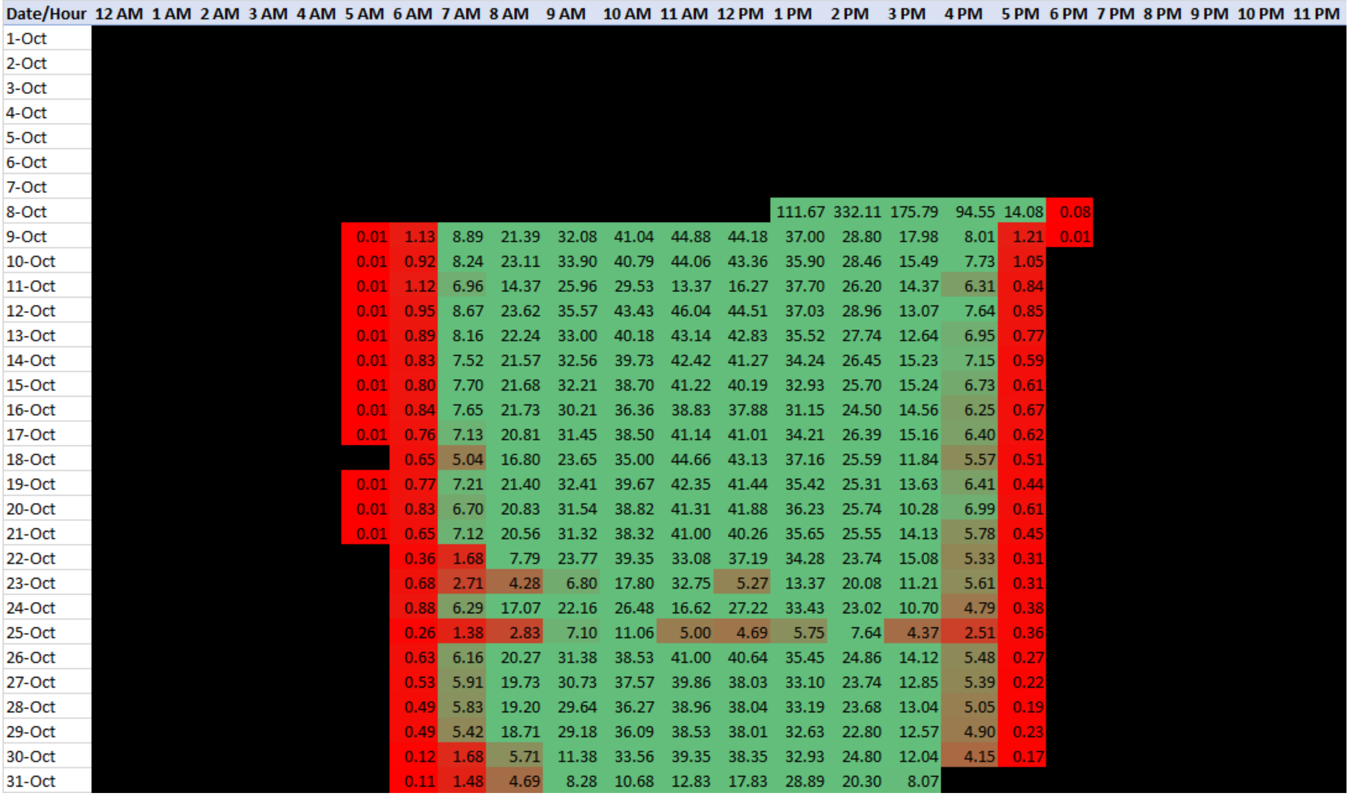
Source: EPRI

Figure 39: Solar Data Availability for Building 2 for September 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Sep							0.13	1.32	3.46	6.30	8.59	9.87	9.24	12.46	13.95	15.76	26.46	14.01	5.88	0.53				
2-Sep							0.03	0.67	2.29	5.77	8.33	13.06	23.22	35.41	42.16	34.32	24.81	13.66	4.94	0.43				
3-Sep							0.05	1.33	5.59	11.05	31.68	33.99	46.33	47.46	41.13	34.21	21.65	11.08	5.03	0.45				
4-Sep							0.11	1.97	11.51	20.77	32.12	39.38	44.60	44.64	43.37	34.82	18.96	8.93	4.75	0.32				
5-Sep							0.10	2.01	11.12	23.76	33.97	40.86	41.96	44.78	41.46	33.11	22.70	12.72	4.53	0.29				
6-Sep							0.09	2.34	9.32	22.10	33.42	40.58	41.76	44.52	40.92	32.31	21.13	12.00	4.13	0.34				
7-Sep							0.09	2.38	8.12	15.54	31.46	36.98	37.97	40.42	36.56	28.96	20.92	10.83	4.32	0.32				
8-Sep							0.07	2.62	9.60	10.64	25.57	39.11	40.25	42.76	39.03	31.43	15.13	11.23	3.95	0.27				
9-Sep							0.08	2.16	10.12	22.07	32.38	39.30	39.65	42.19	37.78	29.19	19.07	11.37	3.97	0.51				
10-Sep							0.08	1.85	9.97	21.42	29.25	37.75	41.39	43.62	40.12	31.85	16.64	11.96	3.66	0.24				
11-Sep							0.08	1.80	10.69	23.07	32.02	40.54	44.25	44.61	41.14	32.18	21.66	12.06	3.95	0.18				
12-Sep							0.08	1.87	10.94	23.91	33.16	41.78	45.57	45.86	42.01	33.00	17.72	12.32	3.91	0.19				
13-Sep							0.04	0.92	7.52	21.22	33.23	42.30	46.06	45.59	42.29	33.36	23.77	13.17	3.89	0.13				
14-Sep						0.03	1.79	12.46	23.91	33.87	42.20	45.26	45.22	41.13	32.27	15.06	10.80	3.46	0.15					
15-Sep						0.04	0.98	4.96	15.26	33.01	40.95	42.65	45.35	41.66	32.51	16.89	11.65	3.55	0.10					
16-Sep						0.03	0.73	4.13	12.40	30.92	38.12	39.56	41.99	38.05	31.84	17.11	11.27	3.32	0.11					
17-Sep						0.03	1.36	6.84	16.33	27.66	38.79	43.87	43.48	39.38	30.84	18.15	10.45	3.09	0.10					
18-Sep						0.02	0.87	3.59	5.02	15.41	35.88	41.30	40.04	39.99	30.63	15.76	10.11	2.81	0.08					
19-Sep						0.04	1.34	4.71	7.54	17.34	19.53	34.52	40.18	36.42	30.08	13.99	8.71	2.69	0.06					
20-Sep						0.04	2.10	9.15	20.89	27.94	36.25	39.37	39.38	35.14	26.87	17.28	8.75	2.41	0.06					
21-Sep						0.05	1.87	9.82	21.74	20.43	36.22	41.17	40.33	36.66	28.85	18.52	8.26	2.47	0.03					
22-Sep						0.03	1.64	9.51	21.31	29.48	38.14	41.78	41.06	37.69	24.13	5.27								
23-Sep						[illegible]	1.71	9.77	21.88	30.23	39.12	42.17	42.57	29.06	15.88	10.96	6.55	1.63	[illegible]					
24-Sep						[illegible]	1.26	5.37	13.68	28.94	37.74	42.49	43.02	37.92	29.67	11.62	8.45	3.48	[illegible]					
25-Sep						[illegible]	1.59	10.38	22.28	32.08	41.16	44.77	44.59	39.76	31.09	15.99	6.98	2.24	[illegible]					
26-Sep							0.28	1.56	3.60	5.58	10.08	10.88	12.82	15.45	15.16	13.19	5.75	1.06	[illegible]					
27-Sep						[illegible]	0.28	1.99	4.15	8.77	9.52	9.58	9.02	11.37	12.85	7.20	3.47	0.71						
28-Sep						[illegible]	1.52	7.45	13.79	20.72	13.49	11.60	13.99	17.62	21.22	14.85	9.11	2.14	[illegible]					
29-Sep						[illegible]	1.65	9.34	20.75	28.48	33.43	36.35	38.90	35.01	8.16		[illegible]							
30-Sep																								

Source: EPRI

Figure 40: Solar Data Availability for Building 2 for October 2021



Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Oct																								
2-Oct																								
3-Oct																								
4-Oct																								
5-Oct																								
6-Oct																								
7-Oct																								
8-Oct														111.67	332.11	175.79	94.55	14.08	0.08					
9-Oct						0.01	1.13	8.89	21.39	32.08	41.04	44.88	44.18	37.00	28.80	17.98	8.01	1.21	0.01					
10-Oct						0.01	0.92	8.24	23.11	33.90	40.79	44.06	43.36	35.90	28.46	15.49	7.73	1.05						
11-Oct						0.01	1.12	6.96	14.37	25.96	29.53	13.37	16.27	37.70	26.20	14.37	6.31	0.84						
12-Oct						0.01	0.95	8.67	23.62	35.57	43.43	46.04	44.51	37.03	28.96	13.07	7.64	0.85						
13-Oct						0.01	0.89	8.16	22.24	33.00	40.18	43.14	42.83	35.52	27.74	12.64	6.95	0.77						
14-Oct						0.01	0.83	7.52	21.57	32.56	39.73	42.42	41.27	34.24	26.45	15.23	7.15	0.59						
15-Oct						0.01	0.80	7.70	21.68	32.21	38.70	41.22	40.19	32.93	25.70	15.24	6.73	0.61						
16-Oct						0.01	0.84	7.65	21.73	30.21	36.36	38.83	37.88	31.15	24.50	14.56	6.25	0.67						
17-Oct						0.01	0.76	7.13	20.81	31.45	38.50	41.14	41.01	34.21	26.39	15.16	6.40	0.62						
18-Oct							0.65	5.04	16.80	23.65	35.00	44.66	43.13	37.16	25.59	11.84	5.57	0.51						
19-Oct						0.01	0.77	7.21	21.40	32.41	39.67	42.35	41.44	35.42	25.31	13.63	6.41	0.44						
20-Oct						0.01	0.83	6.70	20.83	31.54	38.82	41.31	41.88	36.23	25.74	10.28	6.99	0.61						
21-Oct						0.01	0.65	7.12	20.56	31.32	38.32	41.00	40.26	35.65	25.55	14.13	5.78	0.45						
22-Oct							0.36	1.68	7.79	23.77	39.35	33.08	37.19	34.28	23.74	15.08	5.33	0.31						
23-Oct							0.68	2.71	4.28	6.80	17.80	32.75	5.27	13.37	20.08	11.21	5.61	0.31						
24-Oct							0.88	6.29	17.07	22.16	26.48	16.62	27.22	33.43	23.02	10.70	4.79	0.38						
25-Oct							0.26	1.38	2.83	7.10	11.06	5.00	4.69	5.75	7.64	4.37	2.51	0.36						
26-Oct							0.63	6.16	20.27	31.38	38.53	41.00	40.64	35.45	24.86	14.12	5.48	0.27						
27-Oct							0.53	5.91	19.73	30.73	37.57	39.86	38.03	33.10	23.74	12.85	5.39	0.22						
28-Oct							0.49	5.83	19.20	29.64	36.27	38.96	38.04	33.19	23.68	13.04	5.05	0.19						
29-Oct							0.49	5.42	18.71	29.18	36.09	38.53	38.01	32.63	22.80	12.57	4.90	0.23						
30-Oct							0.12	1.68	5.71	11.38	33.56	39.35	38.35	32.93	24.80	12.04	4.15	0.17						
31-Oct							0.11	1.48	4.69	8.28	10.68	12.83	17.83	28.89	20.30	8.07								

Source: EPRI

Figure 41: Solar Data Availability for Building 2 for November 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Nov							0.37	6.07	12.31	16.19	13.49	16.50	15.25	10.58	10.50	9.23	4.01	0.30						
2-Nov							0.10	1.86	4.58	9.15	15.21	28.58	37.75	31.84	23.45	12.97	4.16	0.16						
3-Nov							0.15	2.03	13.03	27.20	34.43	37.61	37.17	31.59	22.00	11.32	3.15	0.12						
4-Nov							0.12	1.90	6.67	22.93	31.55	34.08	33.76	28.64	22.04	12.29	3.81	0.13						
5-Nov							0.11	1.94	8.72	25.87	34.90	37.63	10.58											
6-Nov							0.19	0.97	2.54	5.72	12.60	19.87	19.64	16.75	12.36	6.82	1.80	0.17						
7-Nov							0.16	0.82	2.21	3.72	3.66	11.57	17.43	16.39	11.81	6.43	1.95	0.15						
8-Nov							0.18	1.26	3.69	6.30	19.28	20.57	20.32	17.09	12.67	6.81	1.83	0.14						
9-Nov							0.30	2.02	10.89	12.32	13.32	17.07	18.13	16.64	11.63	6.46	1.30	0.05						
10-Nov							0.09	2.61	8.35	14.03	9.77	8.24	17.85	15.11	11.17	5.82	1.55	0.04						
11-Nov							0.09	2.62	8.93	14.39	4.83	1.79	2.69	13.36	12.00	6.37	1.75	0.01						
12-Nov							0.08	2.49	8.73	14.26	16.85	17.30	19.26	15.00	12.02	6.68	1.50	0.04						
13-Nov							0.09	2.54	8.63	14.24	6.04	1.28	6.60	16.07	11.84	6.22	1.80	0.06						
14-Nov							0.08	2.48	8.55	14.30	16.55	15.94	5.36	14.68	11.98	6.35	1.86	0.04						
15-Nov							0.08	2.45	8.37	13.78	13.74	17.83	17.89	15.41	11.03	0.88	0.47	0.06						
16-Nov							0.03	0.75	2.25	4.85	9.49	8.05	18.14	14.59	8.49	0.92	0.46	0.05						
17-Nov							0.04	0.86	2.14	4.91	9.86	4.41	12.01	15.24	10.81	5.74	1.39	0.02						
18-Nov							0.03	0.73	2.42	4.94	13.23	9.73	14.48	11.78	8.28	3.56	0.91	0.01						
19-Nov							0.02	0.35	1.71	3.96	8.50	11.49	12.70	13.56	6.13	3.26	0.66	0.04						
20-Nov							0.02	0.40	1.86	5.65	13.11	12.74	13.61	11.82	7.32	4.84	0.50	0.04						
21-Nov							0.03	1.88	6.71	12.44	9.19	1.70	3.12	13.34	10.05	5.52	1.36	0.06						
22-Nov							0.04	1.72	7.93	7.96	14.32	14.34	18.30	9.63	9.29	5.56	0.63	0.02						
23-Nov							0.02	1.41	7.18	12.76	16.72	16.45	17.97	13.84	11.40	3.61	1.09	0.02						
24-Nov							0.03	1.51	7.07	11.27	8.17	1.99	0.44				5.76	0.01						
25-Nov							0.02	1.67	7.34	12.94	10.77	1.08	2.53	15.56	11.61	5.86	1.52	0.03						
26-Nov							0.02	1.44	6.74	12.55	15.02	0.86	9.14	15.31	10.65	6.00	0.66	0.06						
27-Nov							0.02	1.34	6.93	6.35	2.59	0.22	0.26	0.23	0.23	0.40	0.91	0.06						
28-Nov							0.01	1.37	5.37	0.21	0.26	0.22	0.21	0.27	0.27	0.44	0.87	0.06						
29-Nov							0.01	1.27	5.73	0.24	0.23	0.25	0.22	13.68	5.00	5.55	1.11	0.02						
30-Nov							0.01	0.34	1.45	2.53	10.62	14.19	12.53	13.59	7.33	5.32								

Source: EPRI

These observations on data availability are vitally important for understanding what the solar PV profile means. Table 10 shows the average sunrise and sunset times for Southern California for the months of June through September 2021. Given the length of day, the tails of the profiles are an interesting indicator of non-trivial solar production that may be attributed to reflection off the horizontal plane onto the actual face of the bifacial solar panel.

Table 10: Sunrise and Sunset Times in Southern California

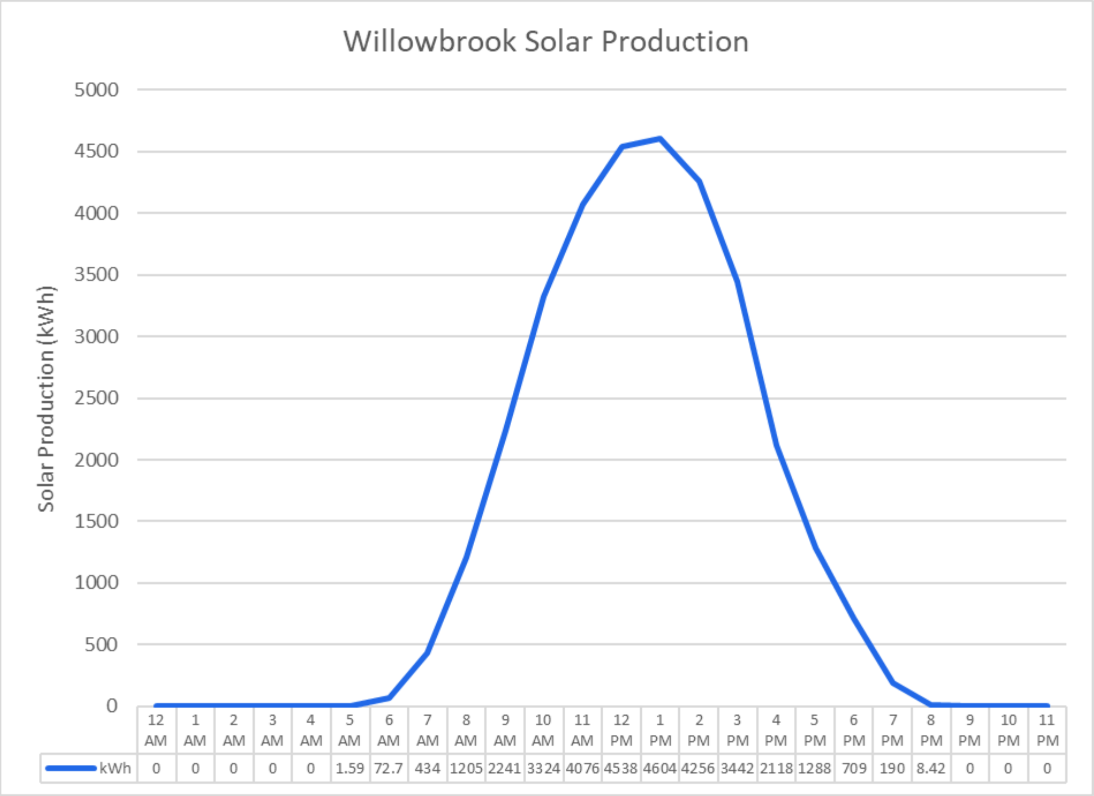
Month	Sunrise Time	Sunset Time
June	5:34 AM	7:57 PM
July	5.39 AM	8:03 PM
August	5:59 AM	7:46 PM
September	6:22 AM	7:08 PM
October	7:01 AM	6:33 PM
November	6:27 AM	4:49 PM
December	6:51 AM	4:45 PM
January	6:56 AM	5:10 PM
February	6:36 AM	5:37 PM

Source: EPRI

Solar PV Profile Analysis

Figure 42 through Figure 47 shows the solar PV profile for both buildings for a summer season (June 1 through September 15, 2021), fall season (September 1 through November 30, 2021), and winter season (December 1, 2021, through February 28, 2022). Given the approximately 117 days in the time period with 4 days of data loss, the Building 2 peak production of 4,604 kWh at 1 p.m. is estimated to be about 40.74 kW during the summer period. Comparing this with the Building 1 site, the PV profile shows much less production. Considering the data loss of 23 days, the peak production is 26.87 kW during the same period. In the fall, Building 2 shows a peak production of about 31.49 kW which is consistent with the decreasing irradiance in the fall compared with summer. At the same time, we see that the peak production for Building 1 (which has much better data availability) still lags Building 2 at 28.33 kW. We also observed that the Building 1 peak occurs at a different time compared with Building 2, which is to be expected given the orientation difference between the two buildings. We also observed that compared with the sunrise and sunset times, there is non-zero solar production outside of these times. As expected, winter peak production is much less when compared with summer and fall, with peak production in Building 1 at 1,647 kWh at 12 p.m., with about 19.61kW and lower 1,302 kWh representing peak production of 15.5kW.

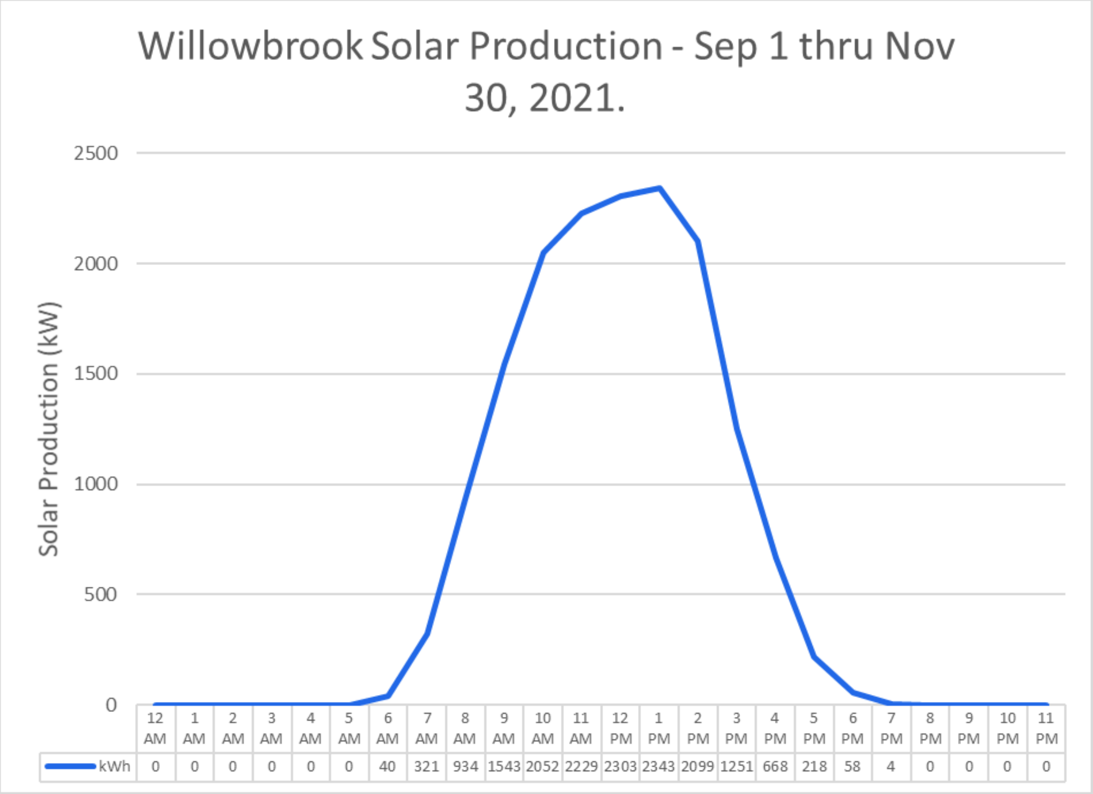
Figure 42: Solar PV Profile for Building 2 for June 1 to August 31, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
kWh	0	0	0	0	0	1.59	72.7	434	1205	2241	3324	4076	4538	4604	4256	3442	2118	1288	709	190	8.42	0	0	0

Source: EPRI

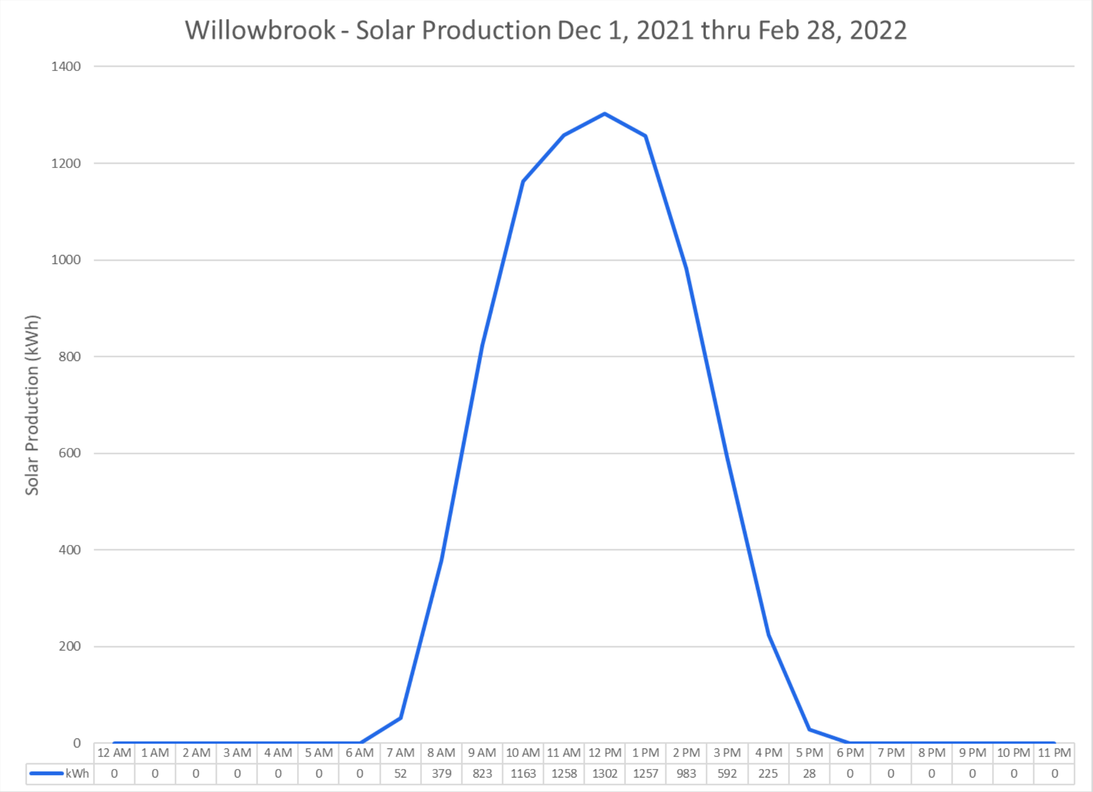
Figure 43: Solar PV Profile for Building 2 for September 1 to Nov 30, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
kWh	0	0	0	0	0	0	40	321	934	1543	2052	2229	2303	2343	2099	1251	668	218	58	4	0	0	0	0

Source: EPRI

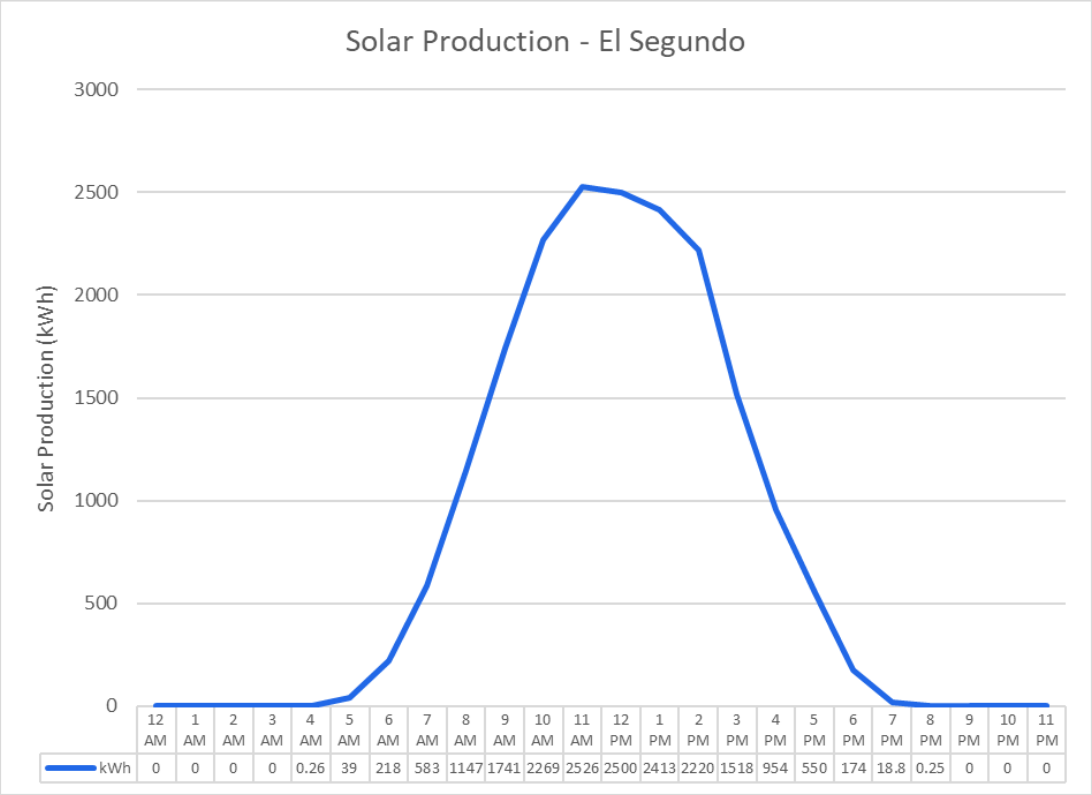
Figure 44: Solar PV Profile for Building 2 for Dec 1, 2021 to Feb 28, 2022



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
kWh	0	0	0	0	0	0	0	52	379	823	1163	1258	1302	1257	983	592	225	28	0	0	0	0	0	0

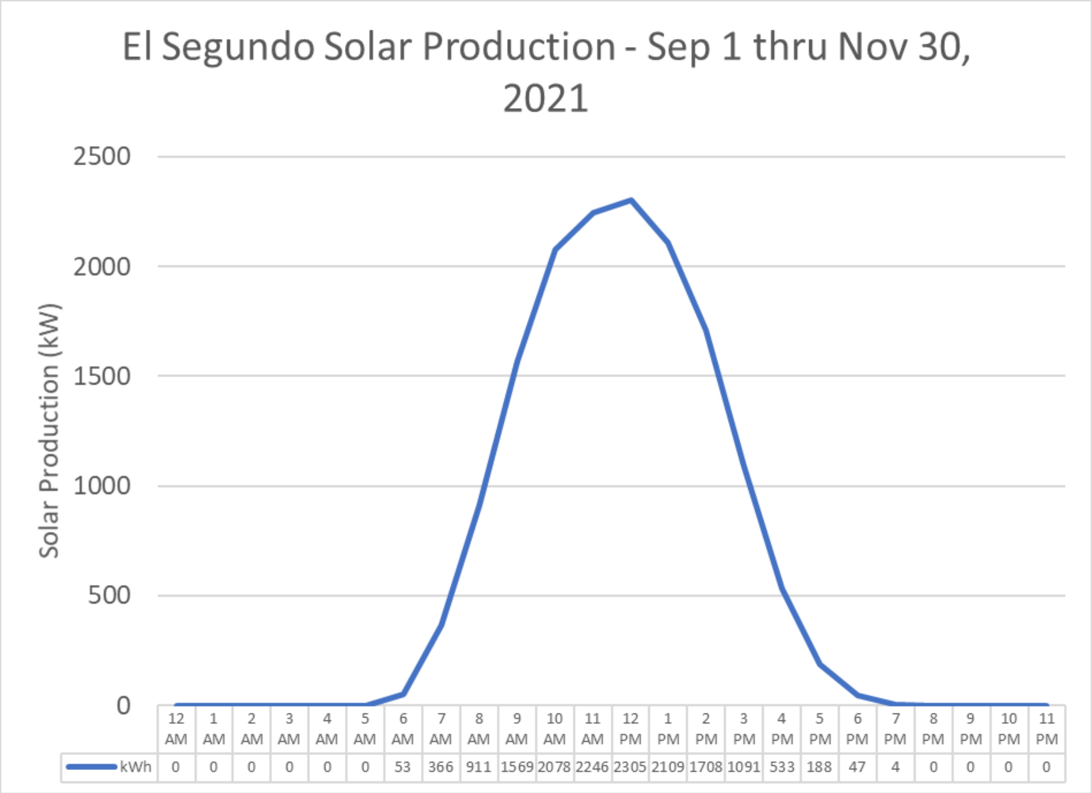
Source: EPRI

Figure 45: Solar PV Profile for Building 1 for June 1 to August 31, 2021



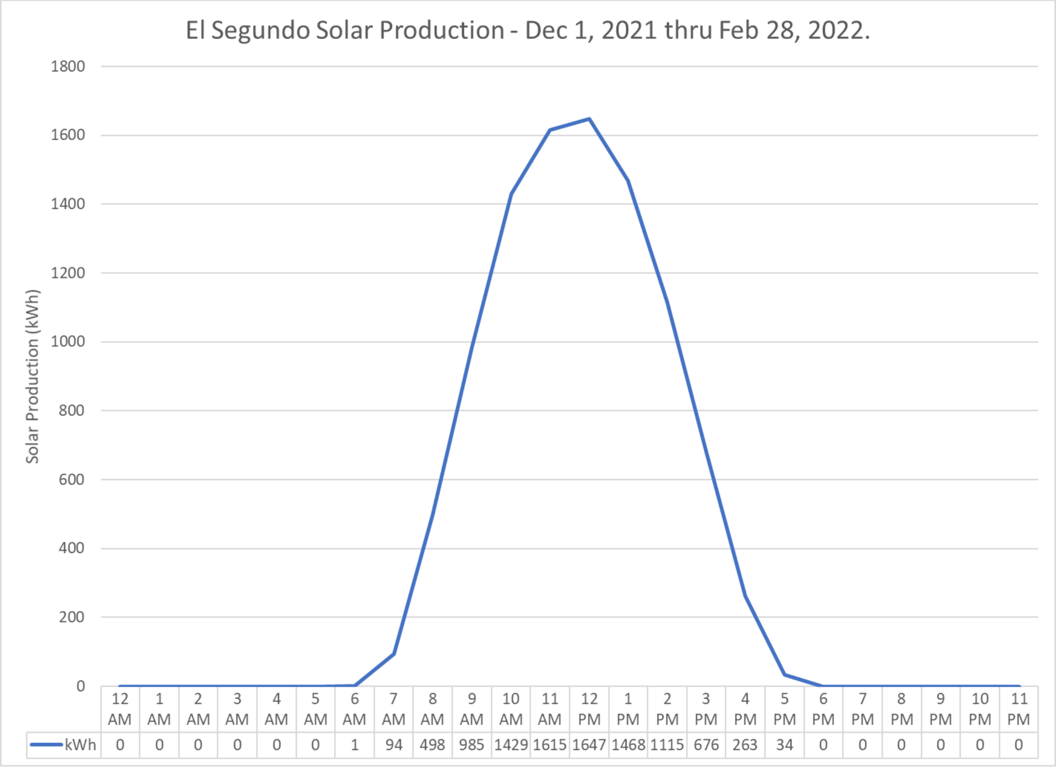
Source: EPRI

Figure 46: Solar PV Profile for Building 1 for September 1 to Nov 30, 2021



Source: EPRI

Figure 47: Solar PV Profile for Building 1 for Dec 1, 2021 to Feb 28, 2022



Source: EPRI

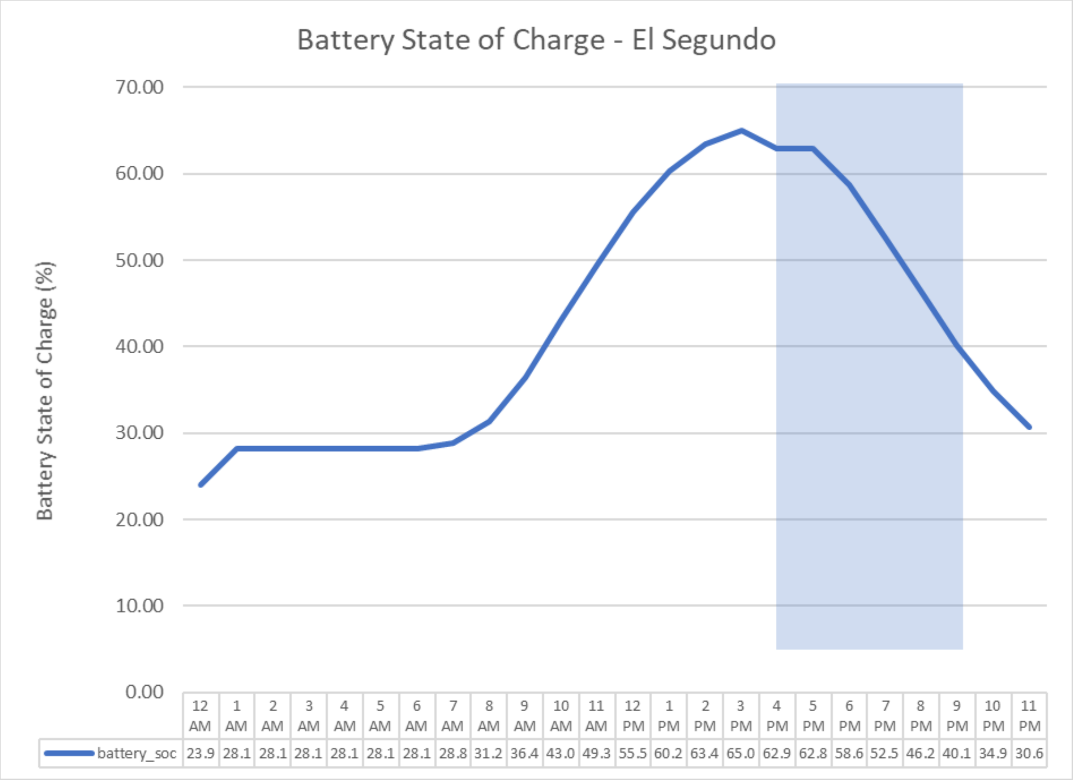
Battery Profile

The battery profile analysis was done by observing the charge and discharge patterns of the two batteries, as indicated by the change in their respective SOC. Given that SOC is a non-cumulative quantity, it is represented as an average over the days pertaining to the hour. Figures 48 to 51 show the average battery SOC profile for both buildings 1 and 2.

