Resilient Solar and Storage Roadmap

City and County of San Francisco, Department of the Environment

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Disclaimer

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Abbreviations

ADA: Americans with Disabilities Act

CCSF: City and County of San Francisco

CPUC: California Public Utilities Commission

DBB: design-bid-build

FEMA: Federal Emergency Management Agency

FIT: feed-in tariff

GIS: geographic information system

HMP: Hazard Mitigation Plan

HRC: Hamilton Recreational Center

HVAC: heating, ventilation, and air-conditioning

IEEE: Institute of Electrical and Electronics Engineers

ITC: investment tax credit

MHHC: Maxine Hall Health Center

ML: Marina Library

MMS: Marina Middle School

MRC: Marina Recreational Center

P3: public-private partnership

PG&E: Pacific Gas and Electric

PV: photovoltaic

SFDEM: San Francisco Department of Emergency Management

SFE: San Francisco Department of the Environment

SFPUC: San Francisco Public Utilities Commission

SGIP: Self-Generation Incentive Program

TMHS: Thurgood Marshall High School

Executive Summary

Resilience to natural disasters is imperative for safe, economically productive cities. In the immediate aftermath of an earthquake, flood, or other disaster, one key element of resilience is continued operation of shelters and critical emergency management facilities. Operation of these facilities depends on reliable emergency power. Traditional emergency power systems use diesel generators with storage tanks, which provide power for only a few days in the absence of the electric or gas grid. However, a recent study has shown that gas and electric networks can require days or weeks to recover from a disaster, leaving facilities with generators at risk of running out of fuel. This has already been experienced in New York City after Hurricane Sandy where a combination of lengthy outages and high flood waters compromised the traditional diesel storage and generator backup infrastructure at hospitals and shelters. With the risk of natural disasters increasing due to climate change, we must turn to more resilient solutions for providing backup power to shelters, medical centers, and emergency operations centers.

From 2015 to 2017, the City and County of San Francisco Solar and Storage for Resilience Project examined the use of microgrids and stand-alone solar electric generation with battery storage to provide resilient post-disaster power to critical facilities. The project evaluated 1,263 potential congregation and shelter sites across the city, 67 of which were identified as shelter sites with power requirements and opportunities to develop resilient infrastructure through solar and storage. Site visits were conducted for 18 of these buildings, spanning all 11 supervisor districts in San Francisco and a range of normal and emergency use types. The project team used observations from these site visits to create representative emergency power profiles for all 67 shelters in San Francisco. Using these profiles, the team found that 8.2 megawatts (MW) of photovoltaic panels and 12.9 MW of battery storage would be required to provide resilient backup power for San Francisco's shelters following a disaster.

Given the high capital cost of deploying this large resource, the project team investigated various financing options — a public-private partnership was found to be a viable pathway for financing resilient solar and storage. Given the added benefit of energy cost savings in normal operation, a public-private partnership financing model would save the City and County of San Francisco 6% over a traditional design-bid-build approach over a 20-year portfolio lifetime.

This roadmap documents the project's steps of identifying critical facilities, surveying power requirements, assessing renewable potential, evaluating financing options to develop the solar and storage systems for resiliency, and modeling individual sites for solar and storage installation. This roadmap also examines the challenges critical facilities face in providing resilient power, such as key technical, political, and financing barriers, as well as the opportunities and policy recommendations to further advance resilient solar and storage development in San Francisco. While this report focuses on a detailed study of San Francisco, the methods and outcomes are applicable to any city or town.

Introduction

Resilience to natural and human-induced disasters is a key imperative for economically productive, safe, and sustainable cities. Planning for resilience requires a view toward both the long-term recovery of a city and the short-term response to ensure that shelters and critical facilities continue operating immediately after a disaster. The importance of short-term resilient planning was emphasized by Hurricanes Katrina and Sandy in 2005 and 2012, respectively, but they are by no means the only examples. According to the U.S. Department of Energy, between 2003 and 2012, 679 widespread power outages occurred due to severe weather, at an annual cost to the American economy of between $18bn and $33bn.[1] In a world where the changing climate is creating more frequent and more intense extreme weather events, these outages are likely to become longer and more frequent, placing increasing importance on ensuring that shelters are resilient. Locally, in the Bay Area, outages are likely to become more serious with the region facing the risk of nearly 1 meter (3.25 feet) of sea-level rise and an associated increase in flooding events due to storm surges.[2]