Observing the patterns of charge increase and decrease through the day, it is clear that the battery charges during times of high solar production (8 a.m. to 3 p.m.), and discharges during the period of peak TOU (4 p.m. to 9 p.m.) and beyond. Throughout the night the charge is constant at around 20 percent. Another point to observe is that the battery Building 2 charges to a higher SOC (~ 80 percent) through the day and discharges about 38 percent (from 77 percent to 39 percent), whereas Building 1 charges to only about 63 percent SOC through the day and discharges about 23 percent (63 percent to 40 percent) during TOU peak hours. Given the significant data loss in Building 1, adjusting for the data loss, the peak of the SOC in Building 1 is consistent with that of Willowbrook (~ 78 percent), and TOU discharge change in SOC is about 30 percent.

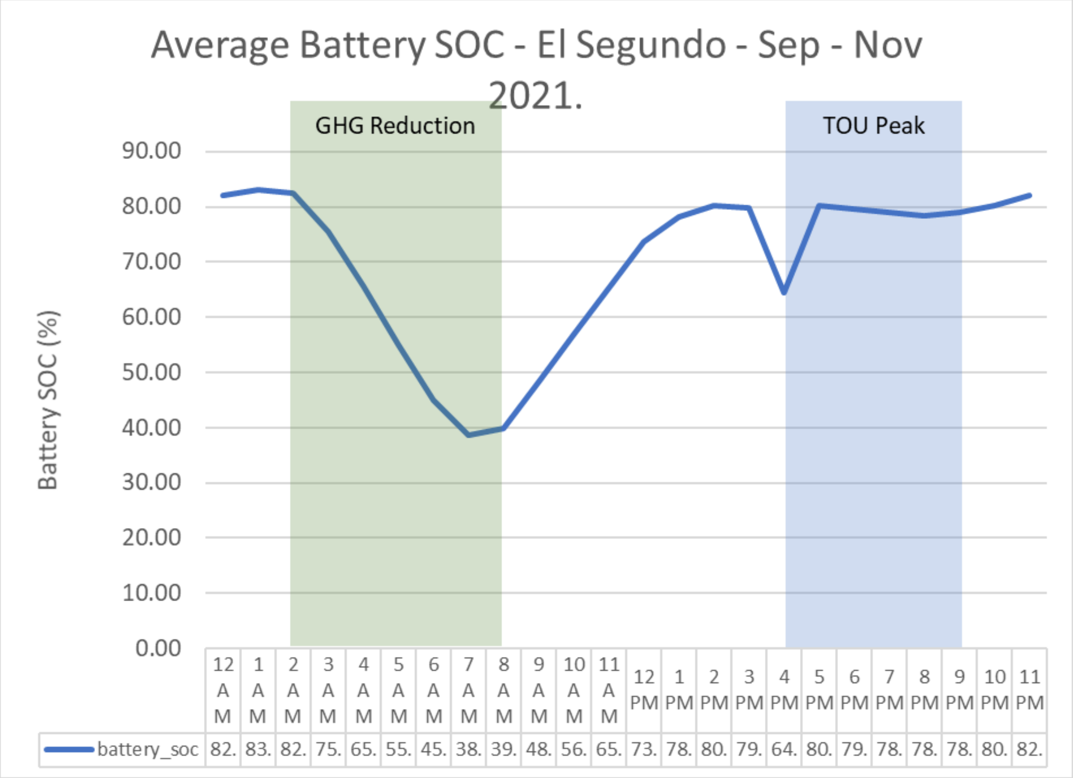
During the fall (September through November), the Building 2 battery continues to charge and discharge based on the TOU pattern. The Building 1 battery is programmed on a profile that discharges between 2 a.m. and 7 a.m. to coincide with the period of highest marginal carbon emissions in the state's electricity grid. The goal is to contribute to understanding of the effects of the reduction in GHG emissions as a result of discharging the battery to the grid and reducing the net energy drawn from the grid. In winter (December through February), both batteries were profiled to discharge in the early morning hours (GHG reduction profile).

Figure 48: Battery SOC Profile for Building 1 June 1 to August 31, 2021



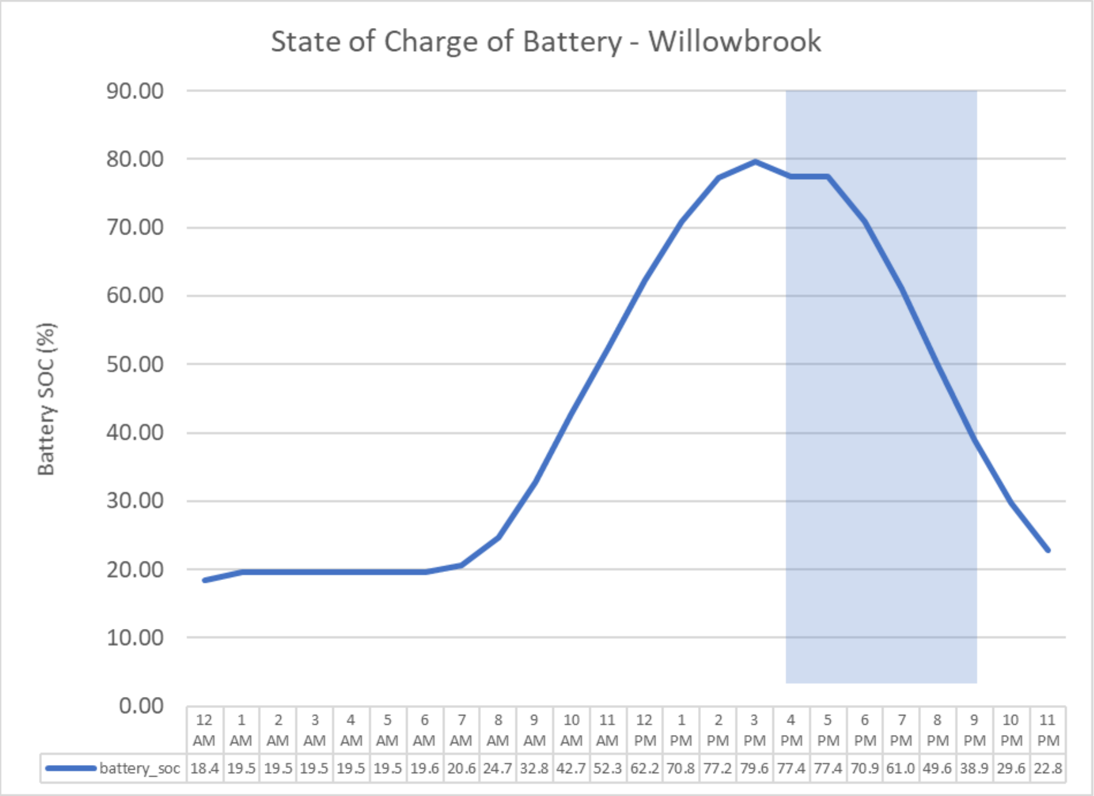
Source: EPRI

Figure 49: Battery SOC Profile for Building 1 September 1 to Nov 30, 2021



Source: EPRI

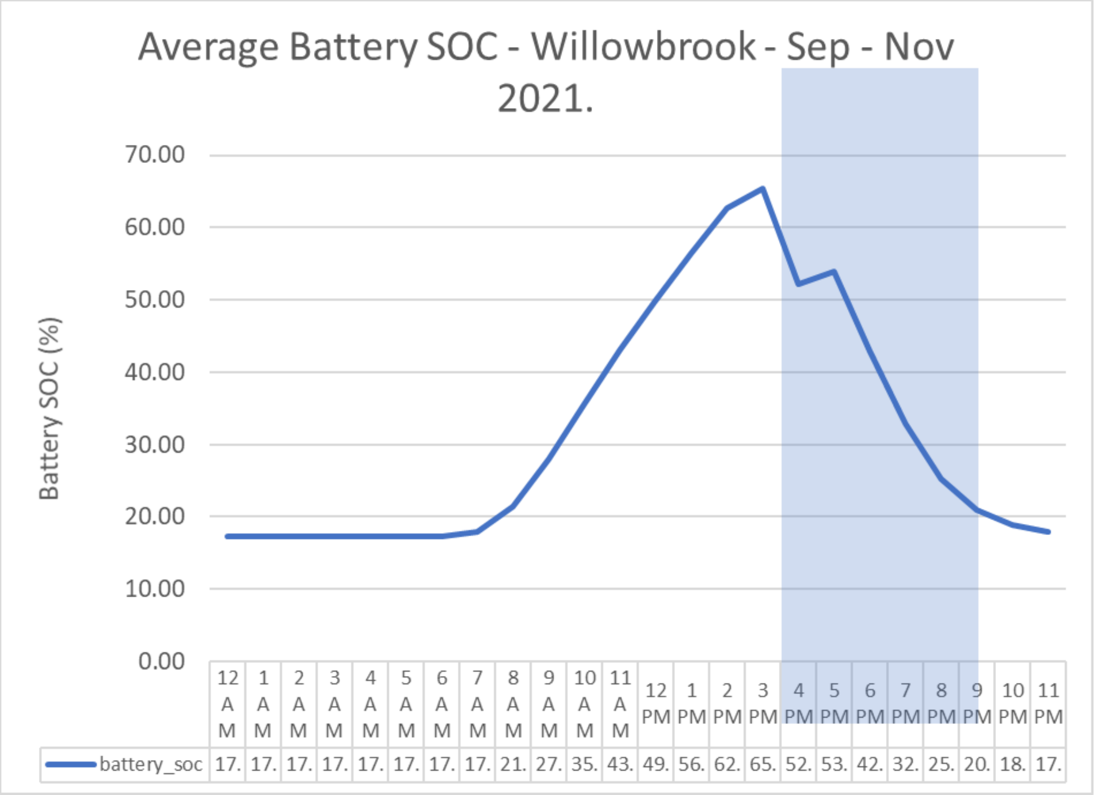
Figure 50: Battery SOC Profile for Building 2 June 1 to August 31, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
battery_soc	18.4	19.5	19.5	19.5	19.5	19.5	19.6	20.6	24.7	32.8	42.7	52.3	62.2	70.8	77.2	79.6	77.4	77.4	70.9	61.0	49.6	38.9	29.6	22.8

Source: EPRI

Figure 51: Battery SOC Profile for Building 2 for September 1 to Nov 30, 2021

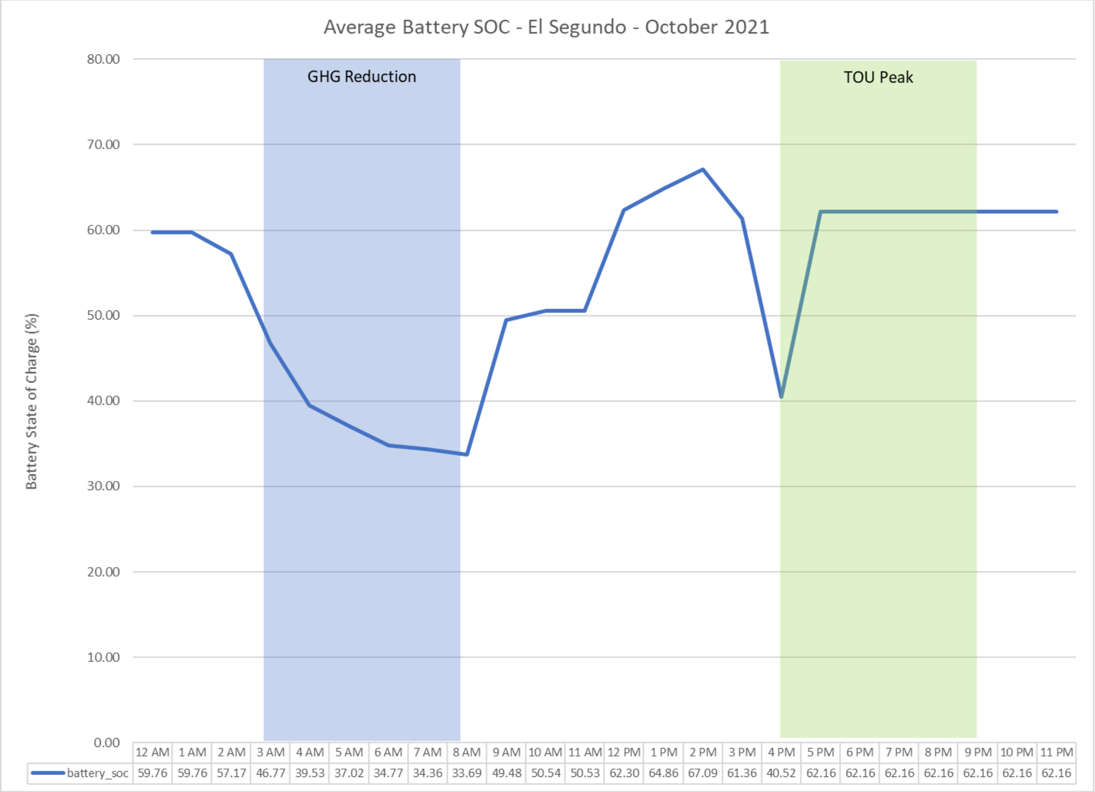


	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
battery_soc	17.	17.	17.	17.	17.	17.	17.	17.	21.	27.	35.	43.	49.	56.	62.	65.	52.	53.	42.	32.	25.	20.	18.	17.

Source: EPRI

During the TOU winter months (Oct 1 thru May 31), the battery profile was set to a "GHG Emissions Reduction" profile where the battery discharges from 3 a.m. to 8 a.m., which is the time period with the highest average grid GHG emissions (based on ISO 2019 emissions data). By charging the battery with renewable power and discharging it during the periods of highest GHG emissions, the GHG emissions profile attempts to zero out the building's source GHG emissions (Scope 2 emissions) during the periods of highest GHG intensity on the grid. As an example, the battery profile after the battery was set to the GHG Emissions Reduction profile is shown for Building 1 in Figure 52. As expected, the battery discharges between 3 a.m. and 8 a.m. After 8 a.m. the battery starts to charge from the solar PV and holds the charge steady during the TOU peak hours. The same profile also continued in winter (December 2021 through February 2022), shown in Figure 53 and Figure 54.

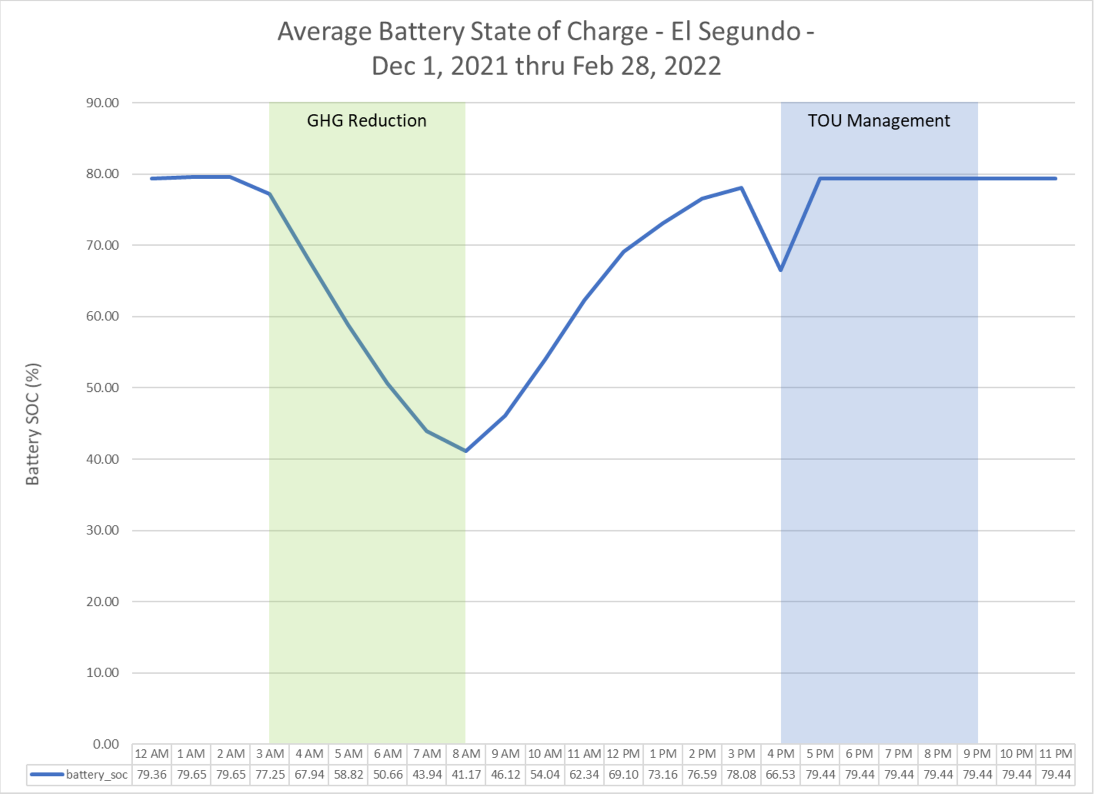
Figure 52: Battery Profile for Building 1 for October 1 to 5, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
battery_soc	59.76	59.76	57.17	46.77	39.53	37.02	34.77	34.36	33.69	49.48	50.54	50.53	62.30	64.86	67.09	61.36	40.52	62.16	62.16	62.16	62.16	62.16	62.16	62.16

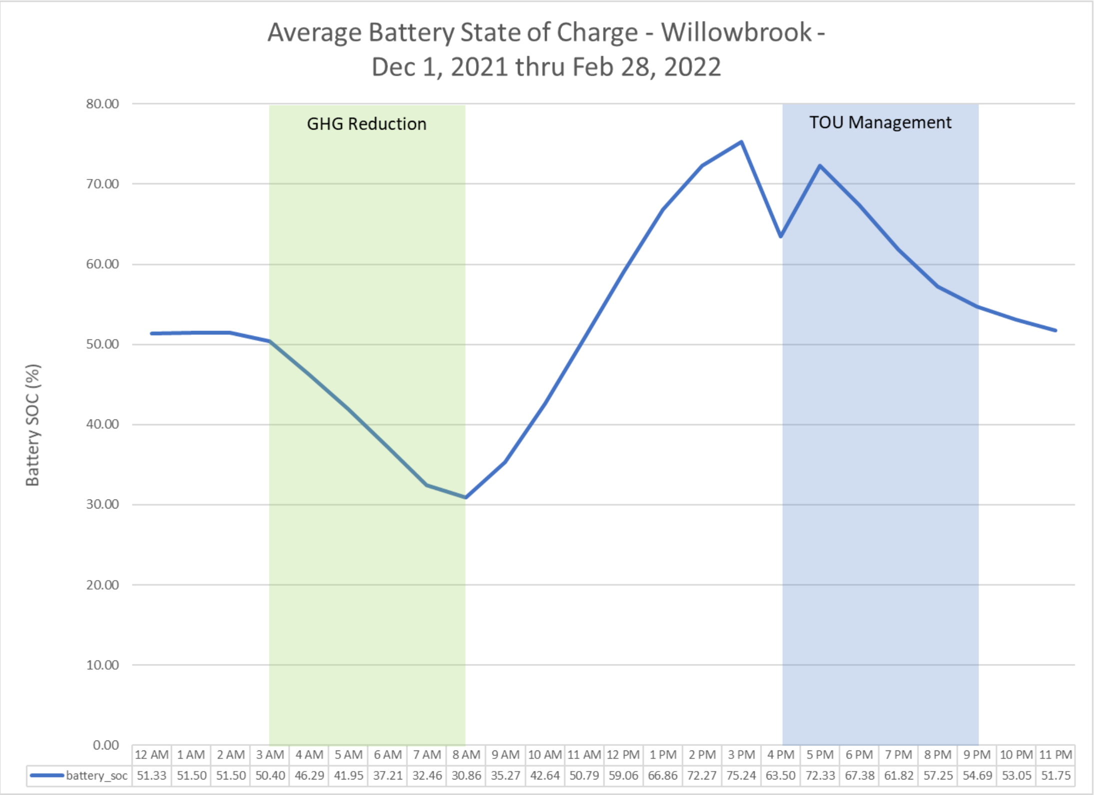
Source: EPRI

Figure 53: Battery Profile for Building 1 From Dec 1, 2021 to Feb 28, 2022



Source: EPRI

Figure 54: Batter Profile for Building 2 From Dec 1, 2021 to Feb 28, 2022

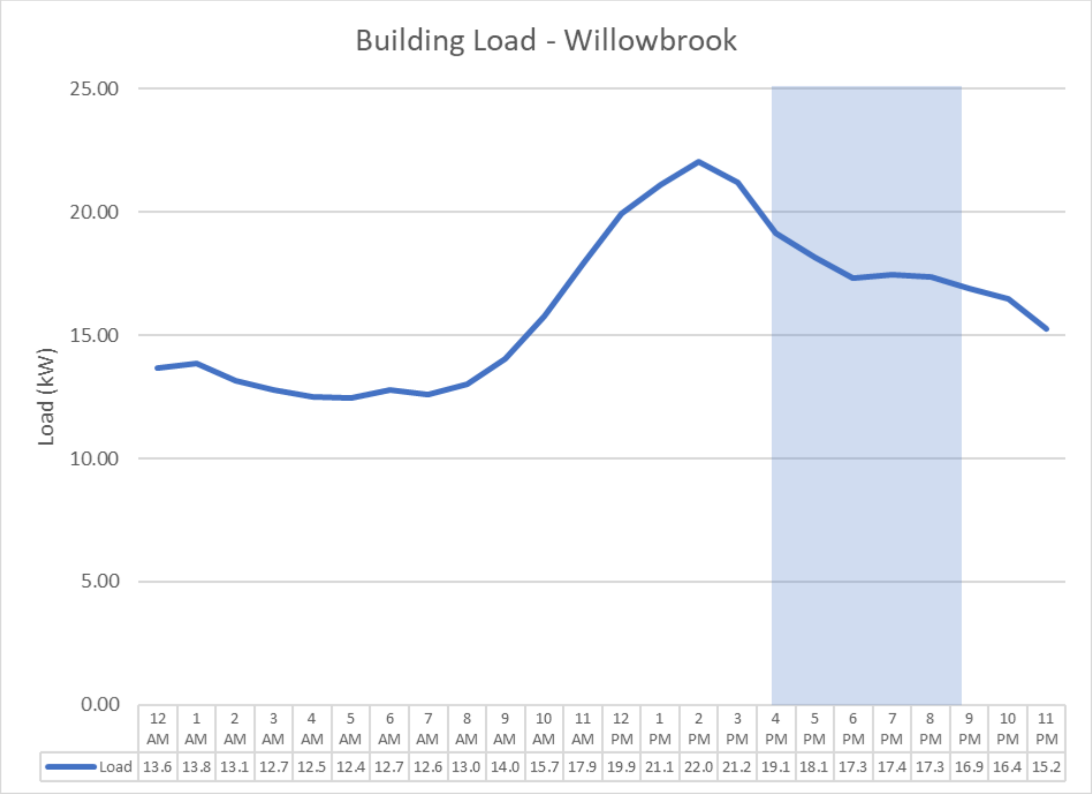


Source: EPRI

Building-Level Load Analysis

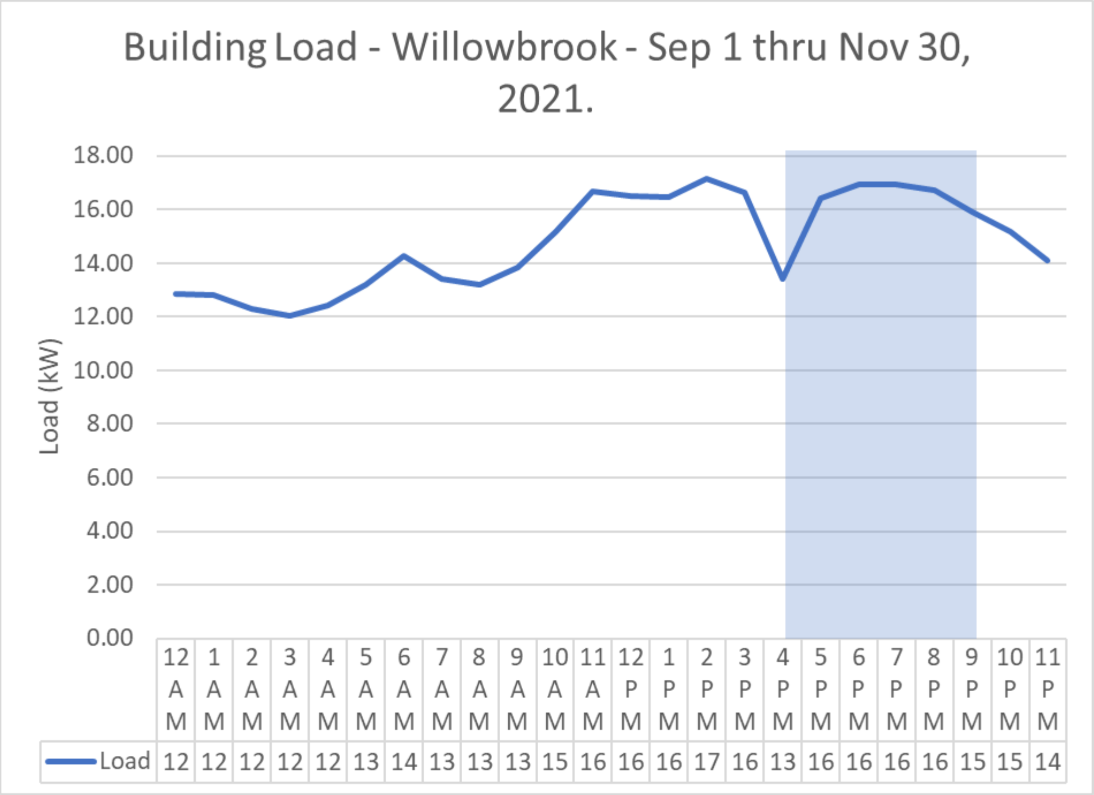
The building-level load analysis is performed for both buildings, followed by a full-scale campus-level Mosaic Gardens at Willowbrook load analysis. Figure 55 through Figure 60 shows the raw load profile at the building level. The term "raw" load distinguishes it from the net load, which is effectively the load after renewable exports (solar and storage). This raw load represents the amount of demand on the distribution system pertaining to the whole building, which includes living areas (apartments) and common areas. The load peaks at about 22 kW around 2 p.m. during the summer and about 18kW during the fall. The fact that the load peak occurs around 2 p.m. is an interesting result considering that typically buildings with solar PV systems tend to peak in load around the time the solar production reduces significantly. Building 2's peak is about 22 kW compared with Building 1, which is at 17.5 kW in summer and 20.1 kW in the fall. The winter performance of Building 2 and Building 1 are shown in Figure 57 and Figure 60 respectively, with both peaking during the TOU peak hours though the TOU rates are lower in the winter compared with the summer. The relative peaks are also similar between the two buildings: around 22kW.

Figure 55: Load Profile for Building 2 for June 1 Through August 31, 2021



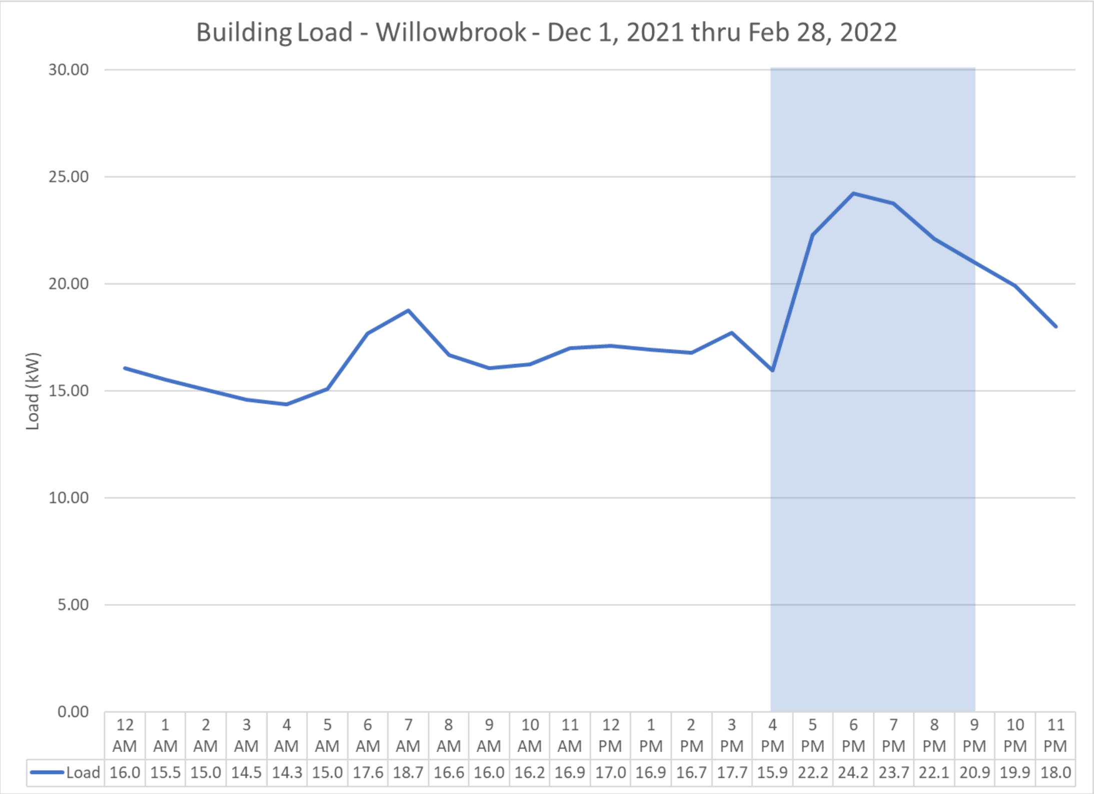
Source: EPRI

Figure 56: Load Profile for Building 2 for Sep 1 to Nov 30, 2021



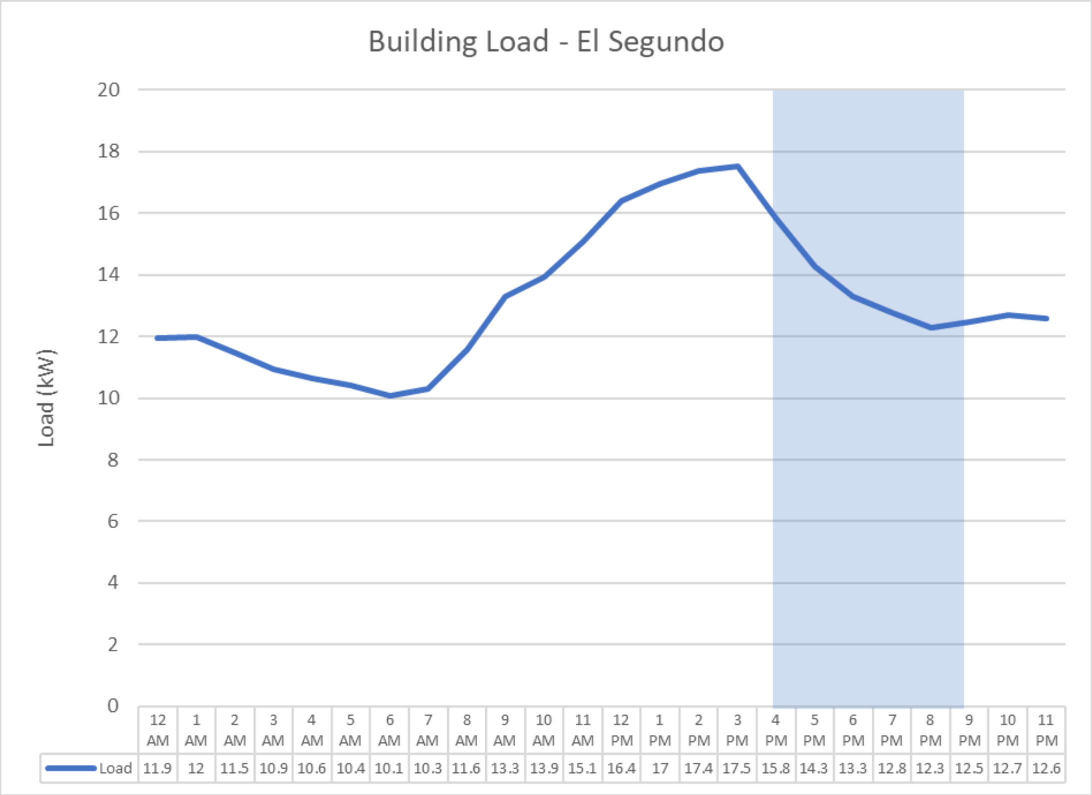
Source: EPRI

Figure 57: Load Profile for Building 2 for Dec 1, 2021 to Feb 28, 2022



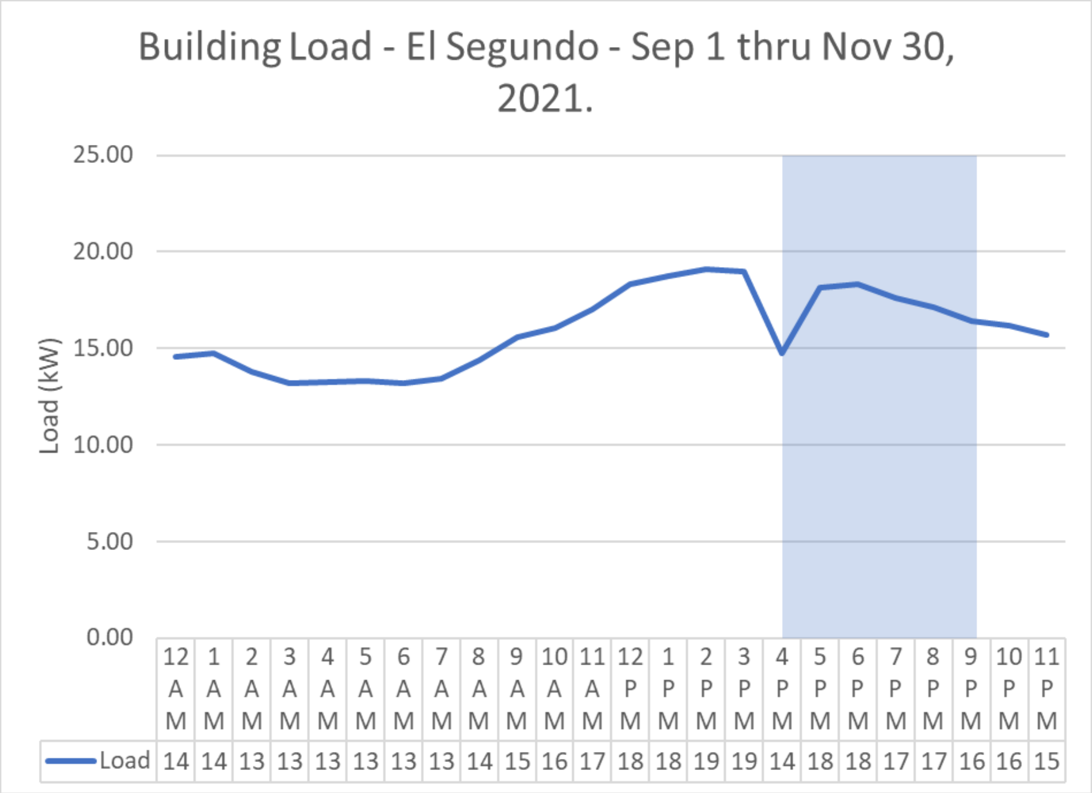
Source: EPRI

Figure 58: Load Profile for Building 1 for June 1 to August 31, 2021



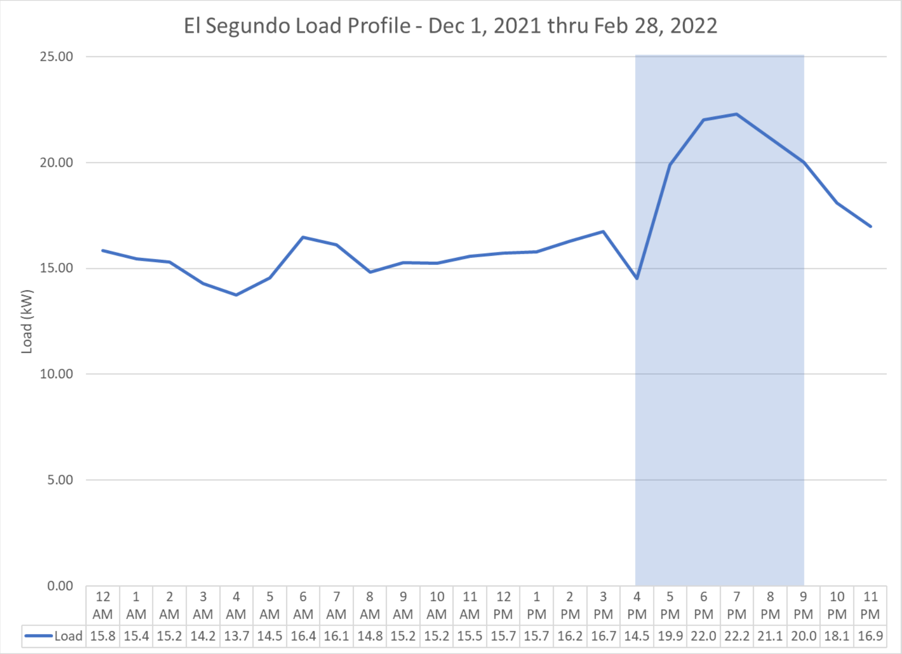
Source: EPRI

Figure 59: Load Profile for Building 1 for September 1 Through Nov 30, 2021



Source: EPRI

Figure 60: Load Profile for Building 1 for Dec 1, 2021 to Feb 28, 2022

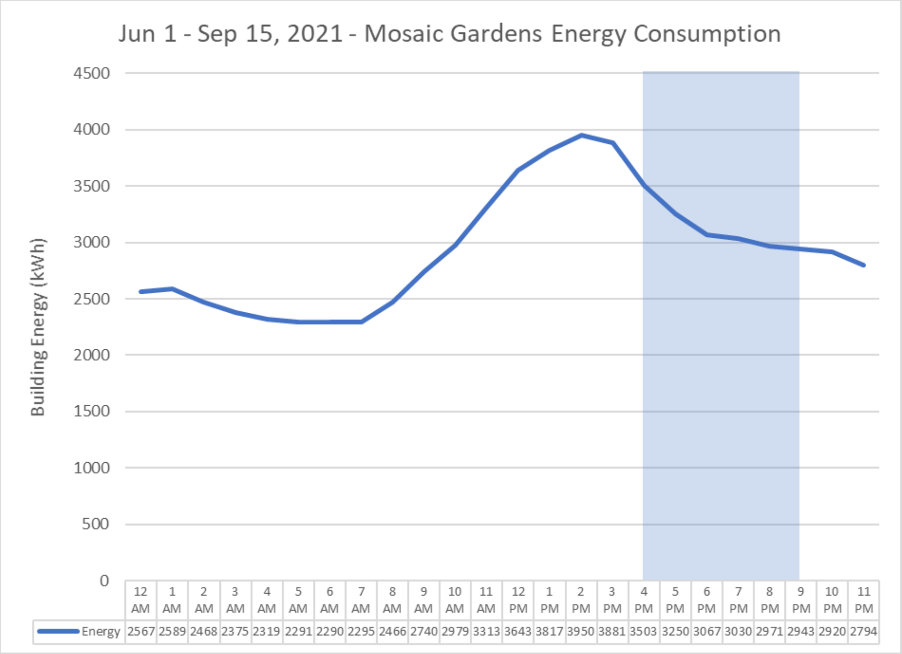


	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Load	15.8	15.4	15.2	14.2	13.7	14.5	16.4	16.1	14.8	15.2	15.2	15.5	15.7	15.7	16.2	16.7	14.5	19.9	22.0	22.2	21.1	20.0	18.1	16.9

Source: EPRI

The campus-level energy profile for Summer 2021 is shown in Figure 61 and Figure 62. All load profiles indicate peaks outside the 4 p.m. to 9 p.m. timeframe and show a reduction in load as the evening progresses. Given that this is the raw load, and the community is being subject to active TOU energy management via messaging done through the OhmConnect messaging platform, an immediate question is "How does this performance compare with the time before renewables, storage, and active load-management methods were employed?"

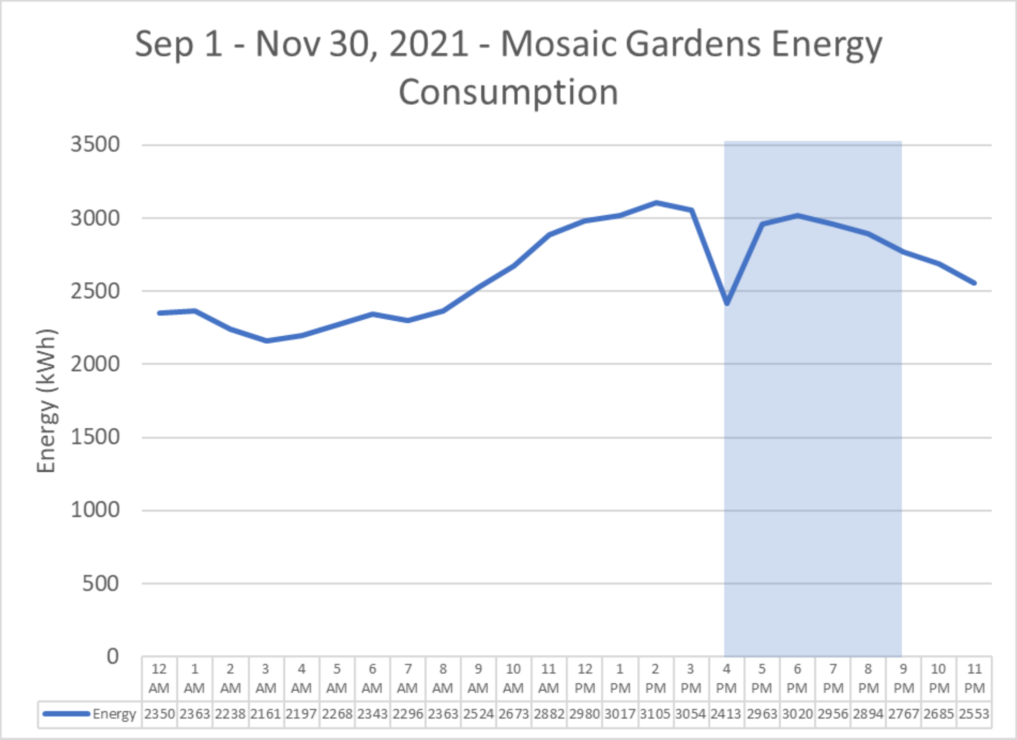
Figure 61: Campus Energy Profile for June 1 to August 31, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Energy	2567	2589	2468	2375	2319	2291	2290	2295	2466	2740	2979	3313	3643	3817	3950	3881	3503	3250	3067	3030	2971	2943	2920	2794

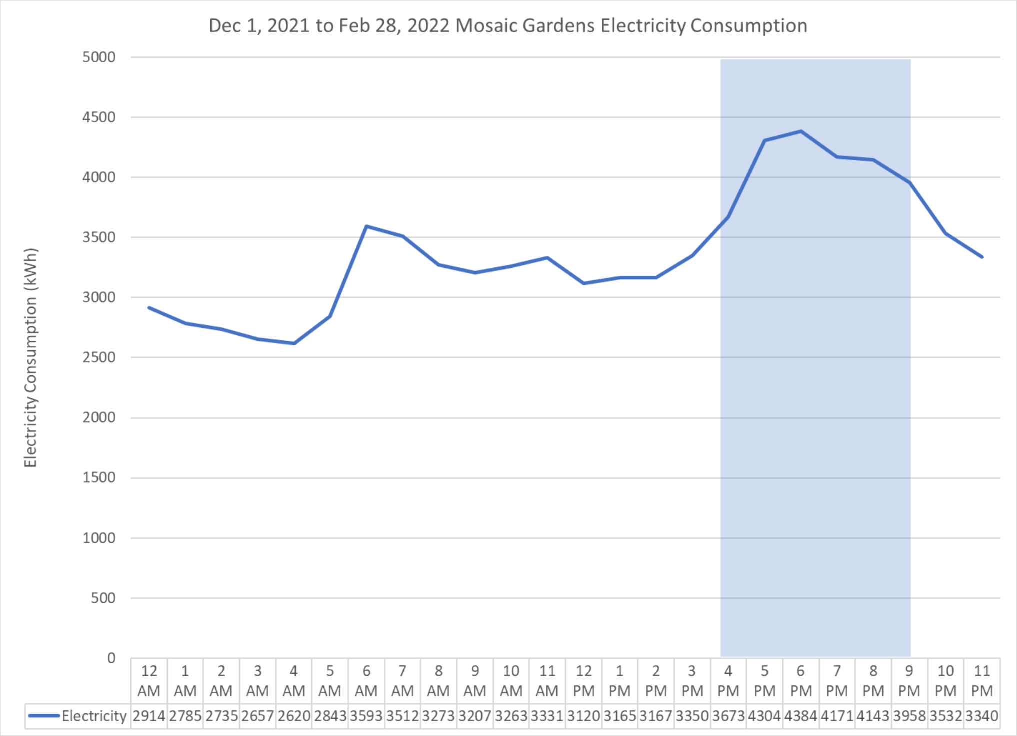
Source: EPRI

Figure 62: Campus Energy Profile for Sep 1 thru Nov 30, 2021



Source: EPRI

Figure 63: Campus Energy Profile for Dec 1, 2021, to Feb 28, 2022

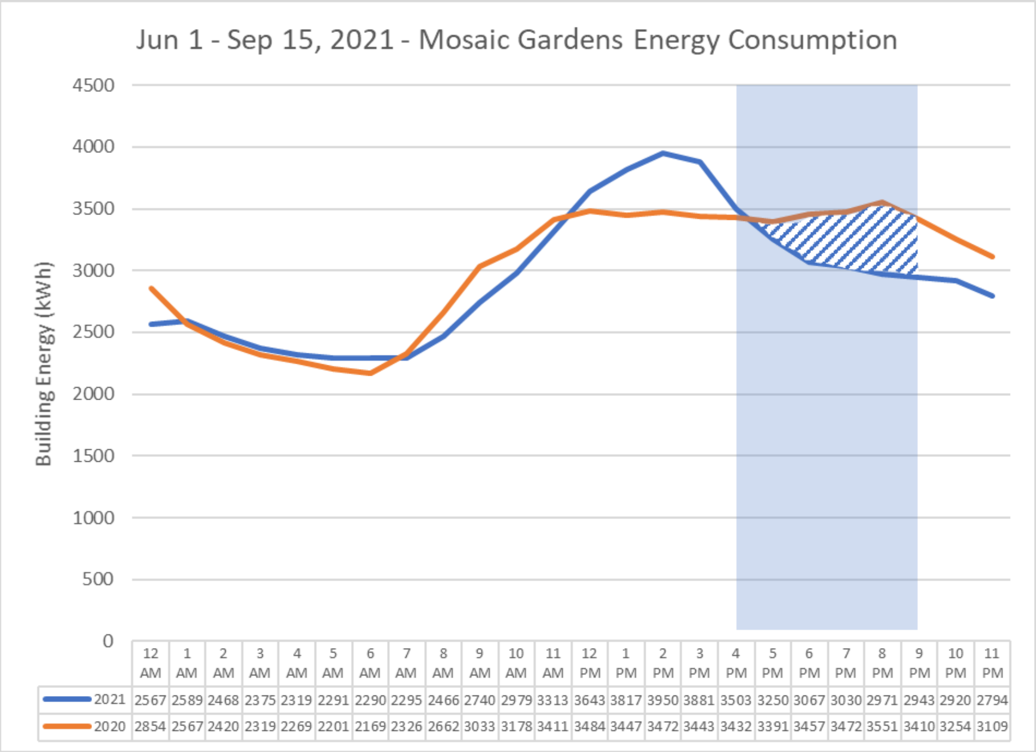


Source: EPRI

Comparison of Pre-Retrofit to Post-Retrofit Energy Performance

To compare the current post-retrofit energy performance with the pre-retrofit performance, the data from 2020 at the unit and common-area levels were compiled together. Of the energy consumption data set of 21 residents that the project team had access to, only six of the homes had data going back to Summer 2020. A method of scaling the data from these six homes was employed alongside detailed hourly common-area meter data available via SCE's customer portal. The result was used to develop an energy performance pre-retrofit. This pre-retrofit performance (2020) was compared with the post-retrofit performance (2021). The result of the comparison is shown in Figure 64 through Figure 66.

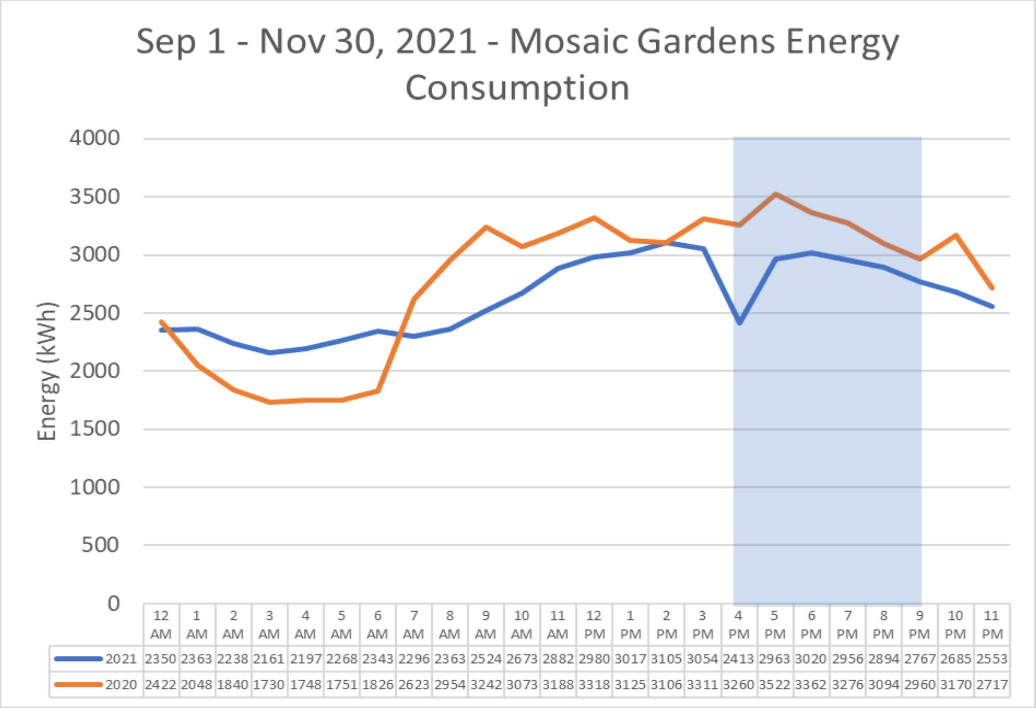
Figure 64: Comparison of Pre-Retrofit (2020) to Post-Retrofit (2021) Energy Performance for June 1 to September 15



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2567	2589	2468	2375	2319	2291	2290	2295	2466	2740	2979	3313	3643	3817	3950	3881	3503	3250	3067	3030	2971	2943	2920	2794
2020	2854	2567	2420	2319	2269	2201	2169	2326	2662	3033	3178	3411	3484	3447	3472	3443	3432	3391	3457	3472	3551	3410	3254	3109

Source: EPRI

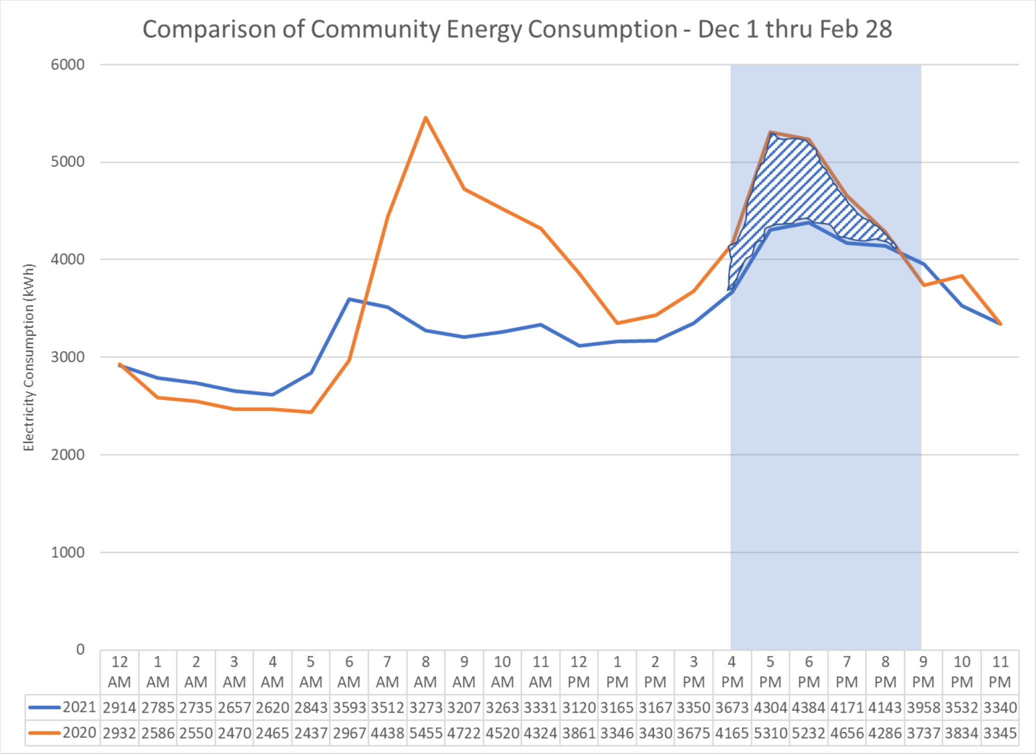
Figure 65: Comparison of Pre-Retrofit (2020) to Post-Retrofit (2021) Energy Performance for September 1 to November 30



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2350	2363	2238	2161	2197	2268	2343	2296	2363	2524	2673	2882	2980	3017	3105	3054	2413	2963	3020	2956	2894	2767	2685	2553
2020	2422	2048	1840	1730	1748	1751	1826	2623	2954	3242	3073	3188	3318	3125	3106	3311	3260	3522	3362	3276	3094	2960	3170	2717

Source: EPRI

Figure 66: Comparison of Pre-Retrofit (2020-2021) to post-Retrofit (2021-2022) Energy Performance for December 1 to February 28



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2914	2785	2735	2657	2620	2843	3593	3512	3273	3207	3263	3331	3120	3165	3167	3350	3673	4304	4384	4171	4143	3958	3532	3340
2020	2932	2586	2550	2470	2465	2437	2967	4438	5455	4722	4520	4324	3861	3346	3430	3675	4165	5310	5232	4656	4286	3737	3834	3345

Source: EPRI

The comparison leads to several observations:

- The energy performance of 2020 had fewer peaks than in 2021, but also the energy used during the 4-9 p.m. timeframe is higher in summer. The energy in 2020 Fall (on a weather normalized basis) is higher almost throughout the day. This downward shift in the entire load profile is more attributable to energy efficiency as opposed to signaling or TOU management. This trend continues and is more heavily pronounced in winter where there is a downward shift in peak as well as overall energy performance.
- The energy performance of 2021 peaks well before the 4-9 p.m. timeframe but is quite similar in trend when compared with 2020 in the summer. In the fall, the energy performance trends are similar to 2020 except for the early morning hours. In winter, there is an elimination of a morning peak as the peak shifts to the evening hours but is also lower in 2021 compared with 2020 by about 13 percent (900kWh reduction on the basis of 5200 kWh for 2020).
- Load-shifting is evident from the 4-9 p.m. timeframe to the 12-3 p.m. timeframe, which leads to the peak around 2 p.m. in summer. Such a pattern is not observed in the fall. This is to be expected (especially after October 1) when the peak TOU rates are lower. There is no perceptible load-shifting behavior observable in winter.
    - Given that this is the "raw" load and not the net load, it is quite possible that the inclusion of exports during the 12-3 p.m. timeframe (solar exports minus what is used to charge the battery) and the 4-9 p.m. timeframe (battery discharge exports), and 2-7 a.m. (battery discharge exports). The load performance for 2021 is expected to be even better.
- The estimated reduction in energy use (shaded in blue hatch) compared with 2020 is about 1.48MWh over the period (June 1 through September 15) and the overall reduction in load (over 24 hours) in the fall is 3.07 MWh. The estimated reduction in energy use over a 24-hour period in winter (December 1 through February 28) is 9.7MWh and 2.9MWh in the 4-9 p.m. timeframe. This corresponds to an 11 percent reduction in energy use over 24 hours and 13 percent during the 4-9 p.m. timeframe.

Time-of-Use Messaging and Demand Response

Ohmconnect and California ISO

Project partner OhmConnect is registered as a "Demand Response Provider" (DRP) with the California Independent System Operator (ISO). DRPs build demand-side resources, or virtual power plants, that aggregate users' electricity reductions as a source of generation. While most electricity resources create new electricity (like coal or solar power plants), DRPs value reductions of electricity as a replacement for new electricity.

OhmConnect bids aggregated residential customers' load reductions as DR into ISO markets on a daily basis. OhmConnect is fully integrated into the ISO market and participates by bidding its virtual power plants' reductions into the Day-Ahead Market and the Real-Time Market. If dispatched in the ISO energy markets, OhmConnect is paid for the reductions it provides. In turn, OhmConnect pays its users for their energy reductions.

OhmConnect seeks to align its bids with when users can contribute their reductions to periods of grid stress, as reflected by prices in the day-ahead and spot markets for electricity. Specifically, OhmHours tend to be called during periods of high locational marginal prices (LMPs), which reflect periods of higher grid stress. However, because OhmConnect values customer engagement, OhmHours that keep customers engaged are called year-round. OhmConnect called at least one event over 164 days in 2020 and 175 days in 2021.

Willowbrook Results

The OhmConnect, Linc, and EPRI teams worked together to enroll as many Willowbrook residents as possible into the OhmConnect program. There were challenges in a few cases when certain residents did not have credentials to their SCE online accounts. In the end, 29 Willowbrook residents signed up with OhmConnect, and of those 29 residents, 21 connected their utility accounts and have been participating in OhmConnect's OhmHour events. You can see a summary of the participation of the Willowbrook residents in Table 11.

Table 11: Summary of Willowbrook Resident Performance

User ID	Number of OhmHour Events	Percent of Successful Events	Max kWh Reduction
1	1	100 percent	0.44
2	56	80 percent	0.95
3	59	80 percent	1.20
4	50	76 percent	1.04
5	56	71 percent	1.22
6	58	69 percent	0.86
7	51	69 percent	1.74
8	59	68 percent	0.67
9	46	65 percent	0.52
10	54	65 percent	1.33
11	53	64 percent	0.61
12	48	63 percent	0.62
13	45	62 percent	1.72
14	51	61 percent	1.28
15	50	56 percent	0.77
16	56	55 percent	2.01
17	49	55 percent	0.16
18	44	55 percent	2.24
19	52	54 percent	1.21
20	55	49 percent	0.59
21	55	47 percent	1.38
Average	*49*	*65 percent*	*1.07*

Source: EPRI

The Willowbrook residents have an OhmHour event between 4 p.m. to 9 p.m., on average, one hour per week throughout the year. Prior to each OhmHour, the Willowbrook residents receive a notification from OhmConnect via email and text message. The notifications come about 24 hours and five minutes before the start of each OhmHour. The Willowbrook residents also receive summaries of their OhmHour performance within about two days of each event. Table 12 provides a summary of every OhmHour event that included at least one Willowbrook resident between June and December 2021. There were 56 unique events, with 765 resident opt-ins or an average of 16 opt-ins per event.

Table 12: Summary of OhmHour Dispatches

	OhmHour Events	Resident Opt-ins	Average Opt-ins per Event
June	10	160	16
July	9	180	20
August	16	160	10
September	7	119	17
October	4	72	18
November	2	32	16
December	5	42	8
Total	53	765	(Average) 15

Source: EPRI

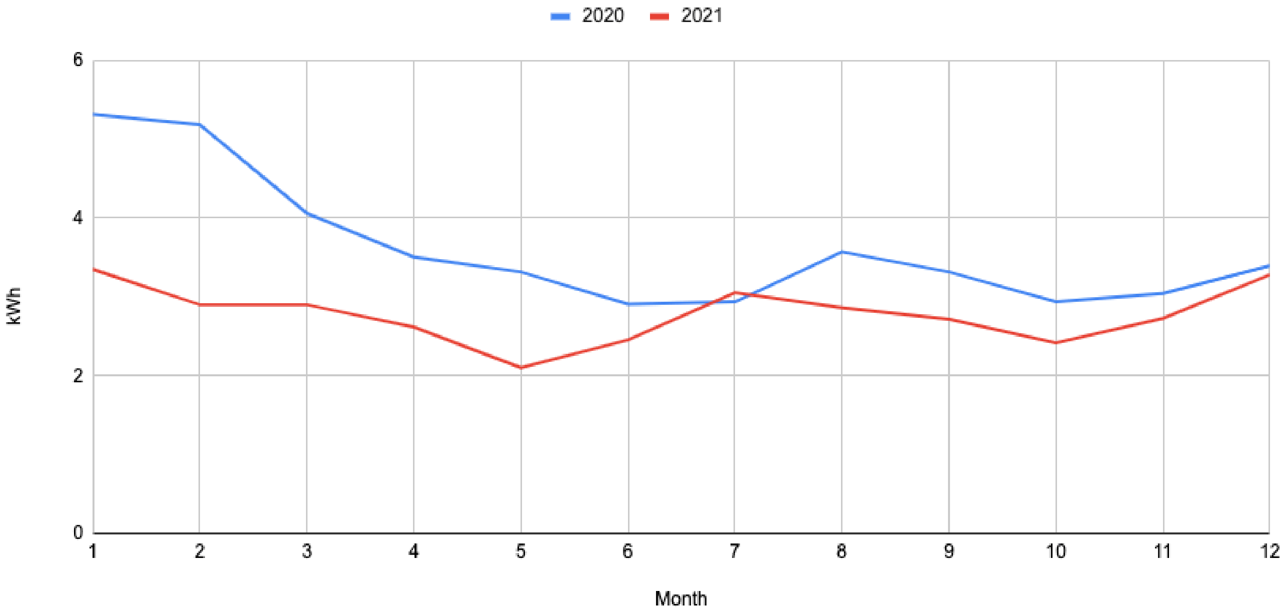
Through January 2022, Willowbrook residents collectively saved nearly 200 kWh through their behavioral participation in OhmHour events. On average, the Willowbrook residents saved ~0.30 kWh during each 1-hour event. During one event, one resident was able to achieve a 2.24 kWh reduction. Nearly 45 percent of the Willowbrook residents have attained Gold or Platinum status on the OhmConnect platform, indicating that they are consistently reducing their energy consumption between 15 percent (Gold) to 80 percent (Platinum), relative to their baseline forecast when called upon to do so. Compared with the population of OhmConnect users in SCE's service territory, the Willowbrook residents generally perform similarly or better.

Time-of-Use Rate Messaging

The residents of the Willowbrook community will shift over to a TOU rate plan offered by SCE in May 2022. For this project, OhmConnect has built out custom messaging for Willowbrook residents around the TOU rate plan. OhmConnect incorporated TOU-related messaging into its day-ahead and day-of notifications for OhmHour events, and OhmConnect has been sending a monthly newsletter to Willowbrook residents with information about TOU rates and energy saving tips.

Using all of the data available to compare monthly averages of daily energy consumption per resident during the 4-9 p.m. window, it appears that energy consumption generally fell in 2021 versus 2020, as indicated in Figure 67. There are several factors that could explain the difference, including: turnover in residents, differences in weather, shelter-in-place-related increases in 2020, and improvement in "energy literacy" from participation in OhmConnect.

Figure 67: Monthly Average of Daily Energy Consumption per Resident Between 4 p.m. to 9 p.m.