San Francisco also faces the constant threat of a major earthquake. The San Andreas Fault lies immediately beneath the western portion of the city, and as experienced in 1906 and 1989, earthquakes can devastate the city. As documented in the San Francisco Lifelines Interdependency Study, a magnitude 7.9 earthquake can disrupt infrastructure operations for days, weeks, and even months.[3] Other disasters may create disruptions to infrastructure as well. Figure 1 shows that gas and transport infrastructure may require up to one year to recover after a major earthquake. Electricity and telecommunications may experience outages of several days or several weeks, depending on the severity of the event. For shelters, police stations, fire stations, medical centers, food distribution centers, and other critical facilities, even short disruptions in service after a disaster may be intolerable; there is a clear need for local power generation with on-site fuel to sustain critical facilities and shelters following a disaster.

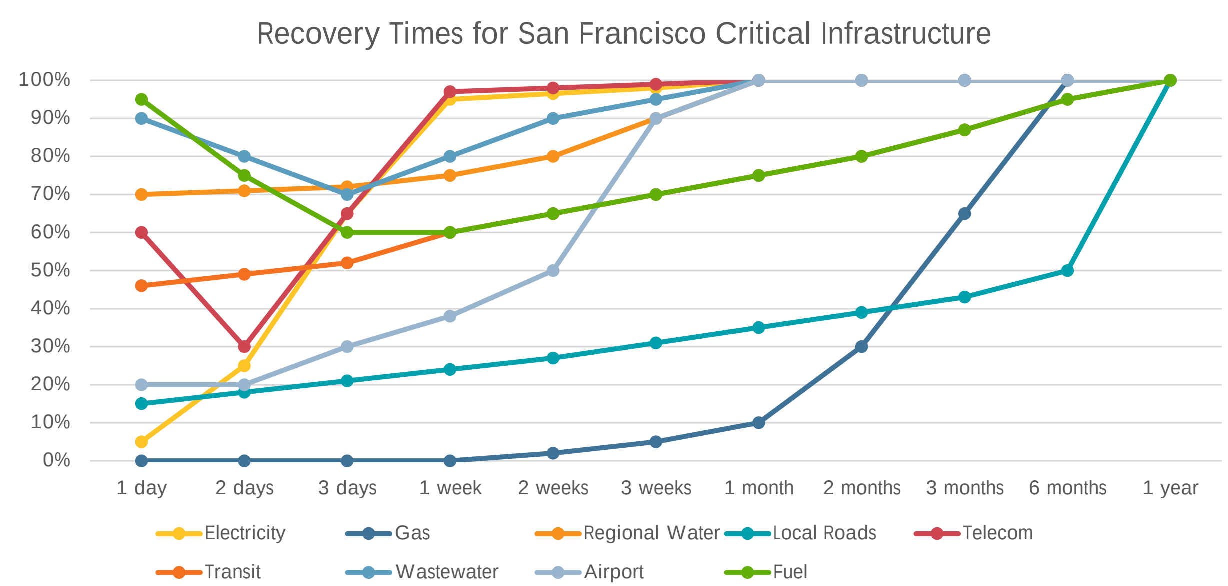

Figure 1: Estimated recovery times for critical San Francisco infrastructure after an earthquake (adapted from the San Francisco Lifelines Interdependency Study)

[1] http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf
[2] http://www.marincounty.org/~/media/files/departments/cd/planning/slr/kickoff-meeting/barnard_csmartkickoff_071014.pdf
[3] http://sfgov.org/lifelines

Solar and Storage as an Alternative to Grid and Gas

As shown in Figure 1, the recovery times of energy infrastructure after an event vary widely. Electric infrastructure tends to recover quickly, with 90% restoration of service after only one week, while natural gas can take up to six months due to difficulties in identifying and repairing line breaks. Diesel suffers from the same disruptions as natural gas when used for backup power generation — transport to areas of critical need is limited by pipeline supplies and road conditions.

Conventional wisdom holds that properly maintained diesel generators with code-required fuel storage will sustain the needs of a community after a disaster. However Hurricane Sandy in New York and the Lifelines study have shown that this conventional approach may not be accurate in the face of more powerful floods and disasters. For instance, after Hurricane Sandy, at least one instance was reported of New York aid workers hauling cans of diesel up 12 flights of stairs to keep a generator running at a medical facility; without these heroic efforts, the diesel generator backup infrastructure would have been unable to keep the lights and critical life support equipment running.