Source: OhmConnect

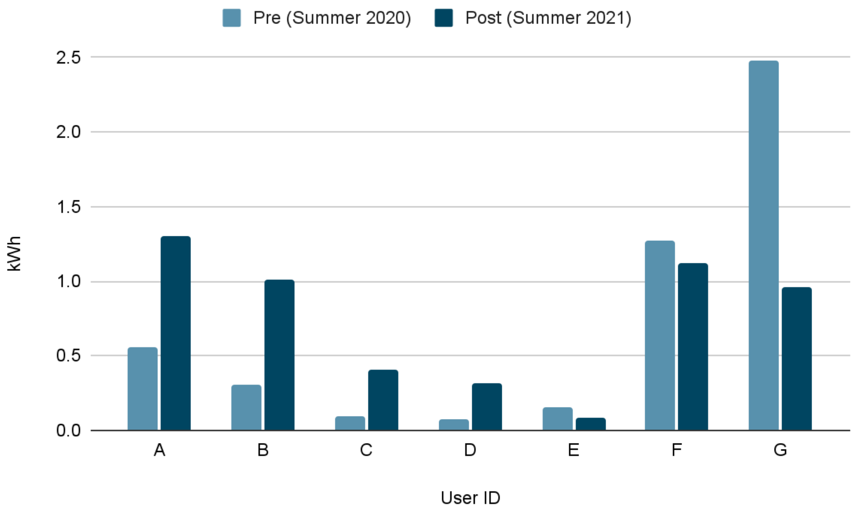
The team wanted to perform a simple analysis to determine whether the custom TOU-related messaging was having any measurable effect on the residents' average energy consumption during the 4-9PM time period during the summer months. The team was able to access historical meter data dating back to the beginning of the summer of 2020 for a very limited sample size of seven Willowbrook residents (due to the occupancy turnover rate among the 21 enrolled participants).

See the data in Figure 68 for a summary of the energy use of those seven residents on the OhmConnect platform.

All 7 residents successfully participated in more than 50 percent of their OhmHour events and saved up to 50 percent compared to their historic baseline. Looking at their reductions in energy consumption cumulatively across all their OhmHour events, 4 of the residents have been successful at saving energy, and three have not.

Using meter data from June to August 2020 and June to August 2021, the average energy consumption (in kWh) was calculated during 4-9 p.m. for each of the seven residents. There is not a clear trend, as four out of seven users have consumed more energy during TOU rate times in summer 2021 versus 2020, and the other three residents consumed less energy during TOU rate times in summer 2021 vs. 2020. This result is not unexpected given the very limited sample.

Figure 68: Comparison of Willowbrook Resident Energy Consumption in Summer 2021 vs. Summer 2020 for Residents with Data Available Prior to Summer 2020



Source: OhmConnect

The team plans to rerun the analysis in summer of 2022 with a larger sample size and after the Willowbrook residents have been transitioned over the TOU rate plans by SCE.

Distribution System Analysis

Overview

This section is designed to answer one of the project's key research questions: What are some alternate business models or arrangements to engage IOUs more effectively in community-scale, customer-sited DER for both end-customer and grid-support benefits? This distribution system analysis evaluated the cost effectiveness of community-scale BTM PV + Storage resources for ratepayers, as well as to the utility grid, especially when these solutions are distributed across other multiple locations within a utility's distribution system. As part of the technical and economic analysis, different control scenarios were studied to determine how the benefits to the end-user and grid can be maximized.

A comprehensive technical and economic analysis was conducted in this project that involved the operation of the integrated PV + Storage system for control objectives among the three different scenarios presented in Table 13.

Table 13: Controls Deployment Schedule

Objective	Scenario 1	Scenario 2	Scenario 3
TOU + EV Peak Shaving (Discharge)	All Months (4 – 10 PM)	Summer Months Only (4 – 10 PM)	All Months (4 – 10 PM)
Solar Balancing (Charge)	All Months (10 AM – 2 PM)	All Months (10 AM – 2 PM)	All Months (10 AM – 2 PM)
GHG Reduction (Discharge)	All Months (3 – 8 AM)	Winter Months Only (3 – 8 AM)	All Months (3 – 8 AM)

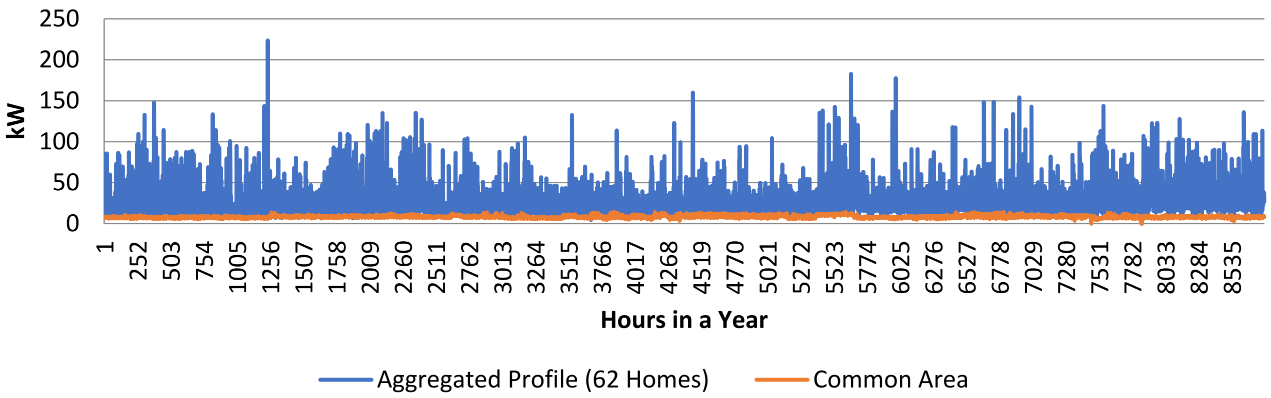
Source: EPRI, 2021

Data and Background

Individual Customer Load Profiles

The community consists of 61 individual homes spread across two housing buildings and a common area that is aggregated to estimate the total community load. These homes are a combination of 1 Bedroom (BR), 2 BR and 3 BR units. Due to the load data unavailability of each of the 61 individual customers, representative load profiles of certain customers (residing in 1 BR, 2 BR & 3BR units) for whom load data was readily available was scaled up based on the total number of individual units of each unit type. Figure 69 depicts the aggregated load profile of the residents (blue) and the common area (red) for a year.

Figure 69: Annual Load Profile of the Community

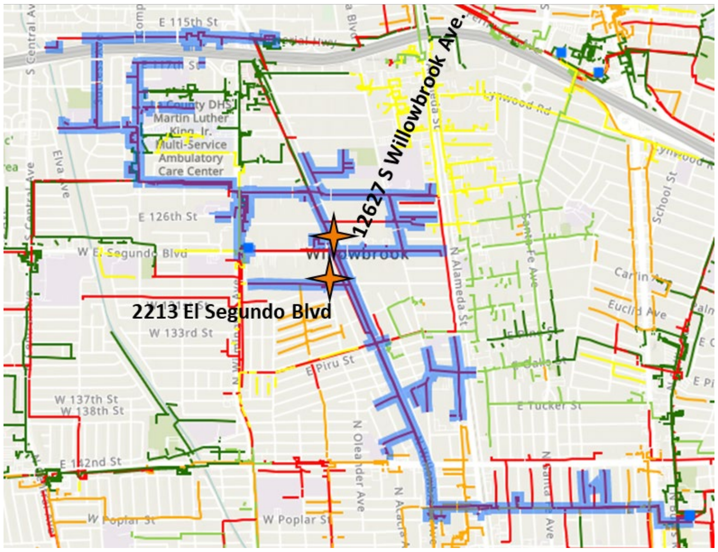


Source: EPRI

Distribution Circuit Load Profile

The Willowbrook community is connected to the Trochu Distribution Circuit, highlighted in blue in Figure 70, which primarily consists of a combination of residential and industrial customers in the SCE territory.

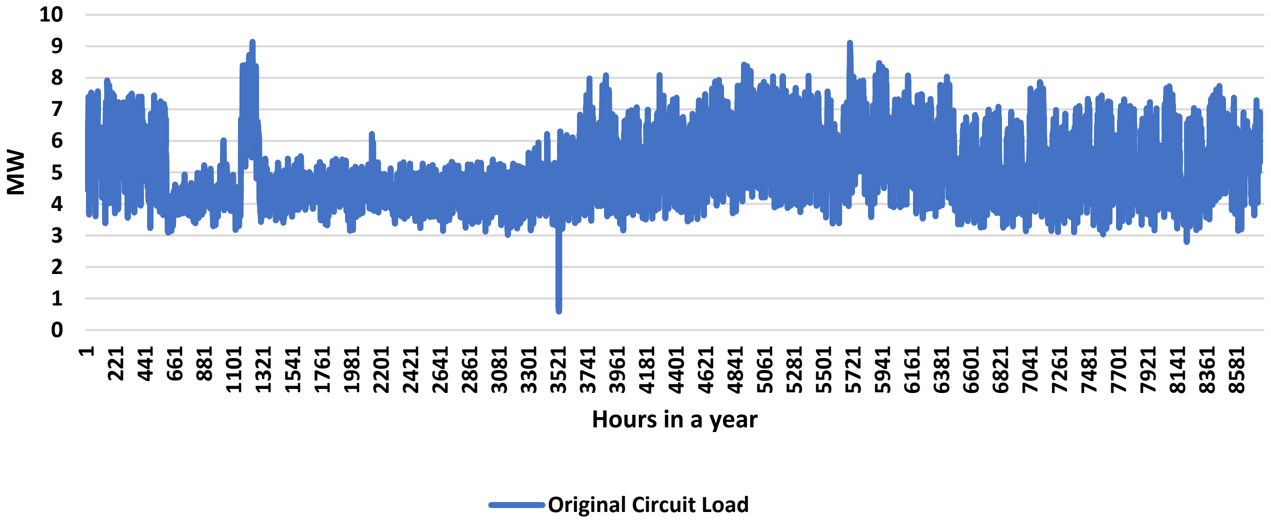
Figure 70: Trochu Distribution Circuit Layout



Source: SCE Distribution Resource Plan External Portal

The annual load profile of this distribution circuit is shown in Figure 71. The circuit has an annual peak load of 9.14 MW. This load profile was used for scenarios 1 and 2 of the analysis.

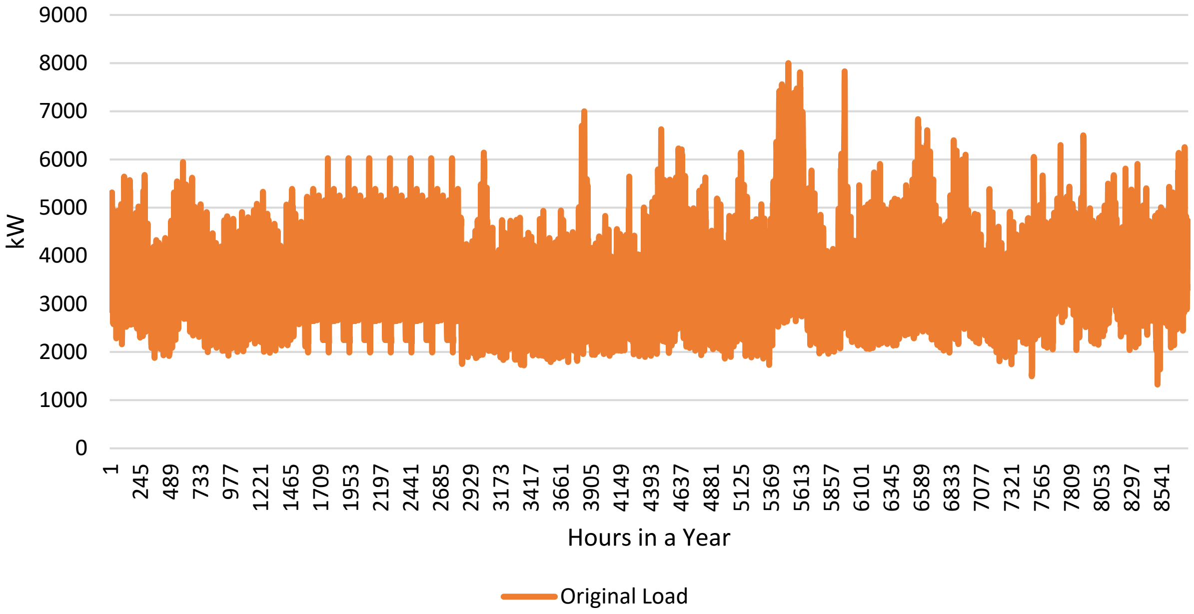
Figure 71: Annual Load Profile of the Trochu Circuit



Source: EPRI

For Scenario 3, the scaled-up load profile of the service transformers serving the Willowbrook Community was used to illustrate the load shape of a typical residential distribution feeder. The annual peak load of this feeder is 8 MW, as shown in Figure 72.

Figure 72: Annual Load Profile of the Scaled-Up Residential Distribution Circuit

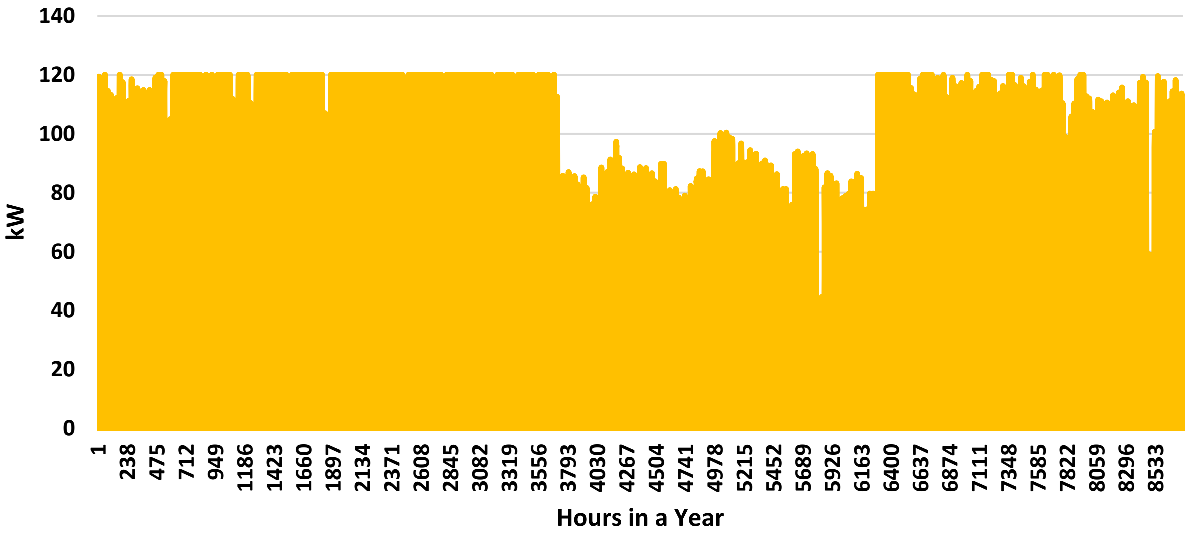


Source: EPRI

Solar Production Profile

The Willowbrook community now includes a 120 kW PV system onsite. The AC solar production profile is shown in Figure 73.

Figure 73: Mosaic Gardens at Willowbrook Annual PV Production Profile



Source: EPRI

DER Technologies

Table 14 shows the DER technology parameters.

Table 14: DER Technology Parameters

Technology	Parameter	Value
Li Ion Energy Storage System	Power	60 kW
Li Ion Energy Storage System	Energy	120 kWh
Li Ion Energy Storage System	Round Trip Efficiency	85 percent
Li Ion Energy Storage System	Lifetime	10 years
Li Ion Energy Storage System	Usable SOC Range	5 percent - 95 percent
Photovoltaic System	DC Nameplate Rating	120 KW
Photovoltaic System	Lifetime	20 years

Source: EPRI, 2021

The roundtrip loss of the battery is incorporated into the modeling as the additional energy required for charging the battery while calculating its state of charge (SOC). For instance, a battery fully charged (100 percent SOC) would be able to provide 120 kWh with its stored energy, while a battery which is completely empty (0 percent SOC) would require 141.17 kWh (120 kWh/0.85) to get its SOC to 100 percent.

Utility Tariff

The Willowbrook community is subjected to the SCE GS-1 (Option E) TOU tariff. The tariff primarily comprises of TOU energy components. This is summarized in Table 15 and Table 16.

Table 15: Utility Bill Components

Summer	Summer	Summer	Winter	Winter	Winter
On Peak	**Mid Peak**	**Off Peak**	**Mid Peak**	**Off Peak**	**Super Off Peak**
$0.4701/kWh	$0.2774/kWh	$0.1828/kWh	0.2975/kWh	$0.1728/kWh	$0.1401/kWh

Source: EPRI, 2021

Table 16: Time of Use Definition

Season	Period	Hours
Summer	On Peak	4-10 PM (Weekdays)
Summer	Mid Peak	4-10 PM (Weekends)
Summer	Off Peak	Midnight to 4 PM & 10 to Midnight (Weekdays & Weekends)
Winter	Mid Peak	4-10 PM (Weekdays & Weekends)
Winter	Off Peak	Midnight to 8 AM & 10 PM to Midnight (Weekdays & Weekends)
Winter	Super Off Peak	8 AM to 4 PM (Weekdays & Weekends)

Source: EPRI, 2021

Scenario Development

This project involves performing both technical and economic analyses involving an integrated PV and storage system to achieve numerous objectives described in the previous section. The first step in this process involves the development of the base and change cases.

Base Case: The "business as usual" operation of the community is defined as the base case. The base case doesn't include any DER, and the total load in the community is served solely by the utility.

Change Case: The change case involves the inclusion of the BTM community-scale PV + Energy Storage system. This system is operated in such a way that it achieves all the objectives defined in the previous section.

The "stackable" aspect of the integrated system to achieve all the objectives identified previously was analyzed through the development of three different scenarios, summarized in Table 17 and Table 18. The timeframe from June to September is referred to as "Summer" and the remaining eight months are referred to as "Winter."

Table 17: Objectives for DER Operation (Scenarios 1 and 2)

Objective	Type	Scenario 1	Scenario 2
TOU Energy Time Shift + EV Peak Shaving	Primary	All Months (4-10 PM)	Summer Months Only (4-10 PM)

Objective	Type	Scenario 1	Scenario 2
Solar Balancing	Primary	All Months (10 AM to 2 PM)	All Months (10 AM to 2 PM)
GHG Reduction	Primary	All Months (3-8 AM)	Winter Months Only (3-8 AM)
Distribution Peak Reduction	Secondary	Aggregated across multiple similar communities based on the operation for meeting primary objective	Aggregated across multiple similar communities based on the operation for meeting primary objective

Source: EPRI, 2021

Table 18: Objectives for DER Operation (Scenario 3)

Objective	Type	Scenario 3
Distribution Peak Reduction	Primary	Aggregated across multiple similar communities based on the operation for meeting the 10 percent annual peak load reduction target
TOU Energy Time Shift + EV Peak Shaving	Secondary	All Months (4-10 PM)
Solar Balancing	Secondary	All Months (10 AM to 2 PM)
GHG Reduction	Secondary	All Months (3-8 AM)

Source: EPRI, 2021

Scenarios 1 and 2 employ a "bottom-up" approach whereas Scenario 3 employs a "top-down" approach.

For Scenarios 1 and 2, the operation of individual communities was primarily driven by the four control objectives defined in the previous section. Operations of similar communities along the same feeder were subsequently aggregated to determine the net load reduction at the distribution level.

For Scenario 3, the goal was to attain a 10 percent net peak load reduction for one distribution circuit. Once this primary objective is met, the feasibility of meeting the secondary benefit is evaluated with the residual capacity of the PV and the BESS. The DER will not offer secondary benefits during those days that have a primary service requirement to avoid conflicts between the two objectives.

Modeling Approach

The first step involved in the modeling of the integrated PV + Storage system is the classification of different objectives into constrained and optimization services. Secondly, for the different objectives described previously, the power capacity at which the energy storage system is to be dispatched is identified. The maximum power capacity for dispatching the battery is estimated in such a way that it does not cause any adverse violations to the distribution circuit. The boundary conditions of the battery are illustrated in Table 19.

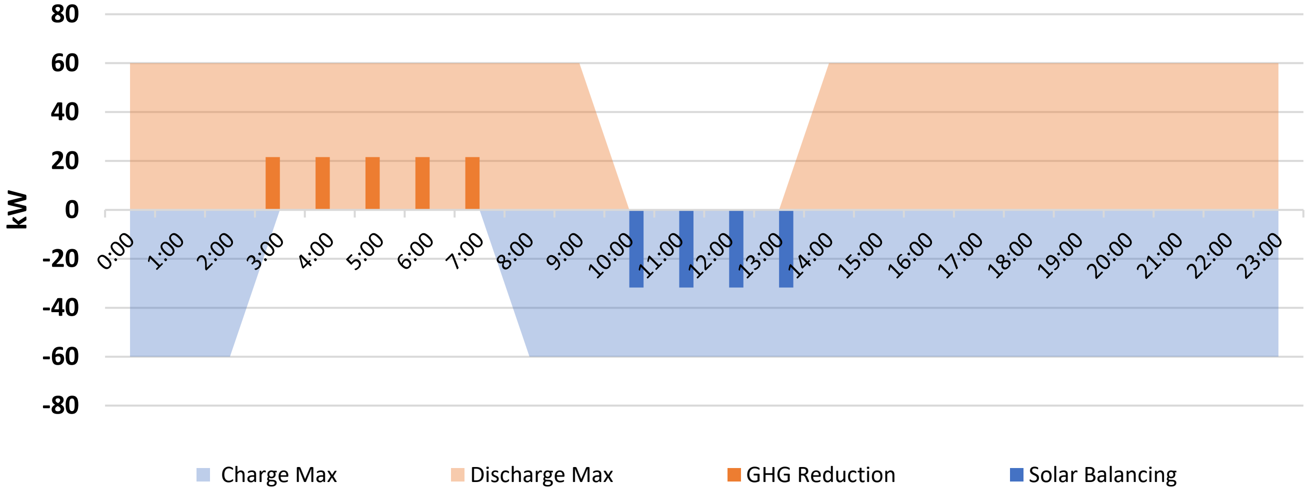
Table 19: Overview of Constrained Services (Single BESS Operation)

Objective	Service Type	Battery Dispatch	Duration	Power Capacity
Solar Balancing	Constrained	Charge	4 Hours	31.76 kW
GHG Reduction	Constrained	Discharge	5 Hours	21.6 kW

Source: EPRI, 2021

The timeseries constraint profile applied to scenarios 1 and 3 and Scenario 2 (only during winter) are illustrated in Figure 74. It must also be noted that the charging is represented by a negative value and discharging is represented by a positive value.

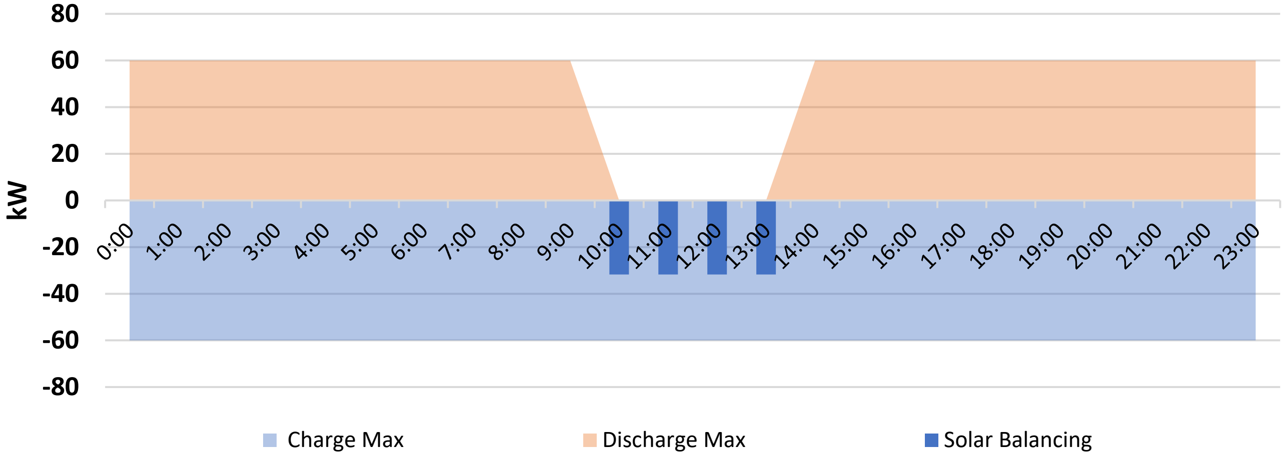
Figure 74: Daily Constraint Profile - Scenario 1, Scenario 3, and Scenario 2 (Winter)



Source: EPRI

The timeseries constraint profile illustrated in Figure 75 applies only to the summer months in Scenario 2.

Figure 75: Daily Constraint Profile - Scenario 2 (Summer)



Source: EPRI

Due to Rule-21 implications, the battery can only be charged by PV, so its SOC must be managed carefully to ensure that all the services identified are served.

DER-VET Overview

The analysis was performed through EPRI's Distribution Energy Resource Value Estimation Tool (DER-VET) by utilizing several different types of data like customer load profiles, distribution circuit load profiles, solar production profiles and utility tariffs.

DER-VET is an open-source, optimization-based planning tool to aid in the design of distributed energy resource and microgrid deployments that maximize benefits to individual customers, ratepayers, and society as a whole that models the operation and subsequent value of a set of DERs, potentially configured in a microgrid and collectively providing a set of stacked services. DER-VET uses load and other site-specific data to optimize the size of the DER concurrently with its dispatch. The technologies modeled in DER-VET include various types of energy storage, intermittent renewable generation, fueled generation, controllable loads, EV, and hybrid resources like combined heat and power CHP. These energy resources can be used in any combination to improve grid reliability, improve customer resilience by providing backup to local critical loads, decrease the electricity bill incurred by the site, participate in wholesale energy or ancillary services markets, provide DR or resource adequacy, or some allowable combination of those.

Services in DER-VET are activities the DER mix can do to generate value. Services are broken into two categories– "pre-dispatch (constrained) services" and "optimization services."

Pre-Dispatch Services: A constrained service is a service relating to reliability, which defines boundaries on the state of the system. Pre-dispatch services require fixed contributions of power and energy from the DERs. These services are treated as constraints in the optimization problem, so are effectively modeled before the operation of the DERs is known.

Optimization Services: An optimization service does not have hard requirements and the DER mix is free to operate in a way that generates the maximum economic benefit with no constraints apart from those that ensure that the result is feasible. These services are usually economic, like customer bill reduction services or wholesale market participation. The operational profile maximizes the combined service value.

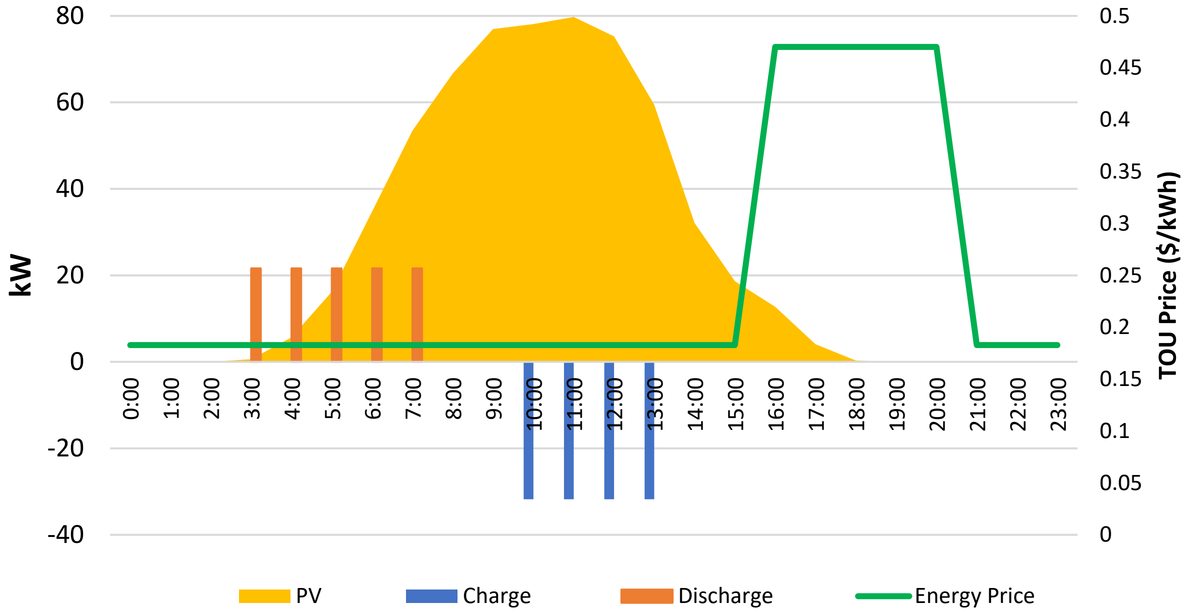
Technical Results

For scenarios 1 and 2, the net load shift is estimated for the Willowbrook community as a first step. Subsequently, the net load shift at the distribution circuit level is determined by aggregating the operation of several other similar communities connected to the same TROCHU distribution circuit as the Willowbrook community.

Scenario 1

In the first scenario, the operation of the energy storage system is identical for all the days since the objectives are applicable throughout the year. Figure 76 illustrates the daily operation of the battery during the winter months. Over the course of the day, the battery discharges in the early morning hours to fulfill the GHG reductions. It charges mid-day to achieve the solar-balancing objective. The excess PV generated is exported to the grid to earn net metering credits.

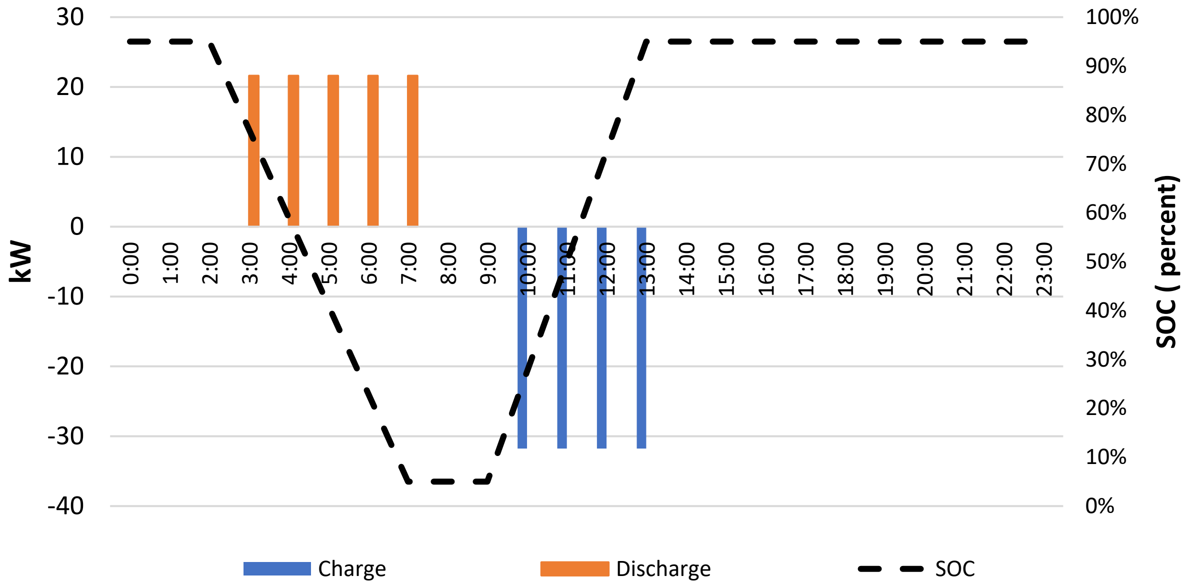
Figure 76: Daily Battery Operation - Scenario 1



Source: EPRI

Figure 77 illustrates the SOC evolution of the battery due to its operation. Since the battery is required to discharge in early morning for GHG reduction, it must be ensured that its SOC is maintained at the maximum level (95 percent) overnight to satisfy this requirement.

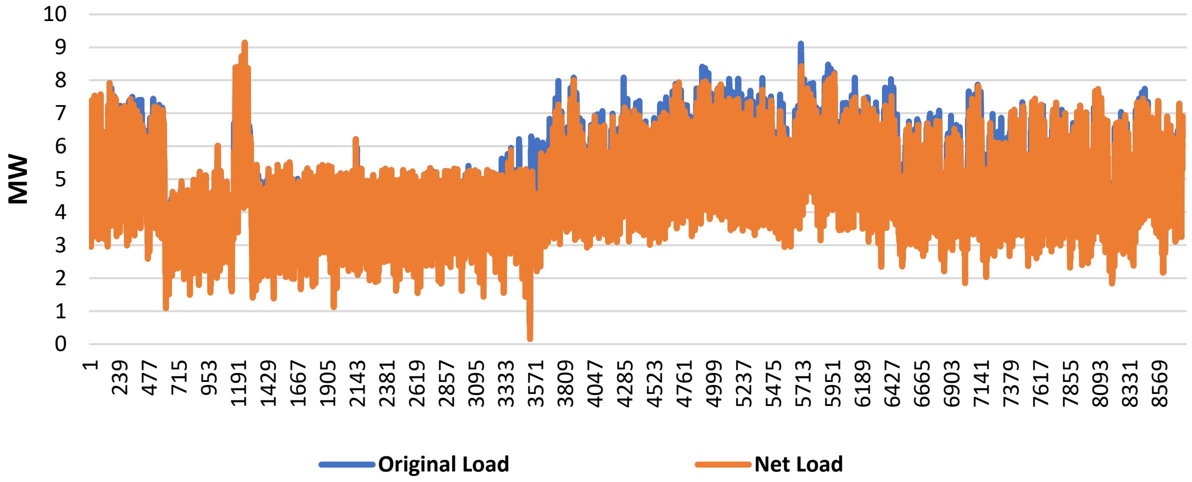
Figure 77: Battery Operation vs SOC Evolution (Scenario 1)



Source: EPRI

By assuming that there is a total of 20 low-income communities similar to the Willowbrook community that are connected to the Trochu distribution circuit, and that all of them are based on the same objective, the estimated net load on the circuit feeder (as shown in Figure 78) is aggregated. An average of 2.1 percent net peak load reduction was achieved over the year due to the operation of the 20 communities at the circuit level.

Figure 78: Distribution Circuit Load Comparison (Scenario 1)

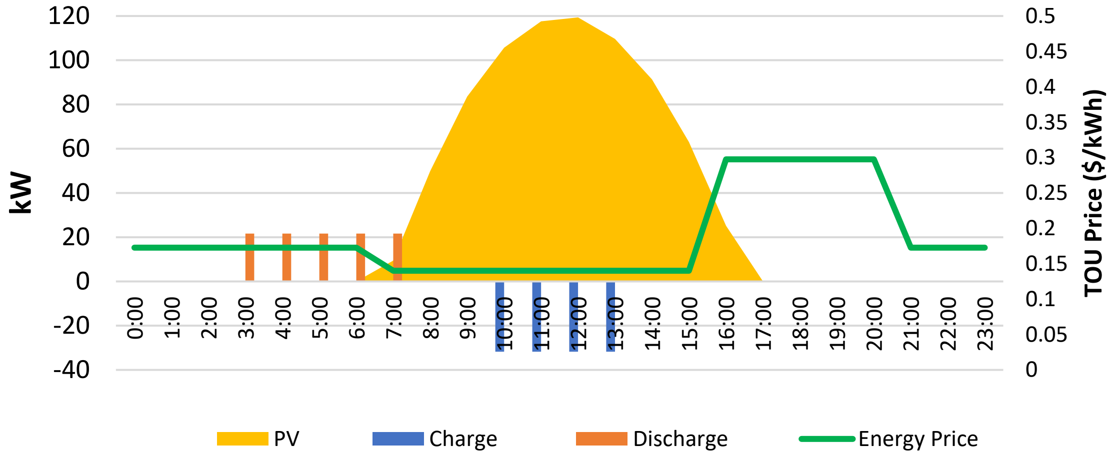


Source: EPRI

Scenario 2

In Scenario 2, the operation of the energy storage system varies slightly based on the season. *Winter Season:* During the winter months, the battery is only operated for the GHG emission and solar balancing objectives. This is achieved by discharging the battery in the early morning (between 3 a.m. and 8 a.m.) and charging the battery during hours of high PV availability (between 10 a.m. and 2 p.m.) respectively (Figure 79).

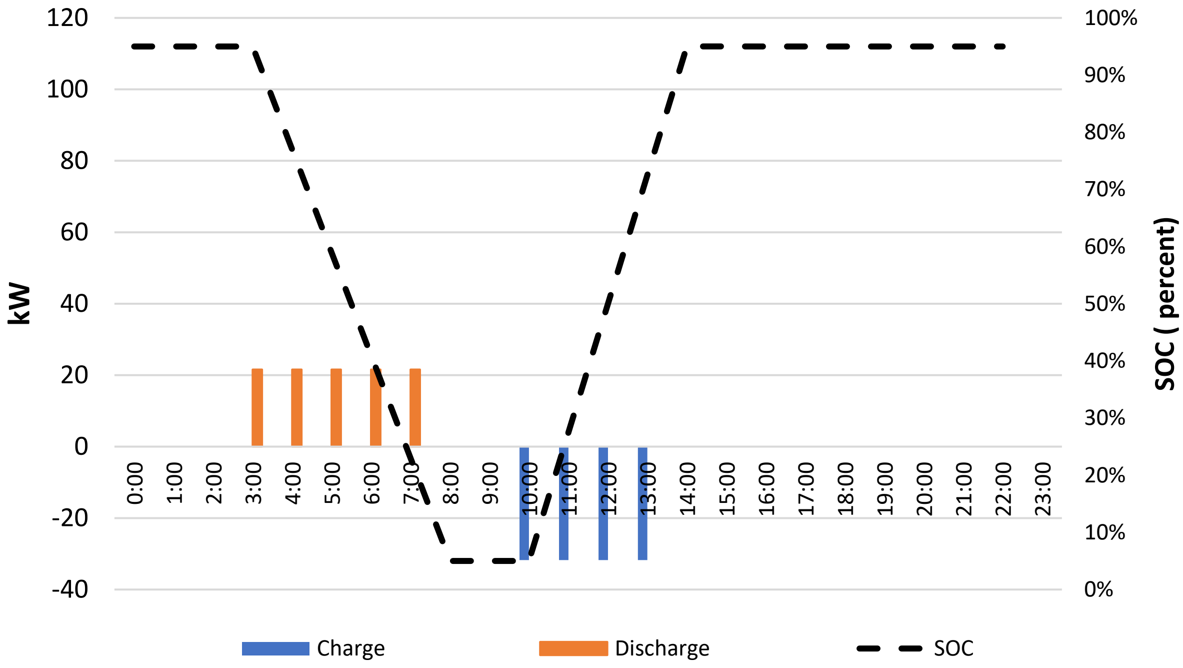
Figure 79: Daily Battery Operation - Scenario 2 (Winter)



Source: EPRI

The SOC evolution of the battery over the day is illustrated in Figure 80.

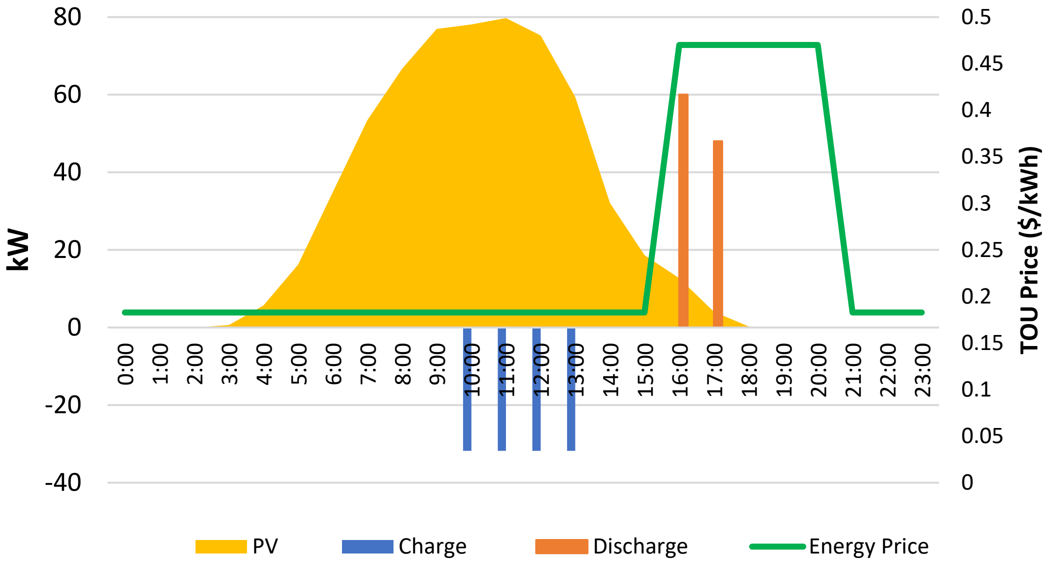
Figure 80: Battery Operation vs SOC Evolution (Scenario 2 - Winter)



Source: EPRI

Summer Season: During the summer months, the battery is only operated for the TOU+EV peak shaving and solar balancing objectives. This is achieved by discharging the battery in the evening (between 4 p.m. and 10 p.m.) and charging the battery during hours of high PV availability (between 10 a.m. and 2 p.m.) respectively (Figure 81).

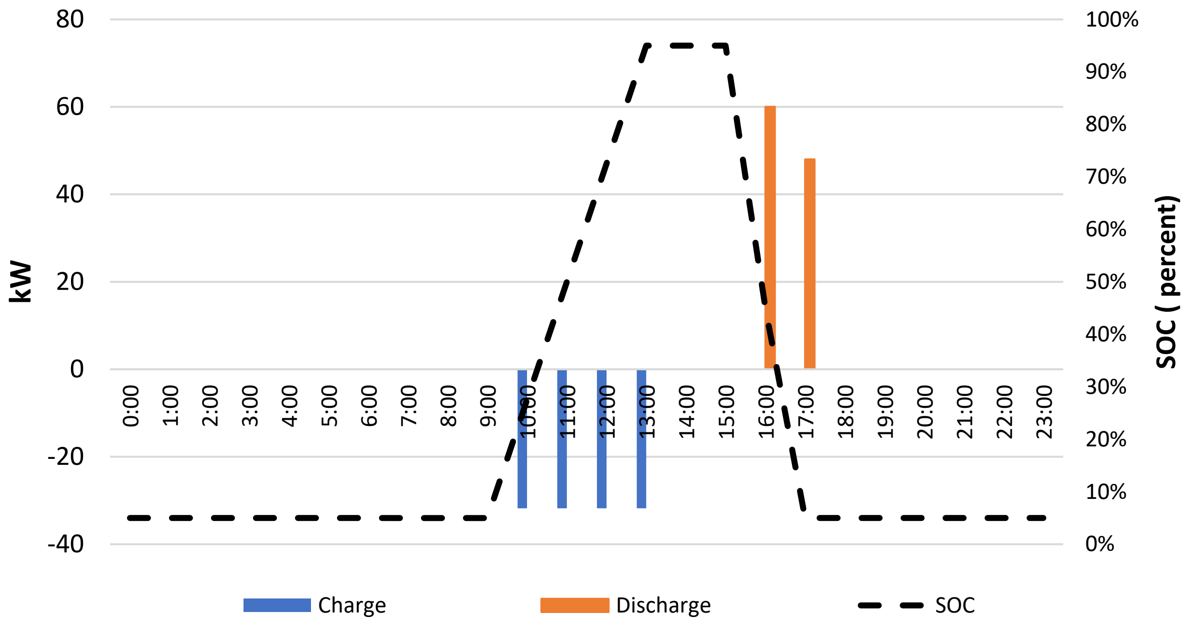
Figure 81: Daily Battery Operation - Scenario 2 (Summer)



Source: EPRI

The SOC evolution of the battery over the course of the day is illustrated in Figure 82.

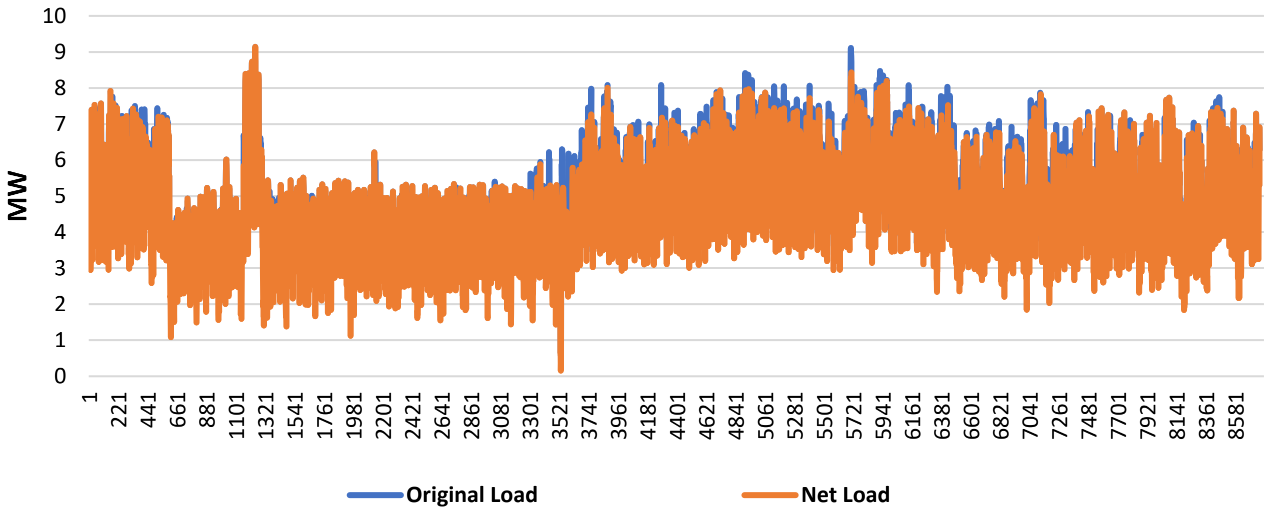
Figure 82: Battery Operation vs SOC Evolution (Scenario 2 - Summer)



Source: EPRI

Similar to Scenario 1, a total of 20 low-income communities like the Willowbrook community are connected to the Trochu distribution circuit, and they are operated based on the same objective. The net load on the circuit feeder is estimated in Figure 83 by aggregating their operations. An average of 3.1 percent net peak load reduction was achieved over the year due to the operation of the 20 communities at the circuit level.

Figure 83: Distribution Circuit Load Comparison (Scenario 2)

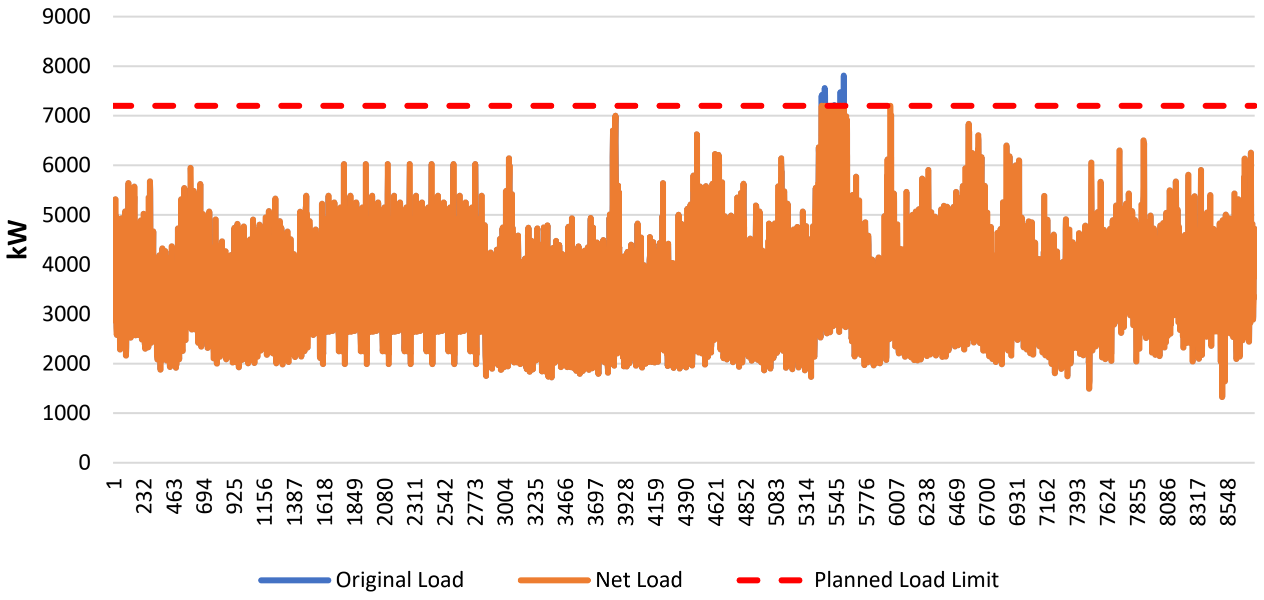


Source: EPRI

Scenario 3

In Scenario 3, the integrated PV+BESS systems of the individual communities are operated to achieve 10 percent net peak load reduction of the residential distribution circuit considered through the aggregated operation of 16 other similar communities. For the residential distribution feeder considered, which has an annual peak load of 8 MW, this 10 percent net peak load reduction corresponds to a planned load limit of 7.2 MW. This operation is illustrated in Figure 84.

Figure 84: Distribution Circuit Load Comparison (Scenario 3)



Source: EPRI

Table 20 represents a comparison of monthly peak load of the original load and the net load because of the aggregated operation of the 16 communities considered.

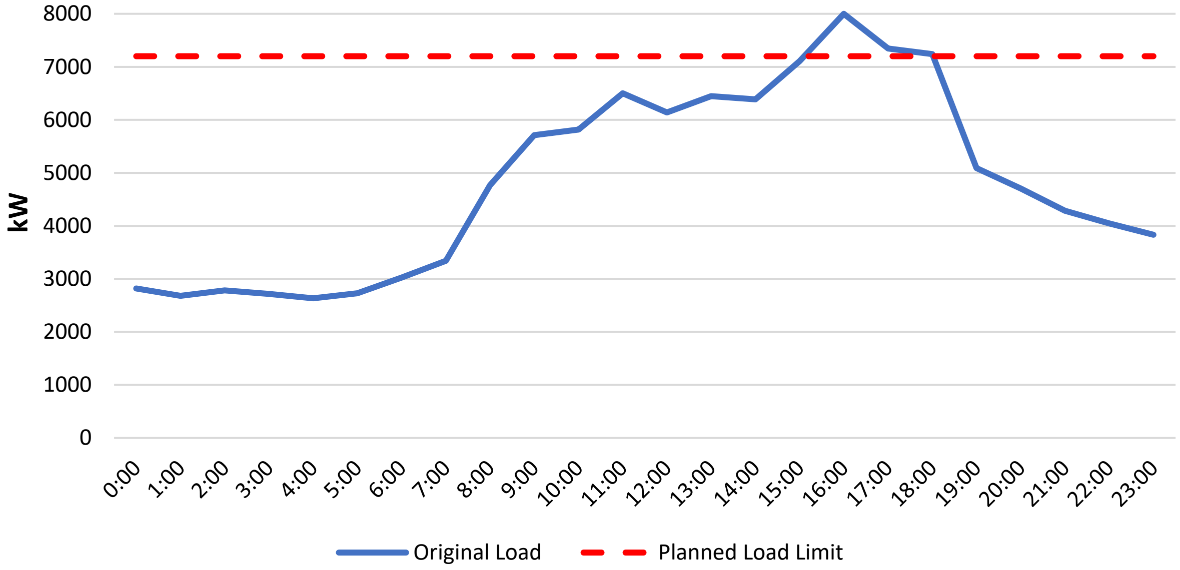
Table 20: Monthly Peak Load Comparison

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Original Load (kW)	5946	5326	6025	6025	6141	7000	6627	8000	7830	6836	6502	6253
Net Load (kW)	5946	5326	6025	6025	6141	7000	6627	7200	7200	6836	6502	6253

Source: EPRI, 2021

Figure 85 represents a 24-hour profile of the summer day where the annual load peak of the distribution feeder occurs. It could be observed that the feeder load exceeds the planned load limit of 7.2 MW between 4 p.m. and 6 p.m.

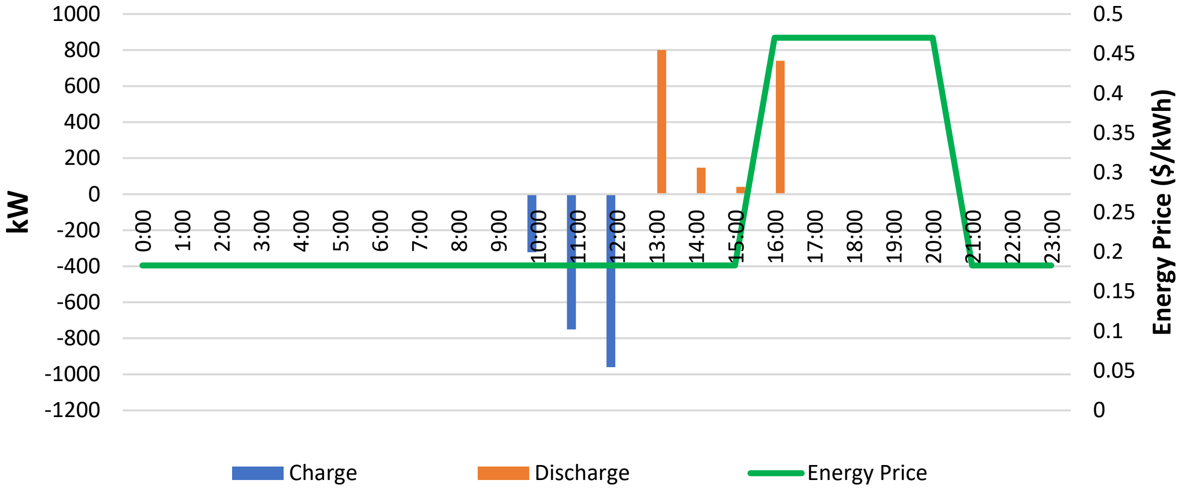
Figure 85: Residential Distribution Circuit Load Profile (Annual Peak Load Day)



Source: EPRI

The daily operation of a single BESS during this summer day is illustrated in Figure 86. The battery charges mid-day from PV to reach maximum SOC to discharge for the distribution peak shaving event during the evening hours.

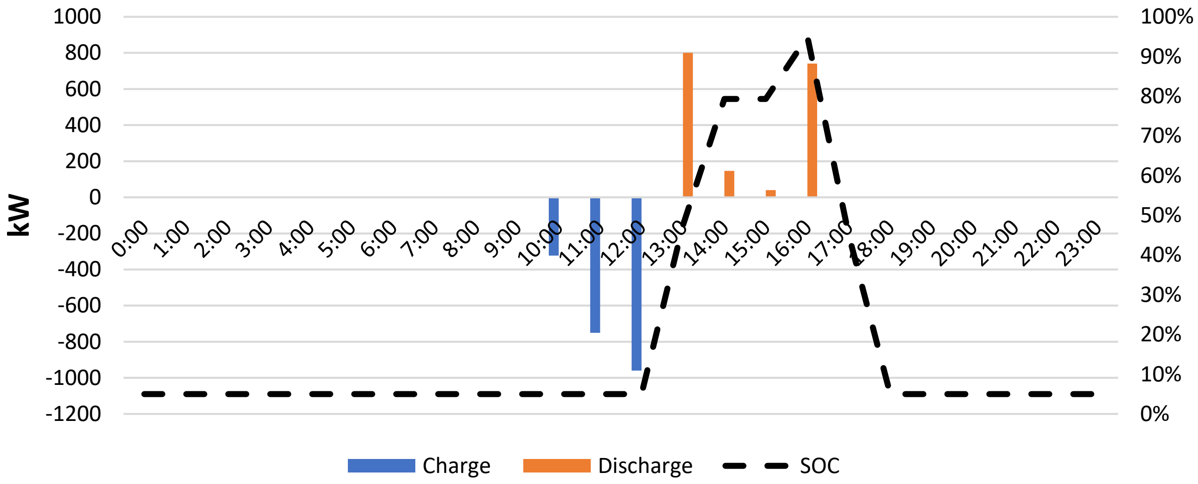
Figure 86: Daily Battery Operation - Scenario 3 (Annual Peak Load Day)



Source: EPRI

The SOC evolution of the battery over the day is illustrated in Figure 87.

Figure 87: Battery Operation vs SOC Evolution (Annual Peak Load Day)



Source: EPRI

Financial Results

There are two differences between the three scenarios analyzed.

The primary difference is the seasonal operational variation of the battery for accomplishing the different objectives (GHG reduction, TOU + EV peak shaving, and solar balancing) described previously. In Scenarios 1 and 3, all 3 objectives are achieved throughout the year, while in Scenario 2 only 2 out of the 3 objectives were accomplished at any point in time.

The secondary difference is that in scenarios 1 and 2, the three different objectives (GHG reduction, TOU + EV Peak Shaving and Solar Balancing) were always achieved. However, in Scenario 3, since these benefits are secondary, they have lower priority as compared to the distribution peak shaving benefit, so are offered only as much as possible. To prevent conflicts, the DER will not offer any of the secondary services like GHG reduction, solar balancing and TOU energy time shift during days when it dispatches for distribution peak shaving events.

The financial benefit of TOU energy time shift and EV peak shaving can be captured by calculating the utility bill of the community in the base and change cases. The financial benefit of GHG reduction and solar balancing is not monetized. An annual comparison of the financial results of the two scenarios for the Willowbrook Community is listed in Table 21.

Table 21: Financial Result Summary for a Single Multi-Family Property

Objective	Scenario 1	Scenario 2	Scenario 3
TOU Energy Time Shift + EV Peak Shaving	$43,967	$17,364	$44,181
Solar Balancing	N/A	N/A	N/A
GHG Reduction	N/A	N/A	N/A
Total	$43,967	$17,364	$44,181

Source: EPRI, 2021

Results Summary

A summary of the technical and financial results of the three scenarios by aggregating the impact of different communities like Willowbrook is shown in Table 22.

Table 22: Result Summary of Similar Aggregated Communities

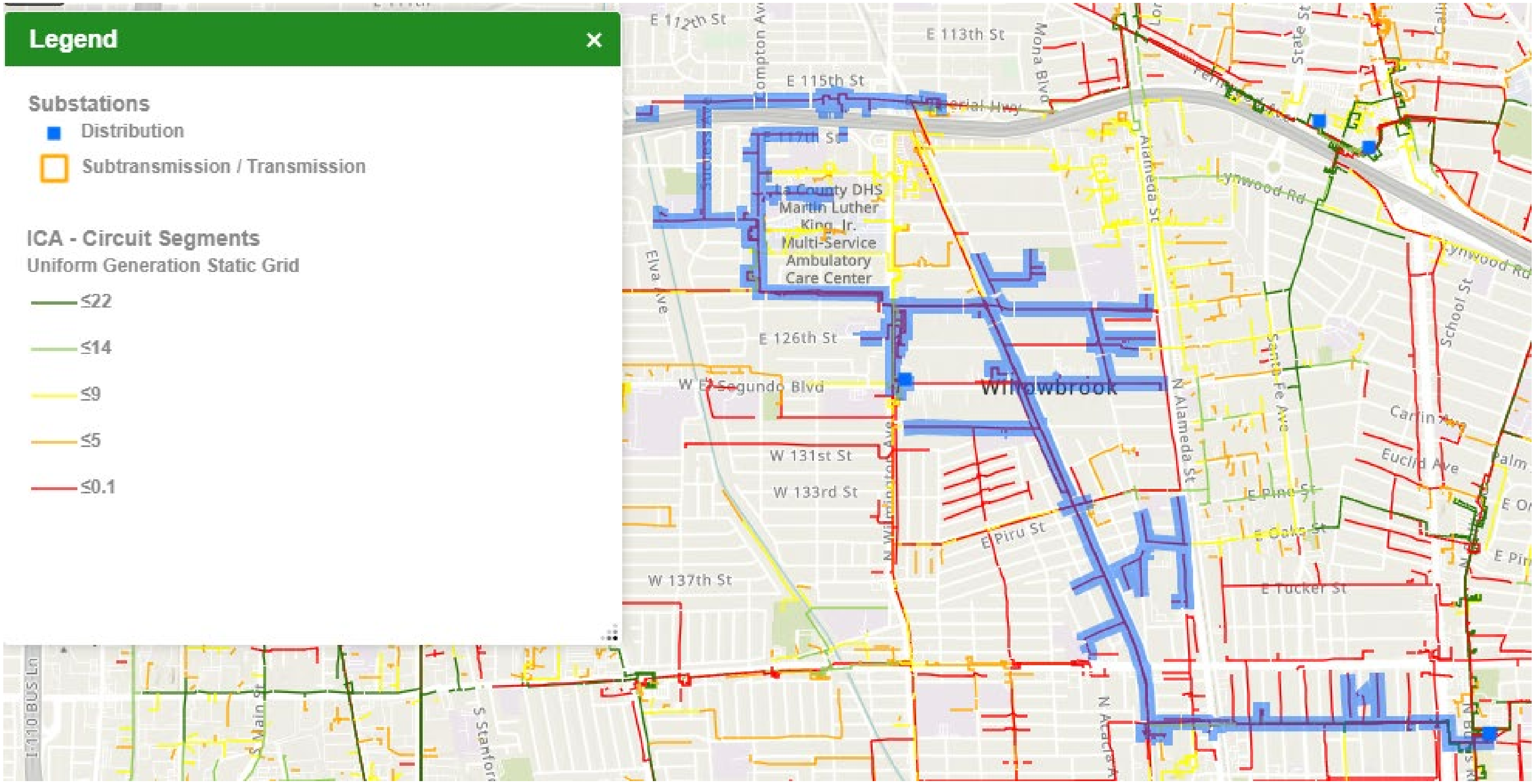
Item	Scenario 1	Scenario 2	Scenario 3
Circuit Level Peak Load Reduction	2.1 percent	3.1 percent	10 percent
No. of Communities Aggregated	20	20	16
Annual Financial Benefit	$879,340	$347,280	$706,896

Source: EPRI, 2021

Hosting Capacity

The DER Integration Capacity Analysis (ICA) of the Trochu distribution circuit is available through SCE. Results appearing in Figure 88 were extracted from SCE's Distribution Resource Plan external portal. It could be observed that the circuit has very limited hosting capacity available to integrate (< 0.1 MW) DER.

Figure 88: ICA of Trochu Distribution Circuit



Source: SCE's Distribution Resource Plan External Portal

Cost Benefit Analysis

The financial assumptions for performing the Cost Benefit Analysis are shown in Table 23.

Table 23: Cost Benefit Analysis Financial Parameters

Parameter	Value
Inflation	1.5 percent
Discount Rate	7 percent
Analysis Horizon	10 years
BESS & PV Lifetime	10 years

Source: EPRI, 2021

The total cost breakdown for the project is provided in Table 24.

Table 24: Cost Benefit Analysis Financial Parameters

Item	Cost
PV System Cost	$132,775
Battery Cost	$109,500
Controller & Software Cost	$31,350
Labor Cost	$198,345
Equipment Cost	$64,000
Design & Construction Cost	$70,030
Miscellaneous Cost	$36,000
Total Cost	$642,000

Source: EPRI, 2021

The 10-year net present value for the different scenarios is summarized in Table 25. It could be observed that none of the scenarios breakeven economically.

Table 25: 10-Year Net Present Value

	Scenario 1	Scenario 2	Scenario 3
NPV (Year 0 Dollars)	($314,214)	($512,547)	($312,619)

Source: EPRI, 2021

Customer Value Proposition

The operation of the integrated PV + BESS for the different control objectives offers the following benefits to utility customers.

Customer Bill Reduction: The integrated DER system is operated in such a way that a major share of the community's load is served by local generation during on-peak hours.

Subsequently, the residual energy generated is exported to the grid to earn net metering credits. This substantially reduces customer utility bills.

Solar Energy – Maximizing Use: The charging of the battery during the afternoon hours ensures that excess solar energy is stored, to be used during the evening hours when TOU peak pricing goes into effect and there is no solar availability.

GHG Emission Reduction: The discharging of the battery during the early morning hours greatly reduces GHG emissions, benefiting California ratepayers.

Distribution Feeder Upgrade Deferral: The aggregated operation of multiple similar communities leads to a net peak load reduction at the feeder level, which in turn aids in deferring the upgrade of the feeder, benefiting the utility economically.

Lessons Learned

This analysis involved the installation and operation of an integrated PV + BESS for accomplishing stacked benefits both at the individual community level and the distribution circuit level (aggregating multiple similar communities).

The development of multiple scenarios demonstrated how the following can impact the technical and financial analysis:

- Prioritizing services based on season of operation can help achieve multiple objectives without causing adverse impacts on the distribution circuit.
- The difference between adopting a "top down" versus a "bottom up" approach for achieving multiple objectives

The analysis also revealed the importance of selecting the right distribution feeder for performing the stacked benefit analysis. For scenarios 1 and 2, a non-residential feeder was chosen so the battery's operation for providing three services (GHG reduction, solar balancing and EV peak shaving) did not coincide with the distribution peak shaving objective since only a 2 percent reduction in net load reduction was possible. However, in Scenario 3, there was significant coincidence among all of the services offered. On top of the 10 percent net distribution peak load reduction, the three other additional secondary services were offered for over 97 percent of the days.

Scenario 1 led to higher financial returns in terms of utility bill reductions since battery operation for TOU energy time shift operation was performed year-round with a 2.1 percent reduction in net load reduction on the distribution circuit.

Scenario 2 yielded lower annual bill reductions since battery operation for TOU energy time shifts was limited to the summer months. On the other hand, it resulted in a slightly higher net peak load reduction on the distribution circuit when compared with Scenario 1.

Scenario 3 led to a 10 percent reduction in net annual peak load and provided bill savings in the same range as Scenario 1, proving that the "stacked benefit analysis" is more effective for a residential distribution circuit than a circuit serving different types of customers (residential, commercial, and industrial).

Integrating Solar and Storage with Smart Inverters and Mini DC Grids

The standard mode of distributing electricity to customers today is AC power. This is primarily a legacy of 20th century technology. Before the advent of modern solid-state power electronics, the only way to step voltage up and down was through transformers, which require AC.

Recent advances in technology are stimulating reconsideration of this for several reasons:

1. Distributed power generation is primarily via PV, which is DC.
2. Energy storage using batteries is DC.
3. Re-connecting DC loads to a distribution system would at first appear simpler in DC than it is in AC, since there is no need for re-synchronization and phase matching.
4. DC power may have the potential to reduce distribution losses by reducing the number of conversions between generation and use.

Until recently, DC power was limited to remote off-grid installations, boats, or campers. As a result of the potential advantages offered by modern solid-state power conversion, there is a growing interest in using DC to power entire buildings or even entire distribution grids, sometimes as residential microgrids. Recent examples of this trend include the recently approved "Block Energy System" (BES) by Emera Technologies, which will provide up to 37 homes with power in the Hillsborough County housing development, Medley at Southshore Bay, within TECO's service area.

Installing DC systems such as the BES is hindered, to some extent, by the limited availability of native-DC appliances of all sizes, from watts to kilowatts. In a modern home, most small loads are inherently low-voltage DC. This DC power is provided by converting single-phase AC to DC via a step-down transformer, a rectifier, and often a buck converter. Increasingly, even appliances that require high power are becoming native DC appliances, for example:

1. Heat pumps: single-speed AC induction motors that drive the compressor and fans are being replaced by variable speed electronically commutated DC motors.
2. Dryers and water heaters: Resistance elements are being replaced by heat pumps, which can be powered by high-efficiency electronically commutated DC motors.