Solar and storage systems, on the other hand, do not rely on a combustible fuel that must be transported over long distances from refinery to use. Rather, access to sunlight is common throughout the city, even after an event that causes a utility power outage. On-site battery storage can extend the ability to use solar energy after sunset or during cloudy days. If combined with a diesel generator, solar and storage can ensure that the diesel fuel supply can be preserved for cloudy periods and nights, thereby extending the duration of outage that a facility can sustain.

Solar and storage emergency power systems offer the following additional benefits:

- **Safety**: Diesel generators require on-site storage of fuel, presenting a health and safety hazard. Solar and storage systems present a significantly safer and less hazardous option by eliminating the need to store liquid fuel. Though there are concerns regarding the safety of lithium-ion batteries, batteries have lower overall risk to human health than diesel fuel storage.
- **Reliability**: Diesel generators can fail due to periods of non-use and lapses in maintenance and regular operation. Solar and storage systems have greater reliability since the system is operated continuously in normal conditions and not used just in emergency conditions, allowing opportunity for early detection of problems when no critical operation is required.
- **Low Maintenance**: A solar and storage system requires less system maintenance than diesel generators. Generators require monthly tests under load, regular inspection, regular cleaning, and replacement of filters, oil, and coolant. By contrast, solar arrays and battery storage systems have minimal ongoing maintenance requirements. Solar arrays should be washed once or twice per year depending on dust exposure, and batteries require monthly visual inspection to confirm that they are free from damage or corrosion. Other required voltage and current inspections are performed automatically in normal operation and require no added maintenance.
- **Environmental**: Through the use of renewable energy rather than fossil-fuel-generated power, solar and storage systems avoid carbon emissions and local air and noise pollution, which are inherent in backup generators. Solar and storage are also used year-round under normal daily operation to reduce grid power consumption and carbon emissions.
- **Economical**: The ongoing costs of solar and battery storage are low due to minimal maintenance needs. Reduced electricity bills provide an additional financial benefit, which helps offset the higher capital cost of solar and storage compared to diesel generators.

Solar and Storage for Resilience

The City and County of San Francisco (CCSF) Solar and Storage for Resilience Project was designed to provide a strategy for solar electric generation with battery storage to become the primary mechanism for emergency power provided at existing and new critical facilities and shelters. The findings indicate that solar and storage can be the backbone of resilient electrical infrastructure for San Francisco's critical facilities and shelters, and that solar and storage can be cleaner, more economically productive, and more reliable than conventional backup generators.

This roadmap documents the findings and recommendations of the Solar and Storage for Resilience Project and provides guidance for incorporating solar and storage as resilient power to critical facilities and shelters. The roadmap is the culmination of work to create best practices and examples of solar and storage for disaster-resilient critical facilities. It is hoped that this process and the guidelines documented in this roadmap will be used to continually improve and update San Francisco's resilience and disaster preparedness, and can also be used by other cities to strengthen their disaster-response strategies. Figure 2 presents the steps taken in the project, which form the outline for the roadmap.