In the context of a DC distribution system or microgrid, with on-site PV generation and BESS, it therefore makes sense to consider DC appliances for two reasons:

1. To improve the conversion efficiency, by eliminating some of the AC-DC conversion steps
2. To decrease costs by reducing the size of the inverter needed to power individual end loads.

Consider, for example, the case of a heat pump, one of the largest, if not the largest load on a residential system, in the context of a grid-tied building with PV generation and battery storage capable of islanding. To drive a modern variable capacity heat pump, power from the PV array must proceed through the following steps:

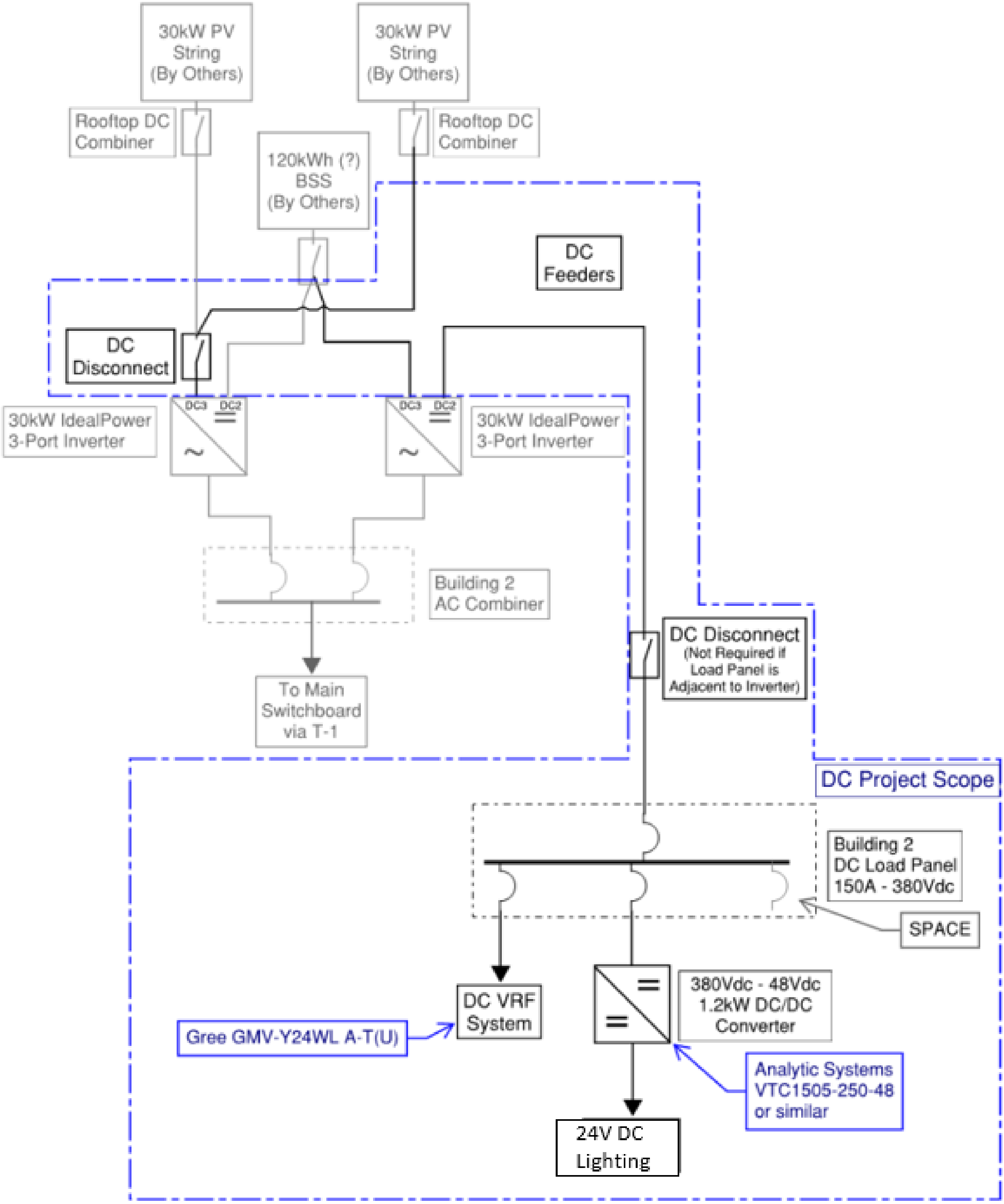
1. DC-DC conversion from maximum power point tracking voltage to battery charge control voltage
2. DC-AC conversion via the inverter to match grid power
3. AC-DC conversion from grid voltage and frequency to DC bus of the heat pump inverter
4. DC to commutated AC as needed to drive the compressor and fan motor

In contrast, if a DC-native heat pump were to be connected to the same DC bus as the battery, conversion steps 2 and 3 could be eliminated. In the case of an islanding building (for example, a resilient building microgrid), the required rating of the building inverter could be reduced by an amount equal to the rated power of the heat pump. This could be substantial since the heat pump is usually the largest single load in the building.

Project Scope

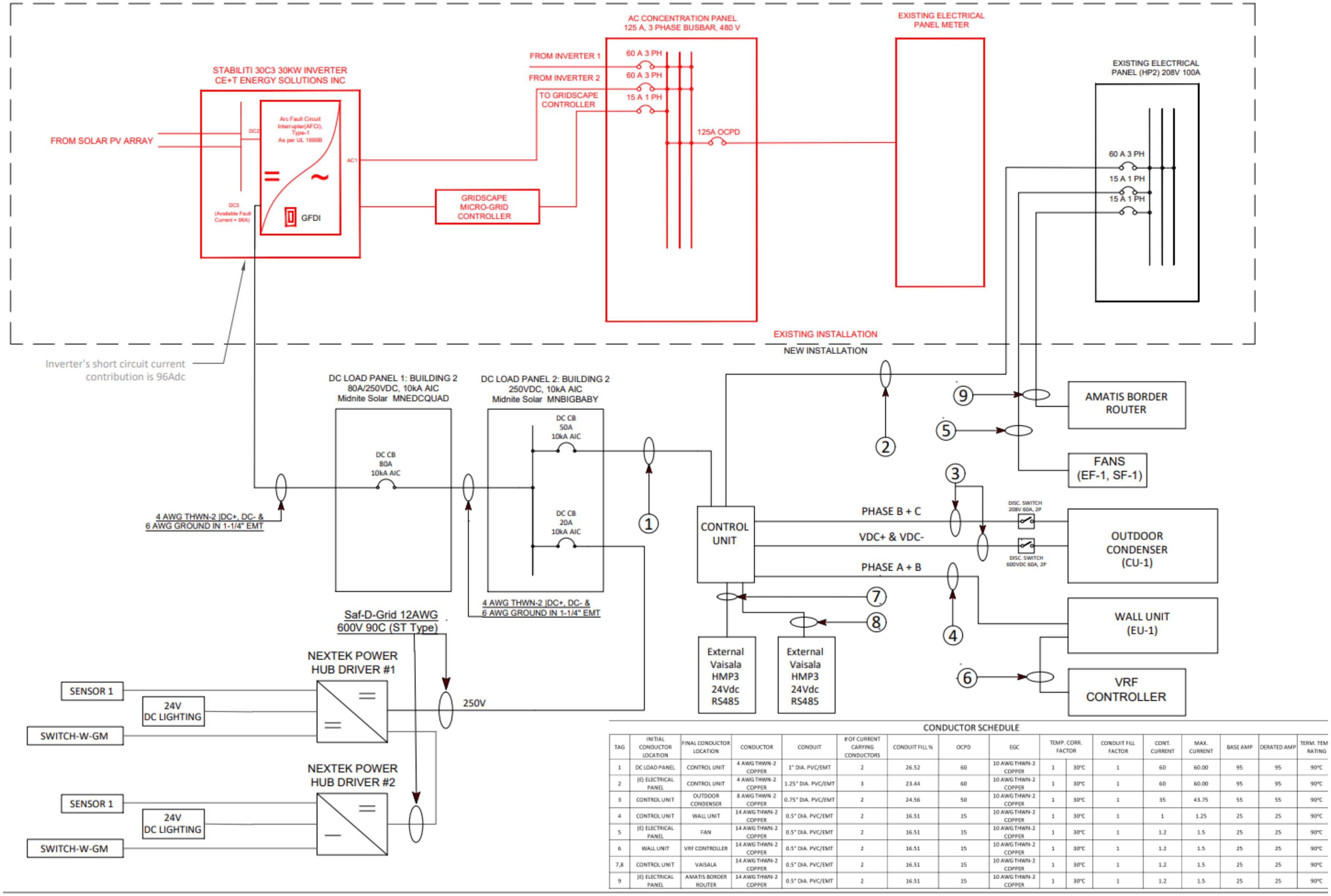
The goal of the DC distribution and appliance demonstration at Willowbrook was to test the avoided conversion losses associated reductions in inverter capacity and cost by using DC power direct from the solar + BESS to feed common area 24VDC lighting and a DC-enabled 4-ton VRF. The DC demonstration single line diagram and detailed design drawing is depicted in Figure 89 and Figure 90, respectively.

Figure 89: DC Distribution and Appliance Demo Schematic



Source: EPRI

Figure 90: DC Distribution and Appliance Demo Detailed Design Drawing



CONDUCTOR SCHEDULE

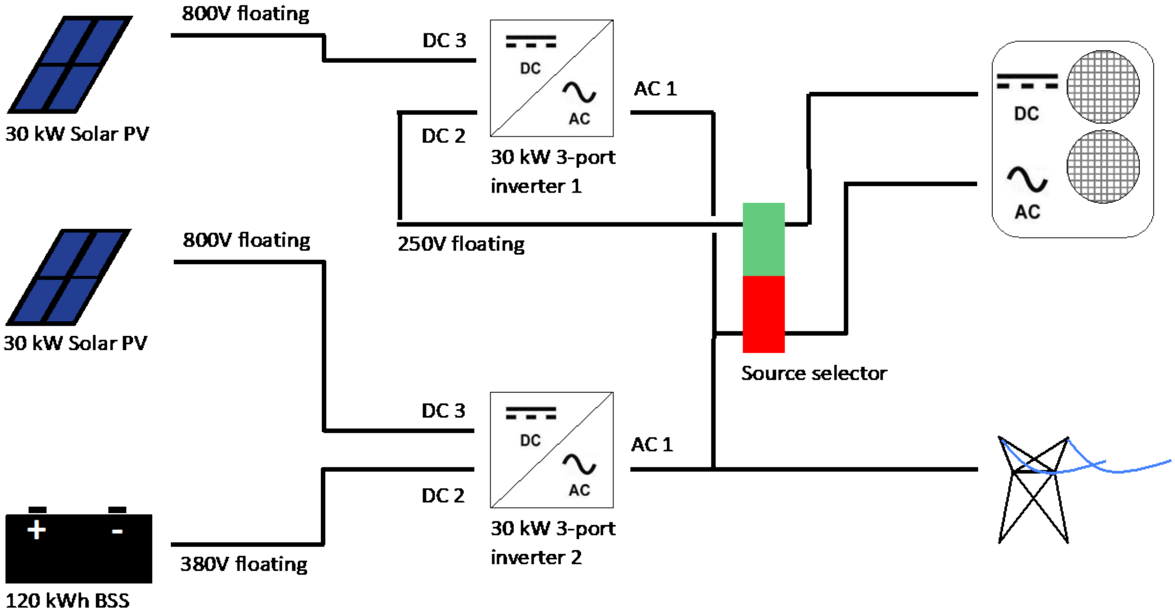
TAG	INITIAL CONDUCTOR LOCATION	FINAL CONDUCTOR LOCATION	CONDUCTOR	CONDUIT	# OF CURRENT CARYING CONDUCTORS	CONDUIT FILL %	OCPD	EGC	TEMP. CORR. FACTOR		CONDUIT FILL FACTOR	CONT. CURRENT	MAX. CURRENT	BASE AMP	DERATED AMP	TERM. TEM RATING
1	DC LOAD PANEL	CONTROL UNIT	4 AWG THWN-2 COPPER	1" DIA. PVC/EMT	2	26.52	60	10 AWG THWN-2 COPPER	1	30°C	1	60	60.00	95	95	90°C
2	(E) ELECTRICAL PANEL	CONTROL UNIT	4 AWG THWN-2 COPPER	1.25" DIA. PVC/EMT	3	23.44	60	10 AWG THWN-2 COPPER	1	30°C	1	60	60.00	95	95	90°C
3	CONTROL UNIT	OUTDOOR CONDENSER	8 AWG THWN-2 COPPER	0.75" DIA. PVC/EMT	2	24.56	50	10 AWG THWN-2 COPPER	1	30°C	1	35	43.75	55	55	90°C
4	CONTROL UNIT	WALL UNIT	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1	1.25	25	25	90°C
5	(E) ELECTRICAL PANEL	FAN	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
6	WALL UNIT	VRF CONTROLLER	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
7,8	CONTROL UNIT	VAISALA	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
9	(E) ELECTRICAL PANEL	AMATIS BORDER ROUTER	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C

Source: Staten Solar

Variable Refrigerant Flow Unit

The experimental setup was based on a 4-ton Gree GMV-Y48WL/A-T(U) VRF outdoor unit, with an associated indoor unit. The GMV-Y48WL/A-T(U) unit is capable of working with either AC power (208/240 V, 1 phase, 60 Hz), or with a DC power supply (100 to 400 VDC). An automatic transfer switch was designed to transfer power to the outdoor unit either via the DC bus of the CET-30 inverter or the AC bus, as illustrated in Figure 91.

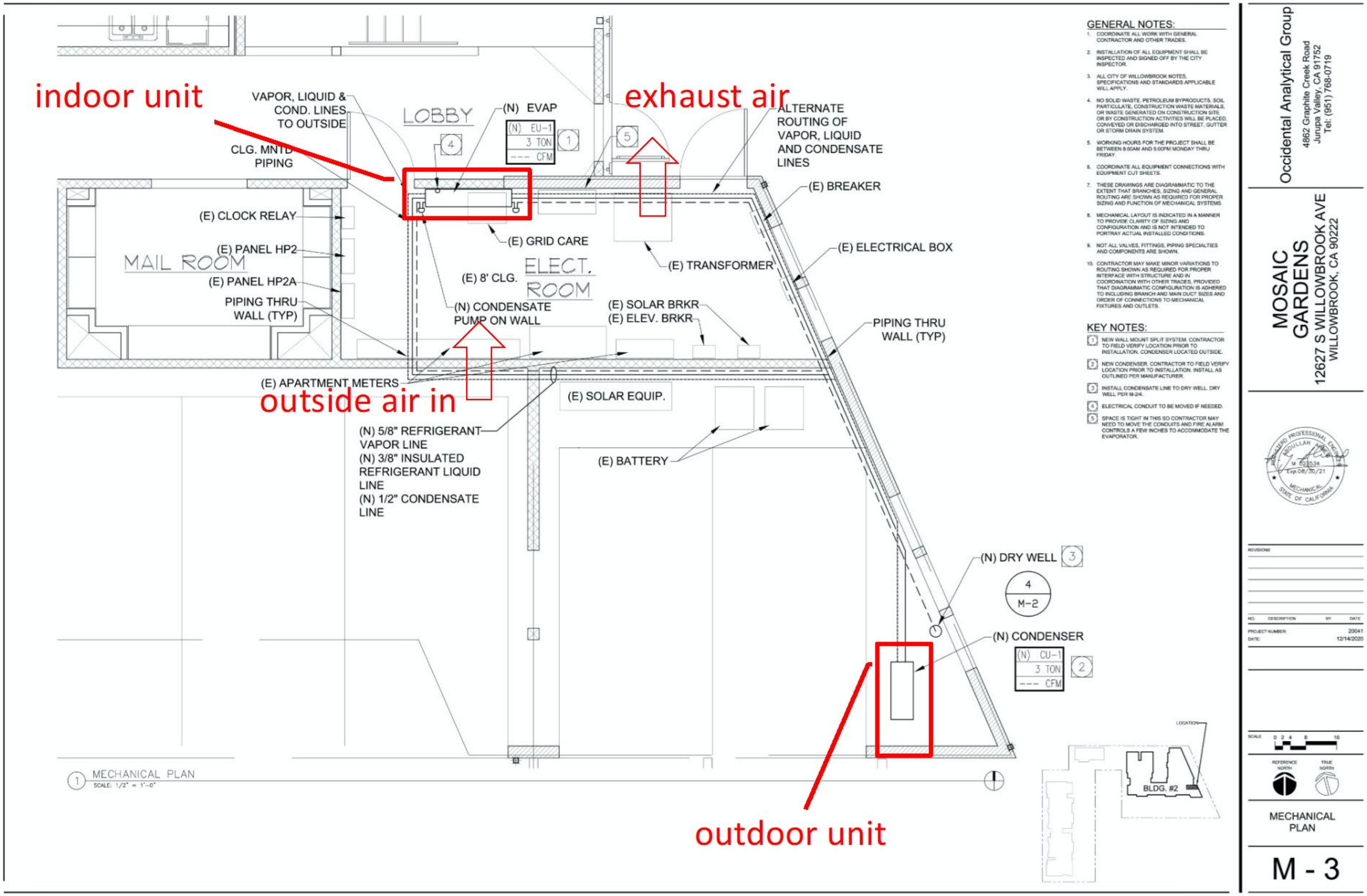
Figure 91: Test Setup for DC-Powered VRF Unit



Source: EPRI

The rationale for using this experimental setup was to understand to what extent the native DC power supply can improve efficiency compared to the AC power supply. Specifically, the monitoring instrumentation provides measurement of the power upstream of the inverter (coming from PV or battery), and power downstream of the inverted, either in DC or AC mode. This would allow the determination of conversion losses in either mode. The instrumentation also would allow the measurement of efficiency inside the VRF unit itself, which in DC mode bypasses the AC-DC rectifier stage. In addition to power measurements, the tests plan also includes thermal performance monitoring of the VRF unit, by measuring indoor unit flow rate, return temperature and relative humidity and supply temperature and relative humidity. The thermal load is provided by introducing outside air, via two fans, at a controlled rate into the test space, which is the electrical room that serves Building 2. For example, cooling load will be simulated, in the warm season, by introducing warm outside air at a rate comparable to the volumetric capacity of the indoor unit fan. By varying the amount of outside air changes, it is possible to simulate an arbitrary load profile to match the rated cooling capacity of the system. Similarly, heating loads can be simulated in the winter by introducing cold outside air. The layout of the experimental apparatus is shown in Figure 92. Note that exhaust air vanes were installed at a location diametrically opposite to the ventilation fans.

Figure 92: Layout of Components to Measure Performance of the DC VRF HVAC Unit



GENERAL NOTES:

1. COORDINATE ALL WORK WITH GENERAL CONTRACTOR AND OTHER TRADES.
2. INSTALLATION OF ALL EQUIPMENT SHALL BE INSPECTED AND SIGNED OFF BY THE CITY INSPECTOR.
3. ALL CITY OF WILLOWBROOK NOTES, SPECIFICATIONS AND STANDARDS APPLICABLE WILL APPLY.
4. NO SOLID WASTE, PETROLEUM BYPRODUCTS, SOIL PARTICULATE, CONSTRUCTION WASTE MATERIALS, OR WASTE GENERATED ON CONSTRUCTION SITE OR BY CONSTRUCTION ACTIVITIES WILL BE PLACED, CONVEYED OR DISCHARGED INTO STREET, GUTTER OR STORM DRAIN SYSTEM.
5. WORKING HOURS FOR THE PROJECT SHALL BE BETWEEN 8:00AM AND 5:00PM MONDAY THRU FRIDAY.
6. COORDINATE ALL EQUIPMENT CONNECTIONS WITH EQUIPMENT CUT SHEETS.
7. THESE DRAWINGS ARE DIAGRAMMATIC TO THE EXTENT THAT BRANCHES, SIZING AND GENERAL ROUTING ARE SHOWN AS REQUIRED FOR PROPER SIZING AND FUNCTION OF MECHANICAL SYSTEMS.
8. MECHANICAL LAYOUT IS INDICATED IN A MANNER TO PROVIDE CLARITY OF SIZING AND CONFIGURATION AND IS NOT INTENDED TO PORTRAY ACTUAL INSTALLED CONDITIONS.
9. NOT ALL VALVES, FITTINGS, PIPING SPECIALTIES AND COMPONENTS ARE SHOWN.
10. CONTRACTOR MAY MAKE MINOR VARIATIONS TO ROUTING SHOWN AS REQUIRED FOR PROPER INTERFACE WITH STRUCTURE AND IN COORDINATION WITH OTHER TRADES, PROVIDED THAT DIAGRAMMATIC CONFIGURATION IS ADHERED TO INCLUDING BRANCH AND MAIN DUCT SIZES AND ORDER OF CONNECTIONS TO MECHANICAL FIXTURES AND OUTLETS.

KEY NOTES:

1 NEW WALL MOUNT SPLIT SYSTEM. CONTRACTOR TO FIELD VERIFY LOCATION PRIOR TO INSTALLATION. CONDENSER LOCATED OUTSIDE.
2 NEW CONDENSER. CONTRACTOR TO FIELD VERIFY LOCATION PRIOR TO INSTALLATION. INSTALL AS OUTLINED PER MANUFACTURER.
3 INSTALL CONDENSATE LINE TO DRY WELL. DRY WELL PER M-2/4.
4 ELECTRICAL CONDUIT TO BE MOVED IF NEEDED.
5 SPACE IS TIGHT IN THIS SO CONTRACTOR MAY NEED TO MOVE THE CONDUITS AND FIRE ALARM CONTROLS A FEW INCHES TO ACCOMMODATE THE EVAPORATOR.

M 023534
Exp. 06/30/21

Source: EPRI

The original test plan included the following experiments:

- Determining the volumetric capacity of the ventilation fans
- Determining the volumetric capacity of the indoor unit fan as a function of fan current
- Measuring power to the outdoor unit as a function of load at various stages (upstream and downstream of inverter) in DC and AC modes.
- Measuring the thermal performance of the unit (COP) as a function of load and, if possible, temperature lift.

These experiments and their outcomes are described in the following section.

Ventilation Fan Capacity

Ventilation to the Building 2 (Willowbrook site) electrical room is provided by two centrifugal fans, operating in parallel. Both fans can be controlled remotely. One of the fans can be turned on and off, while the other can be operated in variable speed mode. By using the variable speed fan only, a ventilation rate between 0 percent and approximately 50 percent can be obtained. By operating both fans, ventilation between approximately 50 percent and 100 percent of full capacity can be obtained. To calibrate the ventilation rate as a function of fan setting, a temporary hood was installed around the fans that could channel the air flow to a TSI flow capture hood for measurement. The temporary flow hood and the measurement flow hood during measurement are shown in Figure 93.

Figure 93: Hood to Convey Air Flow to Flow Measurement Device (Left), and TSI Volumetric Flow Measurement Device in Use (Right)

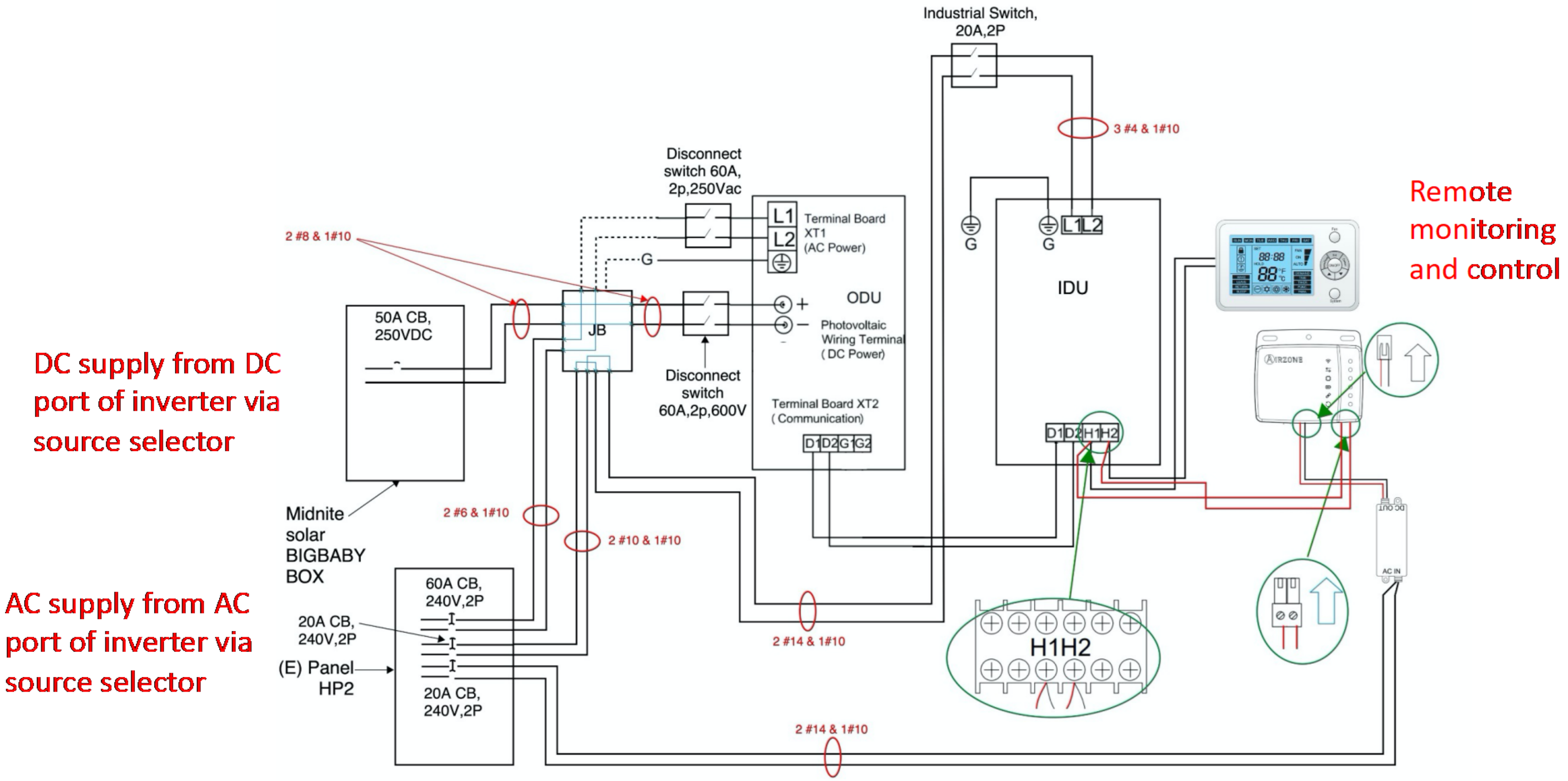
Source: EPRI

The results of the calibration experiments on November 8, 2021, are shown in Figure 88. Based on these results, air flow can be estimated accurately as a function of fan settings using the equation: $\dot{\boldsymbol{V}} = \mathbf{8.64}\boldsymbol{S}$ where $\boldsymbol{S}$ is the combined speed setting and $\dot{\boldsymbol{V}}$ is the volumetric flow rate in cfm. The thermal load is the combined sensible load and latent load, which is a function of the temperature and relative humidity of the outdoor and indoor air, and both can be measured. As an example, for outdoor temperature of 90 degrees Fahrenheit and relative humidity of 65 percent, and with an indoor air setpoint of 68 degrees Fahrenheit with relative humidity of 55 percent, the combined load of 3 tons of refrigeration is achieved with a ventilation flow rate of 430 cfm, well within the range of the ventilation fans.

Power Measurement to Indoor and Outdoor Units

This measurement is obtained by using the AC and DC current transducers located in the 30C3 power converter, in the source selector, and in the AC panel, as shown in Figure 94.

Figure 94: Configuration of Electrical Measurement Devices



DC supply from DC port of inverter via source selector

AC supply from AC port of inverter via source selector

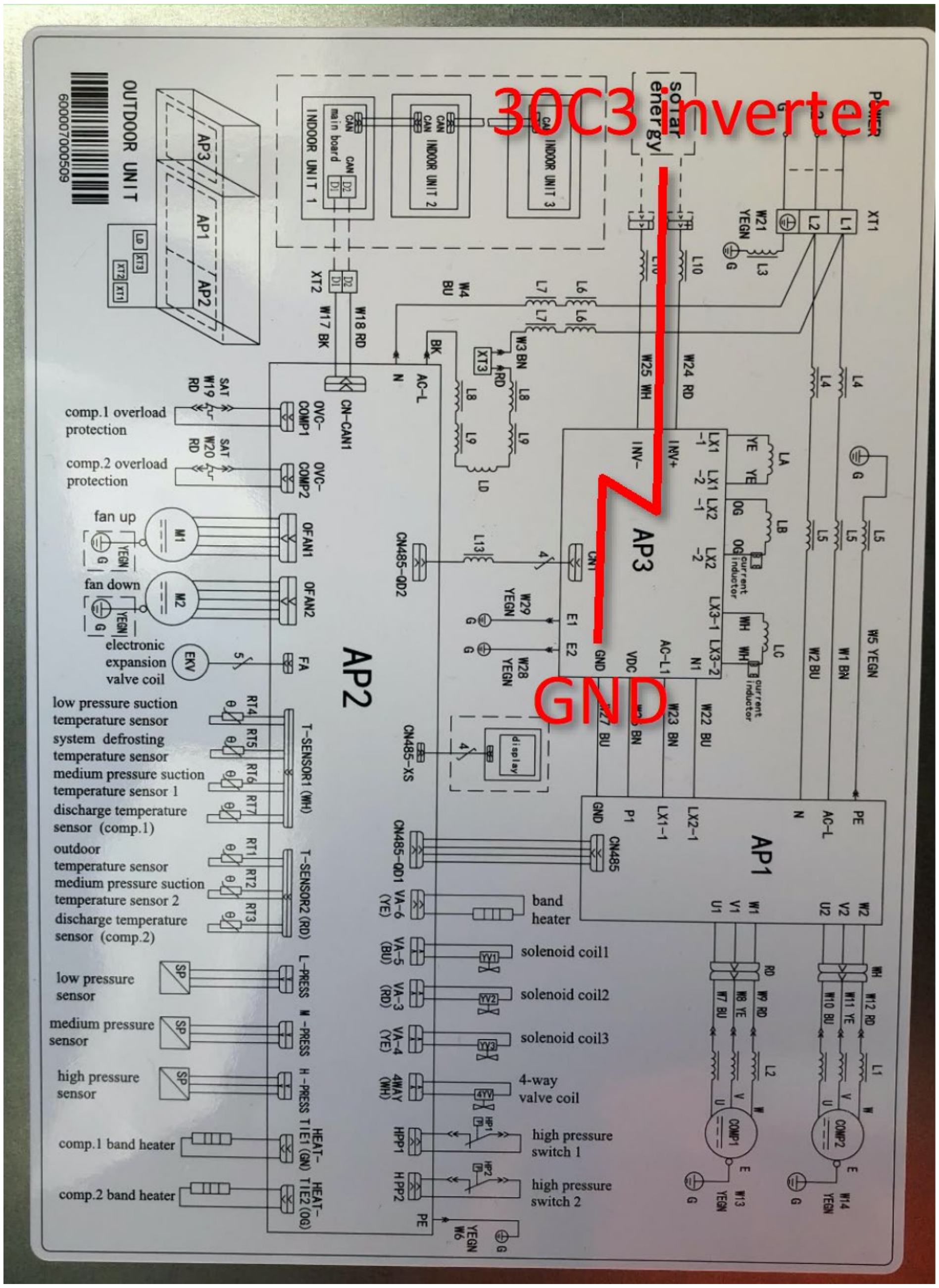
Remote monitoring and control

Source: EPRI

Events During Testing on November 9, 2021

While calibrating the ventilation fans, before the planned measurement of the indoor unit fan volumetric capacity, a fault message appeared on the HVAC status display, indicating a "C2 – communication error between master control and inverter compressor drive." After several attempts at restarting the system failed, and after ruling out a refrigerant leak, it was determined that one of the control boards in the outdoor unit had suffered a catastrophic failure. Specifically, it was determined that the DC board AP3 had failed. The likely cause of damage was the floating DC voltage from the inverter shorting to ground, as indicated in Figure 95.

Figure 95: Ground Short Current Path That Led to the Failure of Board AP3



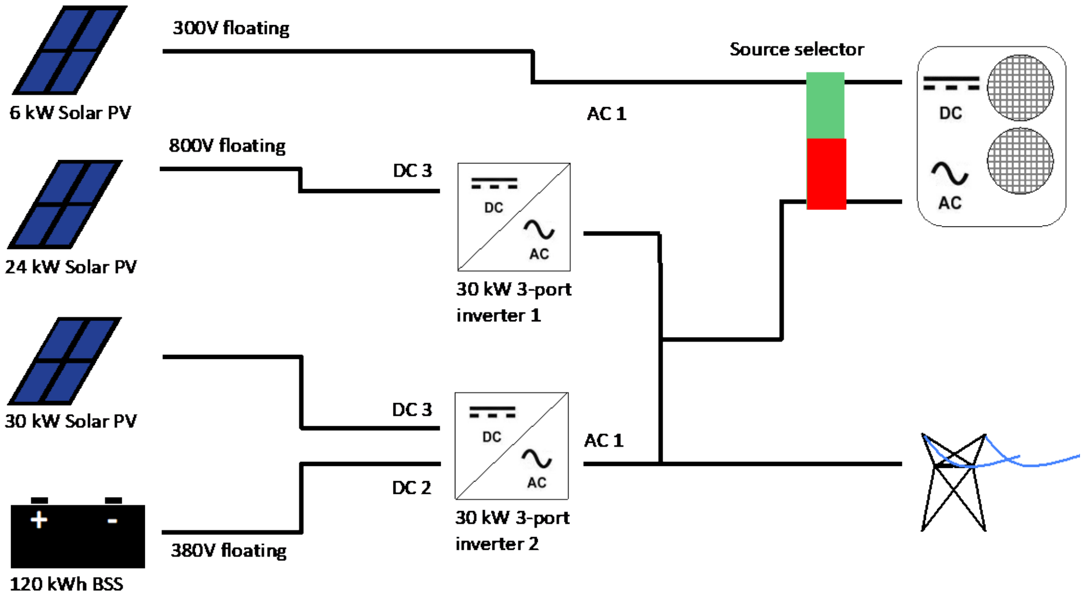
Source: EPRI

Unfortunately, the initial understanding that the outdoor unit could operate in DC floating mode was incorrect, and detailed inspection of the circuit diagrams indicated that there is always a path from the DC supply to the grid. So, the initial design of the system had to be reconsidered. The major implication was that it is not possible to operate the existing hardware in the configuration originally intended, namely using the DC bus of the 30C3 power converter as a source of DC power to the HVAC unit.