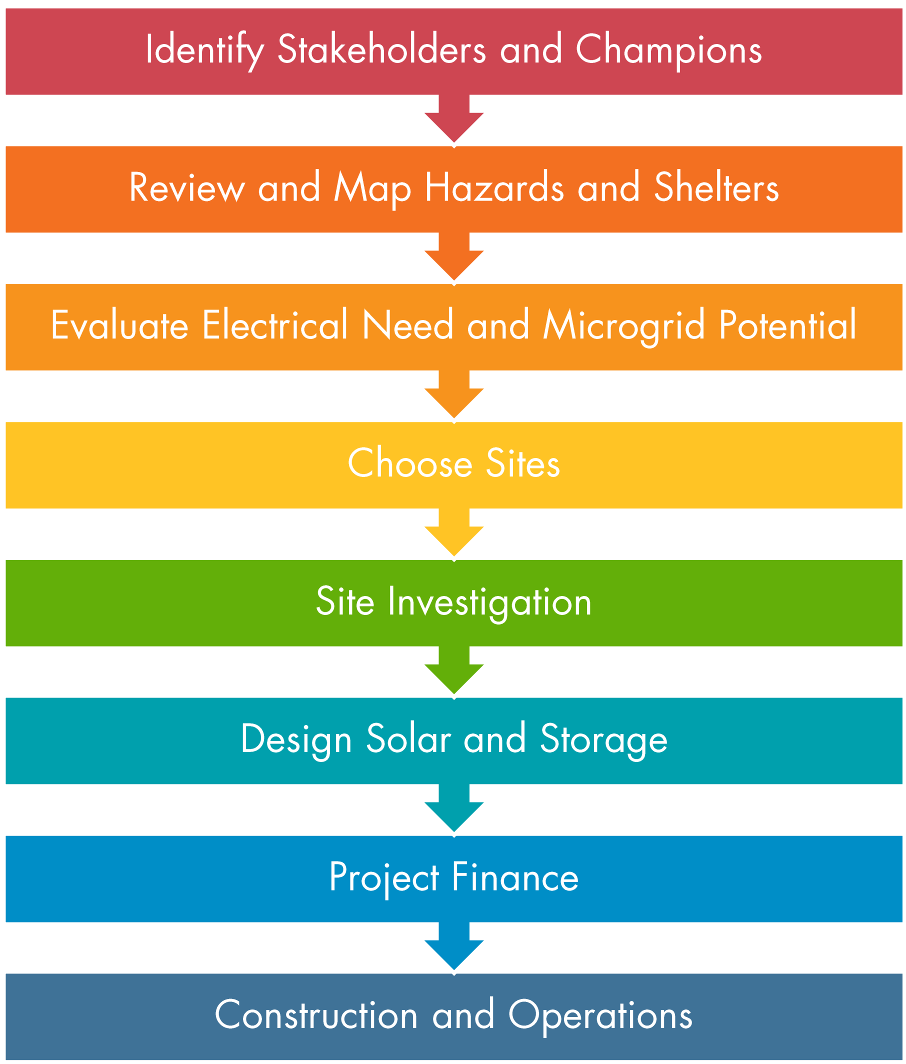

Figure 2: Steps of the Solar and Storage for Resilience Project as presented in this roadmap

Step 1: Identify Stakeholders and Champions

San Francisco is a leader in sustainability, resilience, and disaster preparedness. CCSF has a comprehensive Climate Action Strategy driving a shift to 100% renewable energy by 2030 and is a national leader in renewable power, requiring 15% of roof area devoted to solar on all new buildings in the city.[4] Through the Rockefeller Foundation's 100 Resilient Cities program, San Francisco has produced a comprehensive Resilience Plan and established a Chief Resiliency Officer. Given the constant risk of earthquakes in the city, the San Francisco Department of Emergency Management (SFDEM) ensures the city is ready for disaster through its SF72 Citizen Hub for emergency preparedness and thorough disaster planning.[5]

However, these efforts are coordinated and managed through different departments within the city government. Furthermore, facilities that serve as shelters and critical operations centers are divided across departments based on their typical use. For these departments, managing sustainability, resilience, and emergency operations is ancillary to their primary role within the city. This created a challenge in mapping the stakeholders and facilities to target for solar and storage. Therefore, the first step in the project was to engage interested stakeholders in each city department, explain the project, and build an engaged coalition to advance solar and storage for resilience across the city.

Building this coalition of champions involved reaching out to the Planning Department, the Department of Public Works, SFDEM, the Public Health Department, the Mayor's Office, and all of the elected supervisors. The initial list for engagement was compiled using a list of 225 facilities provided by SFDEM of shelters and critical operations centers required after a disaster. Any department with jurisdiction over one or more of these buildings was approached to participate in the project. The project team was met with enthusiasm from each group they engaged as well as understandable concern about the workload to support the ongoing installation and maintenance. These concerns will have to be addressed in ongoing planning for any projects.

Networking to engage stakeholders and build a coalition of champions had several advantages. First, engaging more key individuals within CCSF helped the project team access new data and engage with facility managers for pilot project sites. Whenever possible, the team chose to examine priority facilities managed by different departments in the city where a solar and storage installation would match with existing project efforts or funding, increasing the chance that a pilot would be deployed and the project would be rolled into an existing workload. Second, engaging city stakeholders across departments offered a chance to align the solar and storage projects with other city goals. For instance, if environmental or resilience issues were not at the top of the agenda for a specific department, learning how a solar and storage project could be paired with facility upgrades or community reinvestment in an underserved area proved powerful. Building a coalition also had the advantage of creating a strong basis of support for future deployment. This will help ensure that as pilot projects are rolled out there is a point person for helping navigate any regulation or requirements that may otherwise hinder project adoption. Finally, engaging the elected officials and trying to target facilities across the entire geography of the city helped build widespread support among the entire city government and population. This is one of the strongest actions that was undertaken and can help push the project beyond the planning stage in the future.