Alternative System Configuration

While the intended configuration of the system is not currently feasible, it is still possible to obtain performance measurements of the HVAC unit in native DC vs. AC, with a small system reconfiguration, as shown in Figure 96.

Figure 96: System Reconfiguration with HVAC DC Supply Sourced Directly from a Subsection of the PV Array



Source: EPRI

In this reconfiguration, a subsection of the PV array is isolated and connected directly to the HVAC unit. After substitution of the AP3 board, the system was reconfigured, and its correct operation was verified on November 30, 2021. Volumetric flow and thermal testing of the system was carried out in early December 2021. Compared to the original testing plan, the downside was that it will not be possible to determine the DC/DC conversion efficiency of the 30C3 power converter.

Measuring Thermal Performance on December 7, 2021

The coefficient of performance is the ratio of thermal capacity $\dot{Q}$ of the system to electrical input. Measurement is from

$$\dot{Q} = \dot{V}\rho(h_{supply} - h_{return})$$

where ρ is the air density and the specific enthalpy h is a function of the measured temperature and relative humidity. These, in turn, are measured using Vaisala temperature and relative humidity sensors located at the return and supply sides of the indoor unit, as shown in Figure 97.

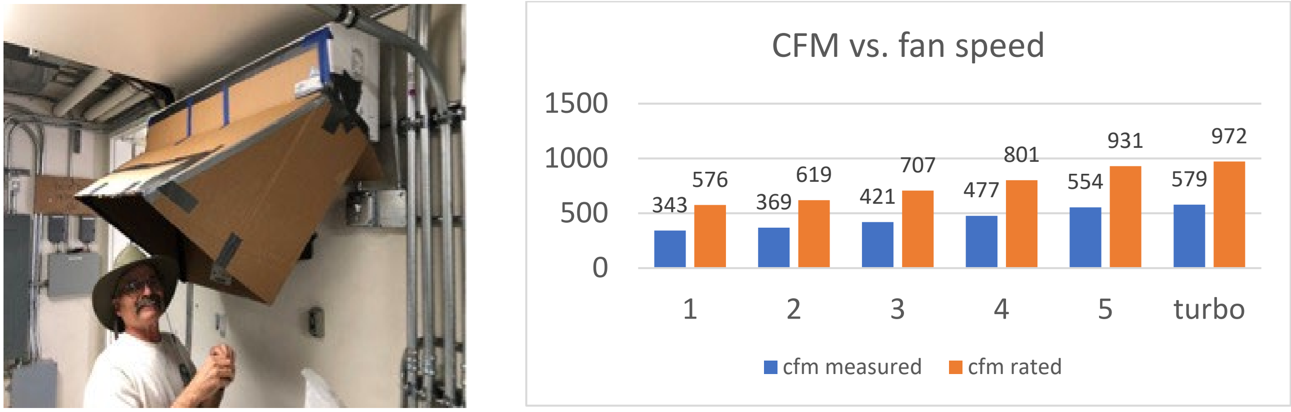
Figure 97: Location of Vaisala T/RH Sensors

Source: EPRI

Volumetric Capacity of the Indoor Unit Fan

The procedure for determining the indoor unit fan ventilation capacity was similar to that used for the ventilation fan capacity. A temporary cardboard hood was installed on the indoor unit to convey supply air to the TSI flow measurement hood, as illustrated in Figure 98.

Figure 98: Determining the Indoor Unit Fan



Adaptor to convey air flow from indoor unit supply to TSI volumetric flow measurement device (left) and flow rate as a function of fan speed setting (right).

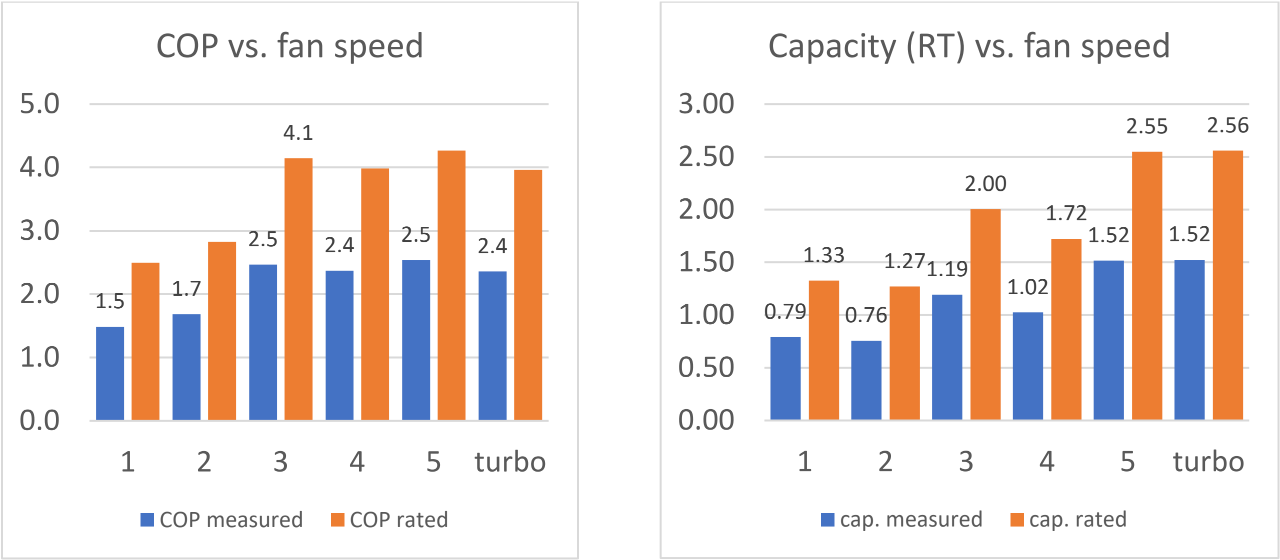
Source: EPRI

Following the reconfiguration of the system, a series of measurements to determine volumetric flow rate through the indoor unit as a function of fan speed setting were conducted using the flow hood. The measured flow rates were substantially smaller than the rated flow, likely owing to the known sensitivity of ductless unit fans to pressure drop. As a result, "rated" flow rates are also shown. The maximum flow rate for the "turbo" setting according to the manufacturer is 972 cfm. Values for other fan speed settings are obtained by scaling the rated maximum value with the ratio of measured volumetric flow rate for the speed setting to maximum measured flow rate.

Thermodynamic Performance

In a typical situation, controlling the temperature of the zone while matching the heating or cooling load for the zone is done by varying the fan speed setting. Thus, to understand how the system performs under typical conditions, a series of tests was carried out to determine performance at various fan speed settings. For each fan speed setting, a 15-minute-long test was performed, recording AC power, supply temperature and relative humidity, and return temperature and relative humidity. The performance of the system at each speed setting was then calculated using the equation for thermal capacity $\dot{Q}$ and the measured power. The outcome of the tests is shown in Figure 99.

Figure 99: System Thermal Capacity vs Fan Speed Setting (Left) and System COP vs Fan Speed Setting (Right)



Source: EPRI

Some general observations can be made from these results:

1. "Measured" performance is lower than "rated" performance. Which is the true one? Probably somewhere in the middle. While the rated performance in obtained under ideal lab conditions, the measured performance is likely sub-optimal: the wall unit is mounted too close to the ceiling, owing to space constraints, restricting air flow to the return side of the unit, while the flow hood adds a static pressure drop on the supply side.
2. Performance is non-monotonic, contrary to the expectation that capacity should increase monotonically with air flow. This is likely a consequence of minute-scale "noise" of the variable capacity unit, which probably seeks to maintain a given air temperature in the face of changing room temperature and step changes in fan speed.
3. Overall, the performance of the system is consistent with that of a modern, high performance variable capacity unit. Ultimately, the goal of this subsection of the project was to evaluate performance in AC mode versus performance in DC mode. Owing to supply-chain issues, namely the unavailability of the source selector and associated metering, we were unable to make this comparison, yet. However, based

on these preliminary results, the team learned that it is not realistic to expect such performance comparisons from a series of short tests. Rather, testing should be a long-term proposition, on the order of several days or even weeks. A likely scenario that would lead a robust comparison of DC versus AC performance would be to run tests on alternate days, with AC power supply alternating with DC power supply, for a period of at least a month in the summer and a month in the winter.

Lessons Learned Towards a Practical System Implementation

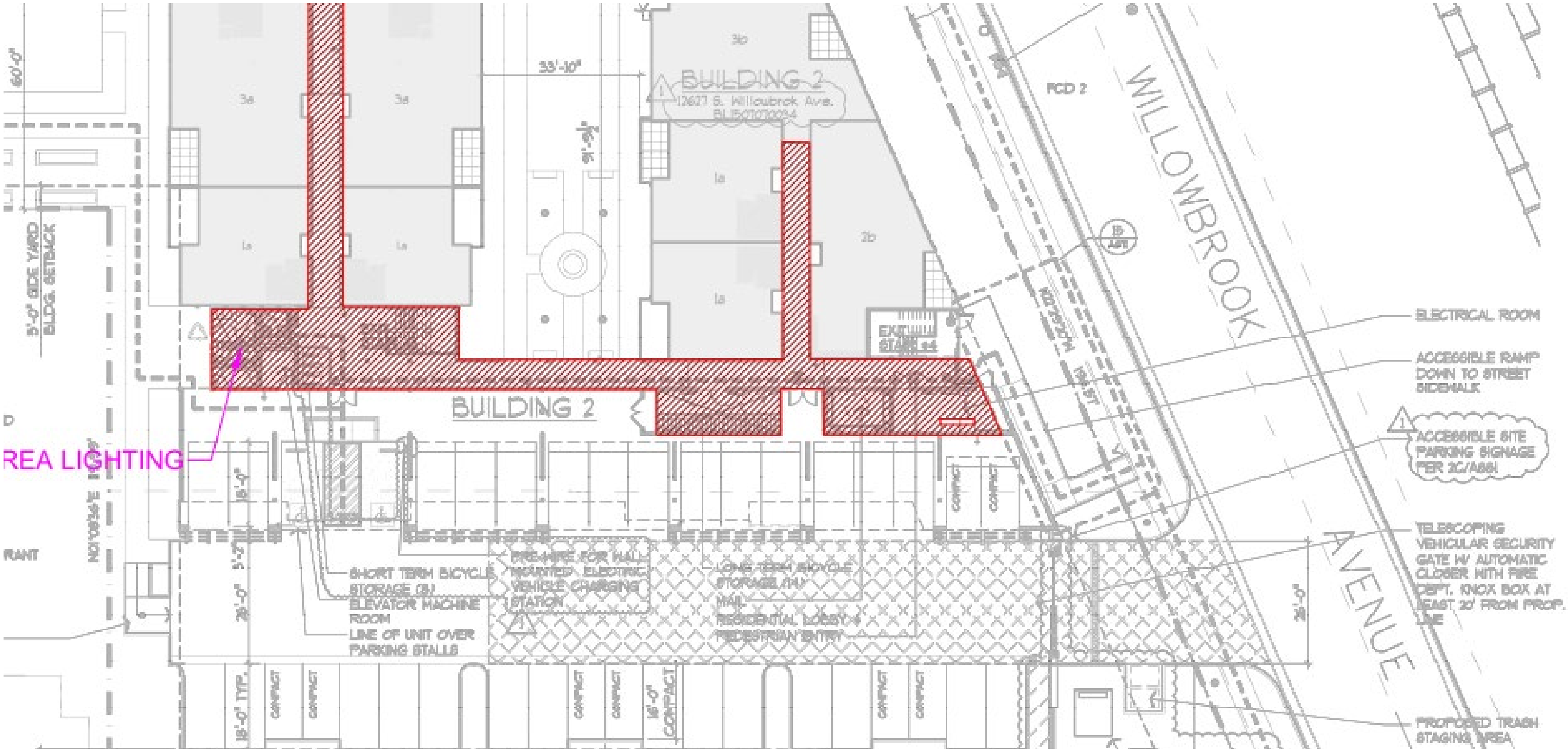
This exercise provided valuable insights into the design process of hybrid AC/DC resilient systems. The primary lesson is that design of these systems is more complex than it appears. Some of the components are incompatible, although manufacturer interest in such systems may resolve some issues in the near future. Some of the components are hard to find – for example, high-voltage DC breakers. While it was not possible to measure DC/DC conversion efficiency of the 30C3 power converter, keeping the system "all-DC" may not result in the expected efficiency gains. Finally, full integration may require some design changes that allow for integration, for example enabling the PV MPPT controller to work in parallel with the battery charge controller. However, this would require both cooperation between manufacturers and standardization.

Lighting

As part of the lighting scope, the project team installed supplemental DC lighting in the common area corridors of Building 2, as depicted in red in Figure 100.

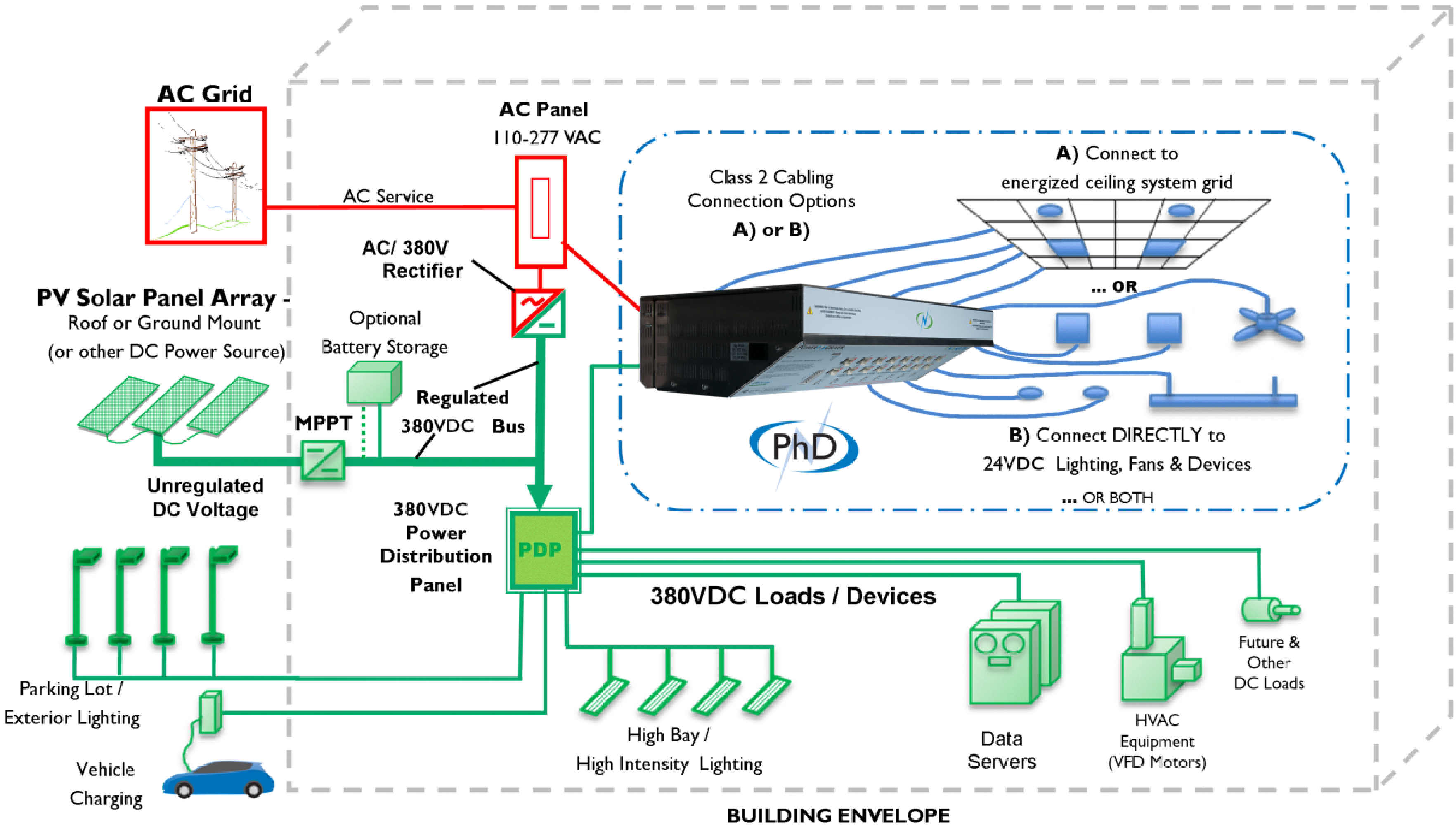
The lighting system components consisted primarily of two 16-channel Nextek power hub drivers, 24VDC Lamar lighting fixtures and Sky (also known as Amatis) bridge sensors and switches. As depicted in the manufacturer Nextek's diagram in Figure 101, the power hub driver converts 380VDC power to 24VDC through 16 individual Class 2 outputs. The power hub driver has a wireless remote control and monitoring system and features a low-voltage DC distribution system for plugging in DC lighting.

Figure 100: DC Lighting Deployment Area



Source: Staten Solar

Figure 101: Power Hub Schematic Diagram



Source: Nextek

The Power Hub Driver (referred to as Power Source Hub in Figure 102, a Nextek-supplied graphic depicting the configuration in use at the Willowbrook project) is interconnected with the Sky (Amatis) bridge, sensors, and switches through a wireless mesh network.

Figure 102: Lighting System Components

Source: Nextek

The Sky border router is connected to the ethernet so that the network is also available online and can be monitored through a phone application and web-based monitoring platform (the monitoring platform keeps the network's programming stored in a cloud). Since all the devices are interconnected wirelessly, when a sensor detects anything, it is communicated to all the devices. The Sky border router functions as the master device. Informed by the switches and sensors and their programming, the Power Hub driver dims the light fixtures or turns them on or off.

Test Plan:

- DC distribution and appliance energy use baseline is measured against a traditional AC distribution and appliance baseline.
- In addition, because the Sky (Amatis) sensors and switches did not carry UL listings, a UL 2108 Low Voltage Lighting System field evaluation will be carried out on site by National Research Lab TUV Rheinland.

As compared to the pre-existing LED AC lighting fixtures, which were already quite efficient at 49/42W 5500 lumens, the replacement 24W 2600 lumens DC light fixtures resulted in a 3.6 percent efficiency gain in terms of lumens per watt. Additional consumption reduction would be possible by reducing lumens per watt through dimming controls and occupancy sensors. However, building codes in general and Title 24 California code require a minimum level of lumens per square foot and occupancy sensors. DC light fixtures are sometimes available in smaller individual fixture wattage; smaller fixtures enable a designer to right size the lighting to achieve the required level of lumens without overshooting.

Controls such as dimmers and occupancy sensors compatible with DC lighting are not readily available. EPRI and project partners worked to establish a functional and code-compliant lighting control system by commissioning TUV to provide a field evaluation under applicable UL criteria. Using these controls, EPRI worked with the site host and vendors to establish a dusk-to-dawn schedule with occupancy sensors, according to the following schedule:

- 5 p.m. to 7 a.m. (dusk until dawn)
- Control strategies: occupancy sensors and wall switches
- 8 p.m. to 6 p.m.: lighting turns off automatically 5 minutes after last occupancy is detected.
- 6 p.m. to 8 p.m. and 6 p.m. to 8 p.m.: AM lighting is on during occupancy and turns off 10 minutes after last occupancy is detected.

Lighting circuits often involve long cables to provide adequate coverage over rooms, hallways, and outdoor spaces. Because of this, cable losses can be considerable. DC lighting often uses low voltage for safety and ease of installation. However, losses are relatively higher when low voltages are used. Losses in a circuit can be considered to be equivalent to I^2R, which means that for the same wattage, a circuit using lower voltage necessarily carries a higher current and subject to additional loss.

For example, 24VDC lighting of the same wattage and using the same length and size of cable as a 120VAC would be subject to 5 times the ampacity and therefore 5 times the cable losses. Cabling losses can be mitigated by using larger cable, which adds cost, or by using higher voltages. A few lighting vendors such as GVA lighting offer specialty architectural lighting products that operate on 380VDC, which can reduce cabling losses when compared to 120VAC lighting circuits. Currently 380VDC lighting products are primarily for specialty architectural and display applications and are not readily available for indoor residential applications such as Willowbrook. Cable losses in the Willowbrook project are mitigated by using a 250VDC lighting driver that is located as close as possible to the light fixes themselves, which are 24VDC.

The primary opportunities identified during this lighting implementation are the need to explore expanding availability of 380VDC (or higher) voltage DC lighting for optimal efficiency, as well as the need to establish availability of UL-listed DC lighting controls.

Chapter 5:
Advancing the Research to Market

Technical and Market Barriers

Direct Current Coupling

The major technical and market barriers concerned the DC-coupled systems, which are discussed in greater detail in this section. Other barriers and lessons learned will be covered in the Lessons Learned section.

Summary

Conversion losses are typically encountered in any system where DC sources and AC loads are present. Where solar PV and energy storage are present, using AC-coupled systems can require that energy be converted three or more times before either use or export. Many types of appliances or equipment convert AC back to DC internally before using local solar generation, as well. As any conversion causes losses, reducing, or eliminating excess conversion steps would improve efficiency.

DC use has long been considered as a path to increase the efficiency of electrical systems where native DC sources such as solar PV are present. Solar modules produce DC power and batteries operate on DC, so the premise is that optimal efficiency could be achieved if DC energy from solar or other renewable sources could be used and stored without conversion to AC. Conceptually, the reduction of power conversion steps and the associated equipment could substantially improve efficiency. While using DC is technically feasible, several technical barriers do exist to reducing conversion steps and increasing efficiency.

These barriers are listed and described in more detail:

1. Bridging varying voltage requirements from multiple appliances requires conversion, reducing system efficiency.
2. Lack of DC-compatible devices and experienced designers and installers
3. Use of proprietary low-volume hardware, creating future servicing and replacement risks
4. Codes and standards placing limits on DC voltages and hence DC use opportunities
5. Potential for unintended consequences from DC coupling of converters with different voltages (such as noise, ripple, negative impedance instability)
6. Beneficial DC coupling approaches for interconnection as it limits total connected kW

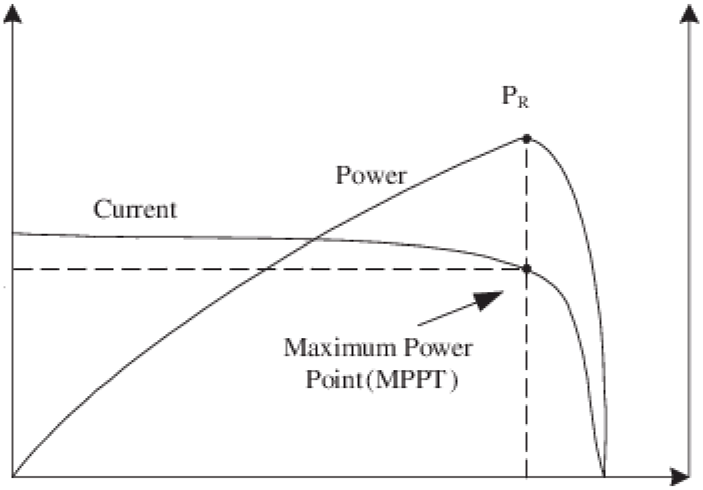
Voltage Mismatch

Voltage mismatch is the root cause for the proliferation of power conversion equipment. Internal voltage requirements for various equipment–from cord-and-plug appliances to luminaires to EV chargers–vary widely. For example, LED lighting internally converts AC input to single digit voltages while electric vehicle supply equipment and circuitry internal to vehicles convert AC input to several hundred volts DC. Computers have several separate internal DC bus voltages. Commercially available solar PV systems typically operate from 300 to 1500VDC and convert that to AC. Many appliances are dependent on induction motors, which require AC power to operate though inverters. VFDs are also becoming more popular, which can conceptually operate on DC input. Several valid engineering reasons exist for the various voltages employed by equipment. Irrespective of the question of AC vs DC, there is limited technical feasibility for all end devices to operate on one single voltage.

One driving reason for higher power equipment to operate at higher voltages is efficiency. Loss in a circuit could be described by current squared times resistance. Where current is doubled, loss is quadrupled. All wire has a constant resistance per length, which varies depending on the cross-sectional area of the wire. Any specific gauge of wire can conduct a specific amperage and power is equal to volts times amps. Meaning that higher voltages enable more energy to pass through the same size cable or semiconductor, or that a higher voltage leads to greater efficiency.

A key function of PV inverters is maximum power point tracking (MPPT), depicted in Figure 103.

Figure 103: Characteristic Curve and Maximum Power Point of PV



Source: Chen Shaixun, Research Gate

MPPT manipulates voltage and current to find the maximum output of a PV array at any given time. If the maximum power voltage is not maintained, the output from the PV array can be less than optimal. Stand-alone charge controllers are available to provide MPPT functionality when DC coupling PV modules with batteries. Batteries also have specific voltage requirements, and manipulation of voltage is typically used to control charge and discharge rates as well as to prevent excursions beyond allowable states of charge. Batteries and PV arrays will require a conversion device that may be a DC converter or an inverter to allow safe and optimal interface with each other, use equipment, or the grid.

Because of the need for various voltages and because transformers do not work with DC power, DC:DC conversion becomes necessary to enable DC use. Like transformers or inverters, DC:DC converters are also not 100 percent efficient but, in some cases, may be higher efficiency than transformers and inverters. Hence, the need for a wide range of voltages for various devices.

Converter Versus Inverter Efficiency

Transformers, DC: DC converters, and inverters are all available with efficiency ratings in the high nineties. All devices will have varying efficiency at varying power levels, and all types have some element of no-load loss if energized. DC converters may still have some advantage over transformer or inverter efficiency. DC converters still involve conversion, which necessarily entails losses. DC converter efficiency is generally higher for lower voltage buck or boost ratios, meaning that efficiency is lower for less similar input and output voltages. Compared to AC use efficiency, DC use efficiency would largely depend on what load is being driven and at what voltage. Voltage and cable size are likely larger drivers of efficiency loss than either a conversion method or AC versus DC.

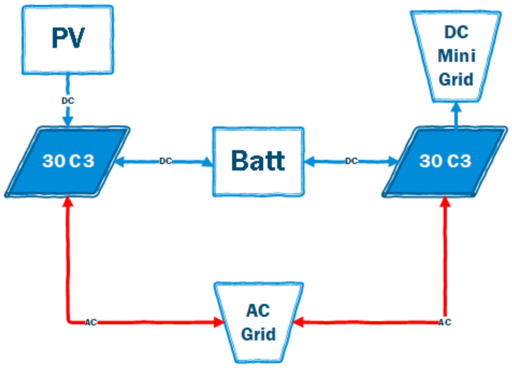
Hardware Availability

For systems employing PV, battery storage and DC loads such as Willowbrook, it may be desirable to have DC coupling between these systems in order to prevent excess conversion steps. To have PV, BESS and DC loads interfaced with an AC system, either several discrete converters or a multi-port product would be required. Princeton Power and CE+T converters, for example, have offered 4-port inverters in the past, but no longer produce them.

Some manufacturers are producing integrated DC-coupled PV and storage systems for residential use. Work is taking place to integrate load control with such productized residential systems, but it is not yet commonplace. For example, Lumin, which generally provides load control hardware, recently announced partnerships with storage providers. There are also large DC:DC converters available for utility-scale projects seeking to DC-couple PV and storage. In the space between utility-scale and single-family residential however, there are very few DC-coupled product offerings. Converters designed to serve multiple general-purpose DC loads are generally laboratory hardware designed and priced accordingly. Converters designed to provide DC distribution are not readily available.

CE+T is currently producing a 30kW three-port bidirectional inverter that is being used to DC couple PV and a battery for the Willowbrook project. This inverter is unique in the market because it is also capable of operating as a regulated power supply for DC loads on one port while being connected to a battery on the other port. Therefore, the Willowbrook project will use two CE+T 30 C3 3-port inverters to integrate PV, batteries, loads, and the grid, as shown in Figure 104. The operation of the two devices will be coordinated by Gridscape's EnergyScope software and metering.

Figure 104: Willowbrook Configuration



Source: EPRI

Available Appliances and Fixtures

Appliances and fixtures for operation on DC power are of low availability or specialty items, such as those made for recreational vehicle use. DC large appliances such as washers, dryers, refrigerators, and oven ranges are not readily available. DC small appliances such as toasters, microwaves, and televisions are similarly lacking. Low voltage DC lighting is readily available at several voltages up to 48VDC through a few suppliers. DC powered HVAC is becoming available that can use 380VDC, but its availability and selection are also lacking. Many types of appliances that use motors, such as refrigerators, are internally starting to use inverters to provide variable motor speeds for efficiency. The first step in such inverters is typically a rectifier that converts the incoming AC to DC for use by the inverter. Such appliances are not suitable or rated for DC input power as is, though internally they are using DC and very little would have to be done to make them suitable for DC input.

Several types of appliances and fixtures operate using shaded pole motors. For example, bathroom ventilation fans use these cheap yet reliable devices. Shaded pole motors cannot operate on DC. Many millions of shaded pole motors are in use in the US. Brushless DC substitutes are available but cost several times as much. Those labeled brushless DC typically rectify AC power to DC, so the technical leap to DC input is minimal though products configured for DC input do not appear to be readily available for residential use.

As described earlier in the Project Results section, Willowbrook is using a DC-enabled Gree VRF variable speed mini split heat pump that can work in 100-380VDC as well as in AC mode. Willowbrook is also deploying 48V DC lighting manufactured by Lamar.

Codes and Standards

Codes are one reason higher voltage DC lighting availability is poor. The NEC treats systems below 50V separately from systems above 50V, so there has historically been a bias towards DC lighting voltages below this point. NEC 210.6 permits lighting voltages over 120V but only up to 277V. 210.6 is referenced in NEC 690 where DC circuits from PV systems are contemplated. Other sections of the NEC and other building codes restrict the convenient use of higher DC voltages for general use. These restrictions do not line up with the most efficient operational voltages for PV and battery systems. Residential PV and battery systems may operate at up to 600V, and commonly operate around 380VDC for efficient conversion to 240VAC. DC PV circuits inside the home have been required to be encased in metallic conduit and conspicuously labeled, which is not conducive to cost-effective general distribution circuits. Restricting DC operational voltages for PV and batteries to 50V, 120V, or 277V would have a corresponding negative impact on efficiency and/or would require larger conductor sizing, which substantially increases installed pricing.

Since 1880 when Tesla and Edison were competing, there have been discussions about AC versus DC distribution. AC distribution has dominated primarily due to the ability to use transformers. Relatively recently, it has become possible to convert DC voltages. High VDC transmission lines are in operation today. DC distribution is conceptually technically feasible, but any effort to do so would have to overcome substantial industrial inertia and would require demonstration of a positive cost-benefit ratio.

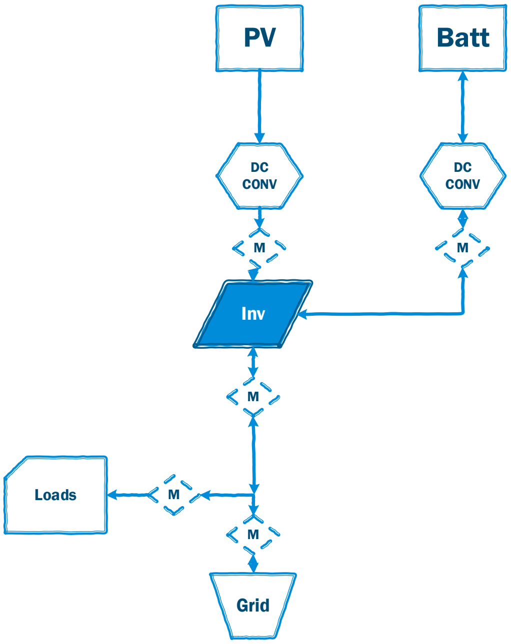
AC arcing behavior has been the subject of much study and is better understood from a safety perspective than DC arcing. Because DC lacks a zero crossing, DC arcing tends to exhibit less self-extinguishing properties when compared to AC arcing. Incident energy and fault current calculations can be more complex for DC systems, especially where multiple sources and converters are in use as with PV-plus storage systems. DC arc fault protection is available and required for some PV systems but may not be readily available for DC use. DC arc behavior, calculation methods, and protection best practices could all benefit from additional study, as well as code and standard development.

Metering and Tariff Compliance

DC metering is another technical and market issue. DC socket meters for utility metering are not available, and a NEMA C12 standard is in progress but did not exist previously. Current transformers used for AC metering do not yet work with DC, so shunts or transducers must be used. The lack of revenue-grade DC socket meters presently creates difficulty where DC coupled PV and storage systems exist in areas with net energy metering (NEM). To ensure NEM integrity, some utilities, including SCE in the case of Willowbrook, specify net generation output meters (NGOM) for qualifying resources such as PV. This is to ensure that customers do not charge the battery with grid power to provide rate arbitrage. In an AC-coupled system with separate inverters for batteries and PV, it is possible to use a standard form 2S socket meter.

To meter the PV output in a DC-coupled system, it would be necessary to install a DC meter, but such revenue grade DC socket meters do not exist. Further, if such a meter were available, it still would not fairly capture the actual qualified output of the PV due to conversion losses in converters and inverters. One potential resolution, which the SGIP considers for small systems, is to utilize integrated inverter metering and controls to assure NEM integrity. The recent *Underwriters Laboratory Standard for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources* (CDR) also makes recommendations for necessary controls and metering points as related to storage and solar plus storage systems that can clarify issues around qualified resources and NEM integrity. Some potentially desirable metering points for DC coupled systems are shown in Figure 105.

Figure 105: Potential Metering Points



Source: EPRI

In summary, DC sources and loads are and will continue to be an increasing part of the electrical system. While there are some factors that point to DC-coupling for systems, each application presently must be evaluated for technical feasibility within available hardware and codes as well as economic feasibility comparing the costs and risks to the potential benefits. The Willowbrook project is proving its technical feasibility through demonstrations of DC-coupled solar, storage, and controlled loads. Demonstration of technical feasibility is often one of the first steps in achieving financial viability for new technologies.

Summary of Approach, Activities, and Products

The project partners navigated several delays and setbacks. First were delays in approvals to conduct extensive due diligence as Willowbrook is a tax credit financed property with multiple lenders, one of which had a poor experience with previous solar projects (leaking from roof penetrations). The due diligence involved demonstrating sufficient contractor insurance and performance bonds to protect the Willowbrook property and its investor against construction-related damages. Second was the prolonged sourcing, testing, permitting, and interconnection processes associated with implementing the emerging technologies of the project scope, especially the DC breakers and controls. Third was the emergence of the Covid-19 virus in early 2020; the ensuing global pandemic resulted in elevated precautionary measures to avoid transmission and exposure among crews, property occupants, and staff, and supply chain issues for some of the components and related setbacks to on-site work. To address these challenges, the project team hired a dedicated construction manager who addressed issues in regular weekly meetings and engaged external stakeholders. Furthermore, a technical advisory committee was formed and met three times throughout the duration of the project, during which some of these issues were addressed.

Program Design

There are several utility tariff and funding programs that influenced the project design that are summarized in the following section.

1. The Federal Incentive Tax Credit for Solar (ITC) is a tax credit that can be claimed on federal corporate income taxes for 30 percent of the cost of a solar PV system that is placed in service during the tax year. The ITC can be used by businesses, but not by a tax-exempt entity. At the project onset Linc, a non-profit, tax-exempt entity, established Linc Renewables LLC as a for-profit entity that would own the equipment purchased as part of the project. This was to capture the estimated $275,000 estimated in ITC benefits that it would otherwise not be eligible for as a tax-exempt entity. Linc, however, had trouble engaging investors for this deal, as it was a relatively small project, and most investors were looking for a portfolio with greater returns. Ultimately, this was not captured due to the lack of Willowbrook investor interest.
2. The Self-Generation Incentive Program (SGIP) is offered by the CPUC and California IOUs to provide incentives for customer-side distributed energy systems, including wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems. Linc evaluated this option to offset the costs for its energy storage components (assuming minimum utilization rates could be met). The property was eligible for the SGIP–Equity incentives that are secured via a lottery. In this example, $100,000 incentives required a $5,000 program deposit and roughly $7,000 paid to the system developer, which requested an operations and maintenance (O&M) contract as a condition to guarantee the SGIP performance standard (minimum use rate), and submit the annual report needed to submit a report to the state. There was concern that the net operating income from the battery would be insufficient to cover the application costs and the O&M charge.
3. The Solar on Multifamily Affordable Housing (SOMAH) program is another program administered by the CPUC that provides financial incentives to offset the cost of a solar PV system for affordable housing. SOMAH is the successor to the Multifamily Affordable Solar Housing (MASH) program that Linc previously used as part of its solar initiative. Designed to maximize community benefits, the program requires that most of the system directly powers tenant meters, but also provides incentives for common area loads. At least 51 percent of the energy produced by the system must be allocated to tenants via VNEM. Property owners are not permitted to adjust rents or utility allowances based on the credits. Eligibility requirements include the following:

- Have at least five units
- Be deed-restricted, low-income residential housing
- Satisfy one of the following:
    - 80 percent of property residents have incomes at or below 60 percent of the area median income.
    - Property is in a defined disadvantaged community that scores in the top 25 percent of census tracts statewide in the CalEnviroScreen.

- Be an existing building or retrofit (with Certificate of Occupancy)
- Have separately metered units
- Be a utility or community choice aggregator customer (with VNEM) in the PG&E, SCE, SDG&E, PacifiCorp or Liberty Utilities service territories

Linc determined that the project was eligible to apply for the SOMAH rebate program. Based on the size of solar system, Linc determined it was also potentially eligible to receive up to $308,000. While SOMAH was not pursued, VNEM was.

4. This project ultimately applied for and used a VNEM tariff. The production and operation of the PV are therefore distributed (allocated) across each of the residential unit meters and the common building meter. Under the VNEM tariff for low-income housing properties, the property owner can choose how to allocate production from behind the meter systems freely to different utility customer accounts. The actual connection of the system is to the common area metering, with submeters for each tenant with a financial reallocation through VNEM.

Lessons Learned

The project team encountered several barriers that included, but are not limited to:

- Making the business case for solar + storage pencil out for the affordable housing property owner to cover O&M fees.
- Major delays in the approvals process for owner and the project team to conduct due diligence for its tax credit financed property lenders as required for solar and storage projects.
- Permitting and interconnection of an emerging solution with a unique DC side connection of solar and storage, with a single inverter.
- Finding sufficient roof space on reflective flat roofs for dual-sided PV.
- Securing compatible DC equipment and expertise for DC distribution and appliance demonstration.
- Finding open-interface products for controls schema.
- Tenant engagement for energy data release and behavioral DR program onboarding due to pandemic-related "Shelter in Place" restrictions, inconsistent computer and mobile device access and bill subsidies by third parties.

Some of the lessons learned are depicted according to the project phase.

Project Engagement

Lessons Learned: Generally, a multifamily property owner faces numerous challenges to implement a solar and storage project.

Most low-income housing is funded through tax credit financing with multiple investors. This type of negotiation took a great amount of time given one of the lender's poor experiences with solar PV to get signoffs from all its investors. During this time, the system was non-operational, and the coordination effort was a drain on the operations staff resources of the property owner.

The VNEM and SOMAH structure means that the benefits of solar accrue mainly to the tenants. The programs effectively prevent the landlord from charging the tenants for the benefits of solar, which means that the property owners must justify solar based only on the common area use. In many cases, common area use is very limited (in this case only 20,000 kWh a year), and that means that property owners, if they are leasing solar, may not be able to cover the lease payments.

Implementation and Deployment

Lesson Learned: DC coupled projects must budget substantial time for testing and interconnection to happen, including how the property owner gets compensated for the time that the solar is not operational while waiting for interconnects.

- This project was unique in its DC side connection of solar and storage with a single inverter. Getting through the permitting process required a substantial amount of work with the permitting authority, as they were unfamiliar with a DC side connection. It was also difficult to obtain approval by the local utility, but it was enabled by prior work the vendor had completed with another utility in the State based on a software-based monitoring solution for non-export Rule 21 interconnect.

Lesson Learned: Unless there is sufficient space on reflective flat roofs, installing bifacial PV cannot deliver the full benefit of higher rated efficiencies.

Canadian Solar 355-watt bifacial panels were installed on available roof space, which included both flat white reflective roofs as well as sloped asphalt shingle roofs. The PV installer then connected multiple strings at different planes of array and with different surface characteristics to an inverter with only one MPPT channel. The effect was the degradation of the overall performance of the modules on the same inverter, even those optimally mounted since they share the same MPPT channel and perform only as well as their least-producing module.

Batteries

Lesson Learned: Lab testing proved an important checkpoint for simulating and validating the integrated system components, namely the battery and inverter. Also, if possible, equipment purchases should only be made after all stakeholder approvals have been secured including funder, authorities with jurisdiction (AHJ), utility, property owners and investors in affordable housing applications.

Batteries in the 60–120 kWh size had limited supplier options at the time of the project design. The manufacturer of the selected battery EnergPort was early in its product development and the feedback from the EPRI lab testing of the integrated system helped to further the commercial readiness of this product for assembly and application, for which it was tested. Resolutions related largely to safety, operability, and transport including provision of loading and unloading equipment and additional strapping on trays, grounding plan, tray with front facing, external

DC disconnect, verification of material selections for durability, verification of thermal sensors, or connector ratings.

Furthermore, the lab testing led to the provision of a NEMA-rated enclosure to protect the indoor rated unit for a carport-enclosed setting. The vendor had purchased the battery prior to the AHJ approval ruling out the electrical room based on inadequate clearances being provisioned, leaving only a carport as a viable alternative.

Inverters

Lesson Learned: Manufacturer defects of inverter components caused thermal events in lab and field testing. Power quality issues are common with multiport inverter system integrations. EPRI used M&V equipment to troubleshoot inverter failures as part of the commissioning process.

Thermal events occurred at lab testing and in field testing with the inverters. In the former, manufacturer Ideal Power (now owned by CE+T) reviewed the damaged unit and found a manufacturer defect, specifically a burned link transformer relating to a likely breakdown of the Litz magnet wire insulation. The unit was repaired under the warranty. The failed inverter in the field appeared to have melted some solder in the power core, which is a separate part of the inverter that sits above the transformer. EPRI monitored the power quality readings and conducted testing to validate the DC input parameters and to confirm whether it was an installer or manufacturer related issue. CE+T diagnosed the thermal overload as stemming from an atypical issue with the gate drive board. A refurbished unit was shipped back to the site.

Controls

Lesson Learned: A general learning is that the integration of solar, storage and loads (DR) is not as easy as it seems on paper.

Most demonstrations of load aggregation work with “preferred” products, i.e., products that have been tested in a lab setting to work together. However, reality is different in that the customer end uses are primarily designed for meeting customer needs and chosen by the HVAC contractor, or plumber, such as programmable thermostats. It means that the systems in the field would not necessarily work with aggregation platforms, especially if the product providers do not have open interfaces to equipment. A perfect example of this were the relatively new Carrier wired thermostats which were installed by the HVAC contractor which are not open interface were not compatible with the openDSRIP controls platform and limited the scope of the controllable loads as part of this project scope.

Construction

Lesson Learned: Have a **local** construction team and dedicated construction manager.

Generally, the construction management consisted of the following regime:

- Proactive project management
- Weekly construction calls
- Proactive follow-up on approvals with AHJ and SCE for interconnections and permission to operate

- Dedicated construction manager
- Covid protocol

Having a dedicated local construction manager to hold all parties accountable to budget, schedule and funder/stakeholder interests was critical to the success of this project. In addition, it also ensured smooth interactions with property management and residents. In hindsight, having a local design-builder would have been preferable to mitigate permitting and installation delays.

Operations

Resident Coordination

Lesson Learned: Having a special resident engagement coordinator with social service/welfare background is highly recommended for transactions involving financial compensation, forms, legalese, and account information with a community of affordable-housing residents. Simplicity in asks and forms and financial incentives, in the form of cash cards, help a lot.

Obtaining tenant signoffs on standard utility energy data releases with the residents was a challenge, which was amplified by Covid social distancing protocol. Forms require a specific account number and format that took multiple iterations and engagement efforts to obtain accurately. Furthermore, many of the residents had their utility bills subsidized, which made approvals a multiple step process since they were not technically the account holder. Also, several of the residents lacked computer or mobile devices or familiarity with using them. They struggled with the signup for the online DR platform, which required a 2-step verification and required online SCE account access via a phone number established upon sign-up.

Fortunately, a special resident services coordinator with background in social service was assigned to assist in the effort and issued cash cards as an incentive. After training with EPRI, this coordinator interfaced with the residents and walked them through the processes individually, step by step with appropriate levels of sensitivity and training. In this case, incentives helped to rally engagement. Simplicity in the sign-up and release forms process and earlier engagement, especially for these types of efforts, would have accelerated and expanded uptake.

Battery

Lessons Learned: The provision of batteries did not pencil out for the affordable housing property owner, affecting the applicability of SGIP and the scalability of a solar + storage solution without a redesigned funding source.

The developer and O&M fees would have been required to guarantee the SGIP requirements would be met to secure the incentive and ensure long-term performance yet were not determined to be cost-effective based on the estimated benefits of the system. Without an O&M agreement beyond the 18-month term ending Q3 2022 that was prepaid by EPRI, the value of the battery is uncertain as the system controller is proprietary to Gridscape. The site owner is considering options including decommissioning the battery and entering into a solar O&M agreement with a separate third party.

Market Impact

Building Product Awareness and Well-Documented Performance History

The ability to demonstrate the installed technologies at an affordable multifamily property in Southern California brings a unique opportunity to build their awareness and test their performance, economics and value proposition for low-income residents, affordable housing owners and operators, and their stakeholders. This includes utilities like SCE, which operates the local electricity distribution infrastructure and implements programs that could provide incentives for these technologies and make them cost-effective to better serve this customer segment with robust energy efficiency and DR offerings.

Informing Industry Stakeholders

Pilot and early adopter customer success stories will be critical to spreading the word on this new technology, which may be shared through a variety of trade publications, webinars, and key industry thought leaders. A key target audience for the project's technology transfer activities included decision makers among affordable housing organizations. This project sought to share this project and the lessons learned to cement the value proposition first-hand, making decision makers increasingly willing to install and incentivize the technology in future new buildings and retrofits. As it became available, more supporting performance data strengthened the impact of the messaging and increased the potential to accelerate market adoption of these new solutions.

Government Channels

State government organizations such as CEC and the CPUC, as well as local government organizations were a particularly important target market for technology transfer activities as they represent an additional conduit for sharing information as they produce a variety of forum and publications that have wide-spread audiences throughout the energy and building sectors. Furthermore, they set out relevant standards and (such as Title 24 JA12 and Rule 21 Phase 1) and can be informed by the demonstration on low-income and affordable housing program implementation requirements.

Utility Channels

Presenting at the EPRI Utility Advisory Council and other utility consortium meetings not only across California but the United States and the world, can assist in disseminating information on the topic that could accelerate technology adoption in energy efficiency and DR funding offerings. The project team focused on technology transfer with utilities that offer low-income energy-efficiency and demand-management programs.

Summary of Activities

Technical Advisory Committee Meetings

The project included two technical advisory committee (TAC) meetings that were attended by a cross section of relevant market players representing utilities, government, research, and industry across the U.S. As part of their committee charge, the attendees provided feedback and direction to the project team, based on their technical or market expertise. The attendees are shown in Table 26 and Table 27.

Table 26: Technical Advisory Committee #1, April 25, 2019

Organization	Organization Type	Name
California Energy Commission	Government/Funder	Liet Le, Eric Ritter
Electric Power Research Institute	Research/Prime	Ram Narayanamurthy, Dean Weng
SCE	Utility	Mark Martinez
Linc Housing	Non-Profit Housing Developer	Michelle Tirto
PG&E	Utility	Lydia Krefta
PG&E	Utility	Mark Esguerra
Sacramento Municipal Utility District	Utility	Jeanne Duvall
Sacramento Municipal Utility District	Utility	Gabriell Leggett
SDG&E	Utility	Chris Roman
SDG&E	Utility	Kate Zeng
Snohomish County Public Utility District	Utility	Suzanne Frew
Southern Company	Utility	Justin Hill
National Renewable Energy Laboratory	Research Lab	Roderick Jackson
Boy Scouts of America	Non-Profit/Property Owner	Jason Lewis
GridScape	Technology Provider	Mark Aiello
Humboldt University	University	James Zoellick
Intech Energy	Technology Provider	Rich Fox
University of Colorado Boulder	University	Gregor Henze
Pennsylvania State University	University	Gregory Pavlak

Source: EPRI

Table 27: Technical Advisory Committee #2, June 29, 2021

Organization	Organization Type	Name
California Energy Commission	Government/Funder	Liet Le
City of Culver City	Municipality	Ashley Hefner Hoang
Electric Power Research Institute	Research/Prime	Agatha Kazdan, Ram Narayanamurthy, Morgan Smith, Siva Sankaranarayanan,

Organization	Organization Type	Name
		Evan Giarta, Ram Ravikumar, Arindam Maitra, Andrea Mammoli, Zack Allen
Gridscape	Technology Provider	Vipul Gore
Kliewer & Associates	Building Scientist	Christie Kjellman
Kliewer & Associates	Building Scientist	Ron Kliewer
Linc Housing	Housing Developer/Site Host	Teri Hoerntlein, Tania Boysen
National Renewable Energy Lab	Research Lab	Roderick Jackson
Ohmconnect	Technology Provider	Elliot Marks
Ohmconnect	Technology Provider	Srinivas Chaganti
PG&E	Utility	Kelly Cunningham
PG&E	Utility	Rachna Handa
SMUD	Utility	Josh Rasin
SDG&E	Utility	Kate Zeng
Snohomish Municipal	Utility	Suzanne Frew
SCE	Utility	Mark Martinez
UC Riverside	University	Alfredo Martinez-Morales

Source: EPRI, 2021

Industry Conferences

On October 11, 2019, EPRI presented this project with PG&E and NREL at the Getting to Zero Forum. The Getting to Zero Forum is a public forum dedicated to zero energy and zero carbon buildings. EPRI participated in the session, entitled *What We Need and What We Have*, highlighting Willowbrook as an exemplary resource integration project example. The description of the session was detailed. The audience included international policymakers, design professionals, building owners, systems manufacturers, and commercial real estate experts.

In 2019, EPRI presented the Willowbrook project at New Energy and Industrial Technology Development Organization's (NEDO) *Smart Communities Workshop* in Japan. NEDO is a non-governmental organization (NGO) focused on public research and development to implement economic and industrial policies to address global energy and environmental problems and enhance industrial technology by integrating the efforts of industry, academia, and government.

In June 2022, EPRI presented the project at the ASHRAE Summer Conference in Toronto, Canada as part of an affordable housing case study and as part of a panel on *Buildings as Transactive Energy Hubs* with the Grid. In August 2022, EPRI will also present the project as part of the American Council for an Energy Efficiency Economy Summer Study in Pacific Grove, California, as part of the Smart and Grid-interactive Buildings track.

EPRI Events

EPRI also held multiple workshops targeting affordable housing owners and developers with low-income program managers at utilities for dialogue on the topic of scalable decarbonization strategies for the low-income multifamily segment were discussed, using the project at Willowbrook as a case study. Table 28 details the speakers at the February 23, 2021, event.

The session was well attended by representatives from, including but not limited to, SDG&E, Southern Company, NYCHA, Seattle City Light, Los Angeles Department of Water and Power, SCE, the Salt River Project, and others.

EPRI advisory meetings address influential utility members that are used to shape EPRI research, develop demonstration and marketing opportunities for technologies and provide a conduit for the advisors to impart information to colleagues at their "home" utilities. Advisory meetings are held twice a year (spring and fall), usually in February and September.

- In 2019, EPRI presented at the *EPRI EU Utility Advisory* conference citing the Willowbrook project. The audience included EPRI and a broad base of international utility members.
- Additionally, on February 2021, EPRI presented the Willowbrook project as one of the highlighted demonstration projects of a joint presentation between battery storage and advanced buildings programs. SCE co-presented with EPRI on the Willowbrook project.

EPRI's electrification conferences explore the critical issues, benefits, and opportunities of electrification. Session tracks usually include residential and commercial electric technologies, affording an excellent opportunity to transfer project technology information to target audiences. Conference attendees typically include utilities, industry, government, and academic leaders.

In June 2021, EPRI organized an electrification conference session convening affordable housing owners, program implementers, and utilities to discuss best practices for reaching rural and urban audiences with decarbonization-related programming, citing Willowbrook as a multifamily case study (Table 29).

Table 28: Learning by Doing: Energy Burden, February 23, 2021

Organization	Organization Type	Name
EPRI	Research/Prime	Agatha Kazdan, Senior Technical Leader
New York City Housing Association (NYCHA)	Affordable Housing Agency	Vlada Kenniff, VP of Energy and Sustainability
Community Housing Partners	Affordable Housing Developer	Cathy Stripling, Green Team Chair
Tennessee Valley Authority (TVA)	Utility	Frank Rapley, Senior Low Income Program Manager
Mercy Housing	Affordable Housing Developer/Owner	Caitlin Rood, National Environmental Sustainability Director

Source: EPRI 2021

Table 29: Urban and Rural Energy Affordability, June 2021

Organization	Organization Type	Name
National Core Renaissance	Affordable Housing Developer/Owner	Tim Kohut, Director of Sustainability Design
Association for Energy Affordability	Low Income Program Implementer (Focused on Multifamily)	Sarah Hill
Tennessee Valley Authority (TVA)	Utility	Frank Rapley, Senior Low Income Program Manager

Source: EPRI, 2021

EPRI Publications

In September 2021, EPRI drafted an article on the Willowbrook project for the organization's monthly *Electrification* newsletter. In this article, EPRI interviewed project team members and project co-sponsor Southern California Edison. The newsletter goes to a broad audience of relevant utility, government, and industry professionals.

Utility Trainings

Southern California Edison, a project co-sponsor, has used the Willowbrook project as a case study for engineer training it offers to its staff, starting in July 2021. SCE representative Mark Martinez stated that the utility will be using the lessons from this and other EPRI projects in the utility's future DER forecasting and modeling work as well. "This is a way to see how smart building systems with DERs can be responsive to future dynamic rate designs," said Martinez. "These projects help identify opportunities for future models of DER programs. This and other projects will continue to help us understand how future customer solar and storage systems can provide local grid reliability, and what we can do to help our customers maximize their benefits."

DR Aggregators

The EPRI and OhmConnect teams are actively discussing whether we could use the OhmConnect platform to support another project with SCE and EPRI at a multi-family building community in Irvine, California.

Virtual Site Visits

EPRI and Linc has facilitated two virtual tours designed to provide utilities, affordable housing owners and operators, engineers, and facility managers the ability to hear directly from the project team and staff and ask them direct and pointed questions about the installed system.

Chapter 6: Conclusions

The results of this project illustrate the extensive benefits that can result from integrated distributed energy resources with controls and behavioral strategies that optimize grid interactions between the building and the grid. While results show lowered energy use and costs for the property residents as well as greater load flexibility and environmental benefits for the utility and larger rate base, the business case for the property owner is new and does not offer generous subsidies and grants. Under the best-performing scenario, utility bill savings under a TOU rate scenario and net energy metering would garner a net present value of approximately ~-$300K, suggesting negative cash flow and a poor investment. The primary lesson learned and conclusion for this project is that programs and policymakers must consider how to improve the end-user’s monetization potential from other benefits like carbon reduction and grid services. Otherwise, these projects will not take off.

Detailed conclusions and recommendations follow.

Advanced Solar Technologies

The bifacial PV panels were chosen as a promising technology to address space constraints that are typical in commercial and multifamily applications through higher efficiencies. Bifacial solar PV modules may not provide improved performance; however, GRI cannot be maximized, and array design is not uniform where roof conditions are not uniform flat white reflective roofs. Module level power electronics (MLPE) may mitigate mismatch between modules and strings. However, MLPE compatible with multiport inverters were of limited availability at the time of procurement. While bifacial PV modules have demonstrated improved yield where these design issues can be addressed, bifacial PV performance gains were not observed because the site design was not optimized for solar exposure.

There is a trades education opportunity for solar techs to be trained on ZNE and solar PV strategies and advanced technologies for roof-constrained applications, which are characteristic of commercial and multifamily properties. The project also provides a general lesson that certain ZNE, grid-flexibility strategies are best adopted much earlier in the site planning and building design phase.

Segmentation of Storage

The team modeled three scenarios that used the storage to address project control objectives to determine which ones offered the greatest benefits to the property and the rate base. Scenario 1 discharged stored solar energy from the battery to offset TOU prices and provide peak shaving during periods of anticipated high EV charging across the rate base, to maximize solar utilization and discharge during periods of high carbon-emission from utility-produced electricity. Scenario 2 was the same as Scenario 2, albeit deploying TOU and GHG reduction objectives only seasonally. Finally, Scenario 3 tested a top-down scenario that prioritized a 10 percent annual peak load reduction at the feeder level while only secondarily addressing other control objectives.

Ultimately Scenario 3 proved that the stacked benefit approach was most effective at providing the most notable annual bill savings and net annual peak load reductions for a residential distribution circuit while addressing the other control objectives 97 percent of the days in the year. Note the full Project Benefits discussion in Chapter 7.

Platform to Manage Customer Loads

Twenty-one, or roughly one-third, of Willowbrook residents successfully enrolled in Ohmconnect, a customized DR aggregation program that bids behavioral demand reduction into the DR auction market. Ohmconnect built out custom messaging and behavioral energy and demand reduction recommendations to prime residents for TOU rates taking effect. During the June to September 2021 timeframe, there were 42 unique events, with 619 resident opt-ins for an average of 16 opt-ins per event. Performance suggests that residents were actively engaged, and that monetary incentives and gamification mechanisms were motivating factors for participation. Sampled residents participated in at least 50 percent of DR events and saved up to 50 percent when compared with their historic baseline.

This demonstration shows that behavioral methods can be highly effective to induce targeted reductions of energy use in a highly cost-effective way (no widgets were installed, and incentives came entirely from revenues from Demand Response Auction Market participation. Gamification and cash earning mechanisms were highly effective.

Distribution System Analysis

Because of difficulties in monetizing grid services from behind the meter storage, the cost-benefit analysis suggests that all scenarios without outside funding support would bear a negative net present value (NPV). Used to estimate the value of a future stream of payments, a positive number suggests an attractive investment with future cash flows. The NPV for the best performing Scenario 3 was -$312,619, which was a negligible improvement over Scenario 1 (1 percent), where all controls objectives are implemented year-round, and a 64 percent gain over Scenario 2 in which TOU and GHG controls objectives are implemented seasonally. It is extremely important to note, however, that this cost-benefit analysis only monetizes the utility bill savings to the property and excludes any financial benefit from greenhouse gas emissions, net peak load reductions, or other distribution services that could defer distribution upgrades. Nor do they add customer resiliency from the DC distribution and appliance project scope, which could benefit the property, utility, and rate base.

Direct Current Distribution and Appliances

This project shows that DC sources and loads show great promise as part of a future electrical system for added resiliency and efficiency. Today, each DC-coupling application must be evaluated for technical feasibility within available hardware and code limits, as well as the economic feasibility of comparing costs and risks to potential benefits. The Willowbrook project is proving the technical feasibility through demonstrations of DC-coupled solar, storage, and controlled loads. Demonstration of technical feasibility is often one of the first steps in achieving financial viability for new technologies. Furthermore, it can inform future electrical code updates and represent another workforce training opportunity.

This exercise provided valuable insight into the design process of hybrid AC/DC resilient systems. The primary lesson is that the design of these systems is more complex than it appears. Some of the components were incompatible, although the manufacturer's engagement and interest in such systems may prove to resolve these issues with future product revisions. Some of the components are also hard to find – for example, high-voltage DC breakers. While it was not possible to accurately measure DC/DC conversion efficiency of the 30C3 power converter, keeping the system "all-DC" may not result in the expected efficiency gains. Finally, full integration may require some design changes that allow for integration, for example enabling the PV MPPT controller to work in parallel with the battery charge controller; this, however, would require both cooperation between manufacturers and standardization.

The primary opportunities identified during this lighting implementation are the need to explore expanding availability of 380VDC or higher-voltage DC lighting for optimal efficiency as well as to establish the availability of UL-listed DC lighting controls.

Lessons Learned

The project revealed the general difficulty of initiating a solar + storage project in a California tax credit-financed multifamily property from making the business case for a property owner to meeting due diligence requirements of its property lenders. There were several emerging technologies in scope that required additional time and resources compared to industry standard technologies to source, integrate, design, permit, interconnect, install, and operate. Funding programs and policy must consider interventions for making low income multifamily solar + storage financially feasible.

Summary of Recommendations

Recommendations for scaling solar + storage + DC + controls at low-income multifamily properties taken from the lessons learned at Willowbrook follow.

- Encourage adoption of decarbonization, ZNE, and grid flexibility strategies as early in the multifamily site planning and building design phases as possible.
- Create workforce training opportunities for the design and application of advanced solar technologies for commercial and multifamily applications that address solutions for roof-constrained applications for solar techs covering bifacial technology and module level power electronics for optimization. Outlets could include the International Brotherhood of Electrical Workers or North American Board of Certified Energy Practitioners, or community colleges.
- Promote updates to standards and building codes for general use of higher DC voltages. For metering and tariff compliance, inverter metering, and controls can be used to ensure NEM integrity. See Chapter 5, DC-Coupling Technical and Market Barriers, for more specific recommendations.

- Convene a manufacturing consortium for establishing common standards for DC use design and equipment standards based on California’s top-use cases. EPRI agreed to facilitate.
- Make incentives available to DC equipment manufacturers to expand availability of DC equipment, such as 380VDC or higher voltage DC lighting for optimal efficiency as well as the UL-listed DC lighting controls.
- The ROI of the affordable housing property owner or manager must be improved to make solar + storage financially viable. While offering clear benefits to the property, utility, and rate base, GHG reduction, net peak load reduction, and added resiliency cannot be easily monetized into cash flows: only utility bill savings. Incentive structures or modifications to SGIP, ITC and VNEM or all should be explored to help property owners or project financers with the business case of doing solar + storage. This includes an assortment of ways to readily monetize benefits that improve the NPV and customer value proposition of solar + storage + DC, especially where there is clear, overlapping stakeholder benefits and alignment with state policies.
- A specialized resident engagement coordinator with a social service or welfare background is highly recommended for engaging with a community of affordable housing residents like Willowbrook. Simplicity and straightforward asks, financial incentives, and gamification mechanisms like cash cards and rewards, helped with uptake.
- PQ issues are common with multiport inverter systems. Lab testing to simulate integrated systems and close monitoring in the field of DC-coupled systems upon commissioning are highly recommended. Also, have a *local* construction team and dedicated construction manager.
- A list of stakeholders for low-income multifamily properties (especially lenders for tax credit financed properties) should be established at the project onset to ensure all are consulted on the project terms. Equipment purchases should only be made after all stakeholder approvals have been secured including permitting authorities, utility, property owner and investors in affordable housing applications.

Chapter 7: Benefits to California

This project delivers benefits to California such as lowered energy costs with greater reliability, increased safety, economic development and environmental safety, public health, consumer appeal and energy security.

Lower Costs

The project is projected to demonstrate energy savings of 137 MWh to the grid on an annual basis solely from solar generation. Adding another 10 percent savings through reductions in losses will save 151 MWh per year just from this one project. The energy and demand savings translate to lower utility costs to serve ratepayers, and ultimately results in lower costs allocated to ratepayers. Extending the results of this project to California’s deed-restricted affordable multifamily households shows potential for a bill reduction of $253 million for California's low-income households. (About 10 percent of California multifamily households are deed-restricted affordable multifamily.)

Greater Reliability

This project demonstrated an integrated solar, storage and end-use load platform and tested control scenarios that support greater grid reliability while supporting intermittent renewable energy resources. This project showed a reduction of evening demand by 8.6 percent during TOU peak periods, which contributed to increased grid reliability, ultimately benefiting all California ratepayers. The project team worked closely with the local utility, SCE, to study the distribution grid impacts (voltage, thermal, protection) that these DERs can potentially mitigate.

Economic Development

This project created new jobs equivalent to eight person-years (five funded by the grant, three funded by match share). This can be scaled to significant job growth if similar retrofit work is conducted statewide for the target sector. The reduction in energy bills and DR participation payments also leaves tenants with greater disposable income, which is particularly impactful for low-income populations, which make up nearly 20 percent of all California ratepayers.

Environmental Safety

This project has the potential to reduce GHG emissions by installing renewable energy and energy-efficient technologies. Extending the results of this project to California’s low-income multifamily households shows a potential for energy use reduction of 1,182 GWh per year, which translates to statewide CO2 reduction of about 83,331 metric tons per year, for California's low-income populations. (20 percent of California's ratepayers are low-income; 75 percent of low income are multifamily.)

Public Health

This project improves public health by reducing pollution and GHG emissions. This project also tests a resilience strategy in disadvantaged communities through the DC distribution and appliance demonstration, which theoretically can help with populations in need of continuous power for medical devices during an outage.

Consumer Appeal

This project is enhancing a sustainable, LEED-certified urban in-fill, mixed use and transit-oriented property that allows people to live close to employment. This project will provide key insights and enhance the comfort and affordability of this housing to further consumers' interest in renting and owning it.

Energy Security

Reducing energy use with energy efficiency and renewable measures provides energy security by avoiding resources needed to build more power plants and being more self-sustained for energy requirements. SCE and affordable housing developer Linc are using the results of this work to inform their future planning and development.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
AC	Alternating current
AHJ	Authority having jurisdiction
AMI	Advanced metering infrastructure
API	Application programming interface
BESS	Battery Energy Storage System
BTM	Behind-the-meter
CAISO	California Independent System Operator
CARE	California alternate rates for energy
CO2	Carbon dioxide
DC	Direct current
DER	Distributed energy resource
DR	Demand response
DRAM	Demand Response Auction Market
GHG	Greenhouse gas
GRI	Ground reflected irradiance
GWh	Gigawatt-hour
HVAC	Heating Ventilation and Air Conditioning
ICA	Integration capacity analysis
IOU	Investor-owned utility
ITC	Incentive tax credit
kW	Kilowatt
kWh	Kilowatt-hour
LEED	United States Green Building Council Leadership in Energy and Environmental Design (Green Building Standard and Certification)
MLPE	Module level power electronics
MW	Megawatt
MWh	Megawatt-hour
M&V	Measurement and verification
NEM	Net energy metering
NRTL	Nationally recognized testing laboratory

Term	Definition
OpenDSRIP	Open Demand Side Resources Integration Platform
O&M	Operations and maintenance
PQ	Power quality
PV	Photovoltaic
SB	Senate Bill
SCE	Southern California Edison
SGIP	Self-Generation Incentive Program
SOC	State of charge
SOMAH	Solar on Multifamily Affordable Housing
TAC	Technical advisory committee
TOU	Time of use
UL	Underwriters Laboratories
VDC	Voltage direct current
VNEM	Virtual net energy metering
VRF	Variable refrigerant flow
WOM	Willowbrook Orchestration Module
ZNE	Zero net energy

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