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[4] https://sfenvironment.org/cas, https://sfenvironment.org/cas/goals, http://docketpublic.energy.ca.gov/PublicDocuments/16-BSTD-07/TN212812-3_20160816T164424_San_Francisco_2016_Local_Ordinance_Staff_Report.pdf

[5] http://www.sf72.org/em/home

Step 2: Review and Map Hazards and Shelters

With core support from internal stakeholders, the next step was to review existing hazard plans to determine the best approach to planning solar and storage, and to map potential threats and shelter locations. Gathering this information is essential for determining the electrical needs and vulnerability of each shelter and identifying key locations for solar and storage deployment. The biggest challenge, however, is that emergency and disaster recovery planning occurs at all levels of government — municipal, state, and federal — and within several agencies. At a minimum, the Federal Emergency Management Agency (FEMA) requires that every local jurisdiction in the United States develop and adopt an all-hazards mitigation plan as a condition to be eligible for disaster-related assistance. Jurisdictions are required to update their plans every five years. San Francisco exceeds this minimum with the following four disaster-preparedness plans:

- **CCSF All-Hazards Strategic Plan**: The All-Hazards Strategic Plan is intended to enhance the city's ability to deter, prevent, respond to, and recover from acts of terrorism and natural and human-caused disasters through the development of one common preparedness vision and strategy. It is a strategic-level plan that highlights 20 goals for disaster preparedness along with steps for implementation, but it does not investigate particular buildings or technologies to be used in disaster preparedness.[6]
- **CCSF Emergency Response Plan and Emergency Support Function Annexes**: The Emergency Response Plan addresses the roles and responsibilities of the CCSF during all-hazards emergency response. Specifically, the Emergency Response Plan identifies and describes CCSF's interaction with regional, state, and federal entities; the role of the San Francisco Emergency Operations Center; and the coordination that occurs between the Emergency Operations Center and City departments and agencies. The Water and Utilities Annex describes the organizational structure and roles that will be utilized to coordinate utility restoration after a major disruption but does not examine energy needs or priorities.[7]
- **CCSF Energy Assurance Strategy**: The Energy Assurance Strategy provides a pathway for San Francisco to become more resilient to any type of hazard that disrupts or threatens the energy supply. The strategy provides actions that enable energy contingency planning in the case of a disaster. However, it does not address storage and microgrid development as a strategy for energy assurance in its current version.
- **CCSF Hazard Mitigation Plan**: The Hazard Mitigation Plan (HMP) represents San Francisco's commitment to making the city safer and more resilient by taking steps to reduce the risk from hazards before they occur. The plan describes the city's natural and human-made hazards, identifies actions the city can take to reduce their effects, and establishes a process for implementing the plan. The HMP identifies power supply failure as a hazard but does not detail a power restoration plan or how temporary generators can play a role in providing power to buildings following an emergency.[8]

In all of the plans, long-term power outages have been identified as a significant risk element in hazard management and relief following a disaster. However two deficiencies stand out: First, the plans do not yet identify which facilities require backup power and should be treated as critical post-disaster. This hampers the ability to effectively size solar and storage, or to plan which facilities should be prioritized

[6] http://sfdem.org/ftp/uploadedfiles/DEM/PlansReports/StrategicPlan2008.pdf
[7] http://sfdem.org/plans
[8] http://sfdem.org/2014-hazard-mitigation-plan

for deployment. Furthermore, the plan review revealed that information on the locations of critical facilities was not available to all departments in the city and was not organized such that city officials within and across departments could easily access key information about disaster-facility preparedness or vulnerability to disasters. Second, the need for backup power to buildings and city infrastructure is highlighted in the disaster-preparedness plans. However, no concrete plans have been developed showing financial, technical, or planning processes for achieving backup power with renewable technologies. The studies suggest that solar and storage should be studied but have not yet done so. In light of the Lifelines report and the prospect of being without gas or diesel for long periods, there is an increased imperative to accelerate the study of these safe, renewable, and self-sufficient options.

In this, San Francisco is not alone. A review of comparable city management plans showed only directives to investigate the use of solar and storage with no actual deployment or guidance on how to leverage solar and storage as post-disaster backup. No city has investigated microgrids as a solution for post-disaster resilient power supply. For a fuller comparison, the Emergency Plan Review report available on the Solar and Storage for Resilience project webpage[9] provides an in-depth comparison between the San Francisco HMPs and the plans of other cities.

With neither San Francisco nor any other city is yet fully understanding and embracing solar, storage, and microgrids as resilient backup in the case of a disaster, the city once again has the opportunity to lead the nation in combining sustainability and resilience to create a more robust emergency power network.

Mapping Critical Buildings

The first recommendation from evaluating the disaster-preparedness plans was to identify and map all of the critical buildings in the city and store the information in a single location. Starting with the four hazard plans and lists of facilities from each city department, the project team complied a master list of facilities. Each department in the city was found to have its own list of the critical facilities under its purview. Facilities may be included on multiple lists or only one, and not always with the same identifying name. Therefore, the first task in identifying critical facilities was a process of outreach to all relevant departments within CCSF to compile a list of the facilities that could require post-disaster power. This outreach involved conversations with the following departments, which oversee critical facilities:

- SFDEM
- Department of Real Estate
- Department of Planning
- Fire Department
- Police Department

This list, which is accessible to CCSF departments and stakeholders, should be kept continuously up-to-date to reflect the changing landscape of the city and ensure ongoing disaster preparedness. It also helps meet FEMA requirements, which include a list of critical facilities as a prerequisite for engaging in aid operations after an event.

As a tool to assist in solar and storage planning and critical-facility identification, the project team created an interactive online map with all of these facilities located. To further centralize relevant resilience and emergency preparedness information, the hazards endemic to each critical facility

[9] https://sfenvironment.org/solar-energy-storage-for-resiliency

site were added to the map. City-provided Hazus assessments, aerial photography, hazard maps, Neighborhood Emergency Response Team (NERT) staging areas, and other sources were used to gather this data.

The identified hazards are as follows:

- San Andreas Fault
- Hayward Fault
- Soil liquefaction
- Landslide
- Tsunami
- Wildfire
- Reservoir inundation
- Heat vulnerability

Along with risks to each site, the critical facility information and city data were mapped to show the locations of buildings, potential microgrid locations, and city information including land plots and supervisor districts. A screenshot from this map is shown in Figure 3.

By collecting this information and centralizing it in an interactive map, the project team created a portal for understanding post-disaster energy management in San Francisco. The database can also be updated continuously as new data become available, providing an advantage over static maps that quickly grow outdated. It is imperative to keep this resource up-to-date, both to ensure effective planning for additional resilience measures in the future and as a tool for the city and FEMA in the event of a disaster.

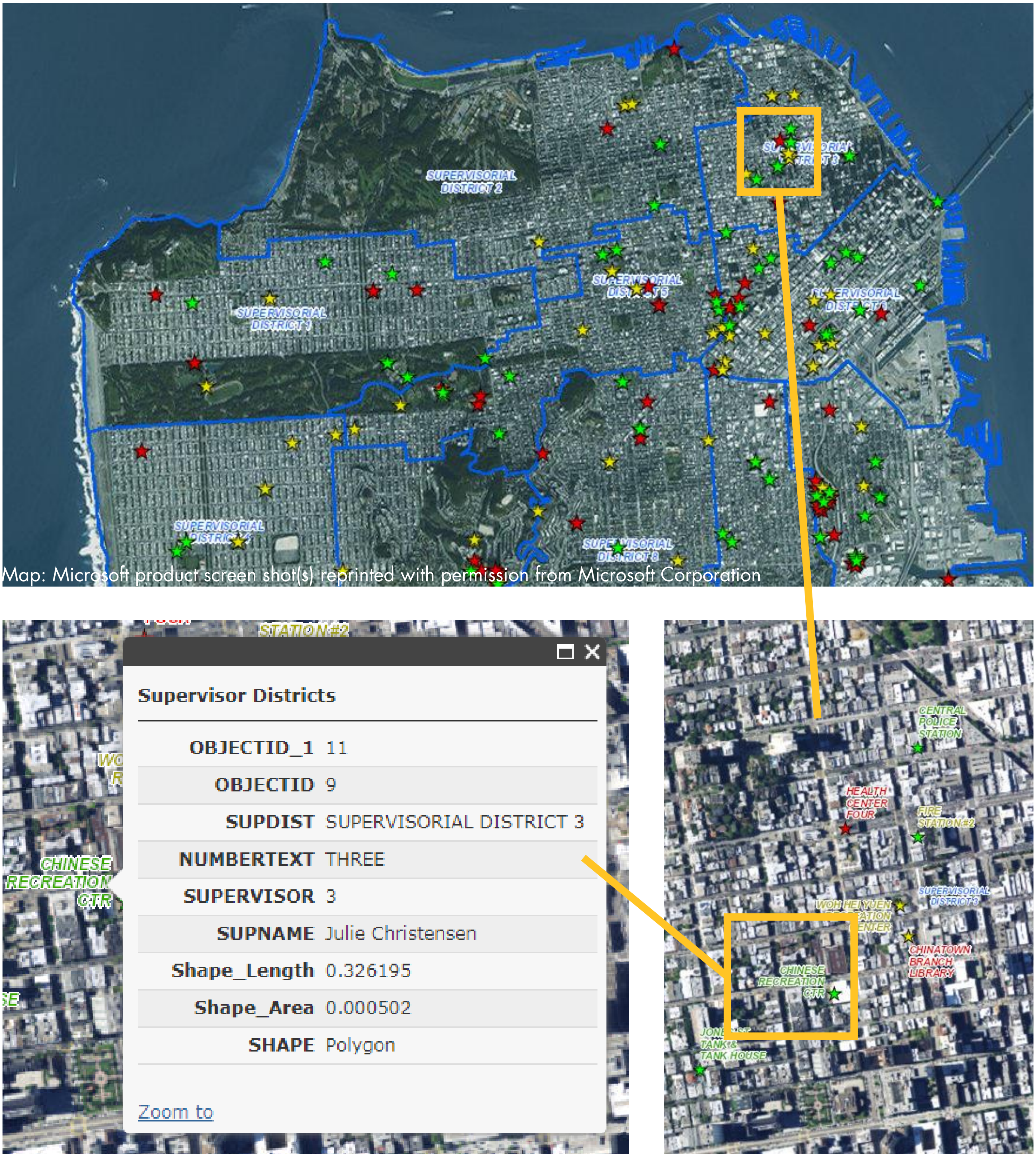


Figure 3: GIS mapping of critical facilities in San Francisco and excerpt showing the data available for a single facility

Step 3: Evaluate Electrical Need and Microgrid Potential

Identifying and mapping the locations of critical facilities and their hazards and electrical requirements in a single database was an important step toward providing resilient post-disaster power infrastructure. However, identifying key locations for solar and storage deployment required additional information. To enable a solution reliant on solar and storage, the project team needed a strategy to screen candidate facilities to determine their appropriateness for resilient backup power. This strategy involved identifying the following:

1. **Facilities with power requirements.** Not all facilities require power immediately after a disaster. Those that do not require power immediately can be eliminated from further consideration prior to mapping. SFDEM provided a summary of post-disaster facility power needs for this study, indicating how many days after an event the facility would require power. Where data were missing, conversations with the departments overseeing each facility were used to understand the nature of the site and its potential power needs. This evaluation reduced the number of critical facilities considered for solar and storage from 1,263 to 225 buildings. Many of eliminated facilities were open areas designated as safe spaces for gathering after a disaster. In general, power was found to be needed at sites that maintain a critical response function, provide medical services, or serve as shelters and aid-distribution centers. In cooperation with SFDEM as the coordinating agency, San Francisco Department of the Environment (SFE) and the project team identified buildings that meet these criteria, which include the following:

   - Police stations
   - Fire stations
   - Hospitals/clinics
   - Disaster-relief coordination centers
   - Shelters (e.g., recreation centers)
   - Kitchens (e.g., Salvation Army)
   - Public-assembly buildings
   - Response-staging areas

   The electrical needs for each facility were added to the previously described interactive map to inform future evaluations of power needs and solar and storage deployment for resilience.

2. **Hazus category for each facility.** Hazus is FEMA's geographic information system (GIS)–based natural hazard analysis tool, which identifies the likely safety of a facility after an earthquake or other significant disaster. Even critical facilities range in their Hazus rating from facilities that can be occupied immediately after a disaster to those that cannot be occupied. Those at the lower end of the ratings should not be prioritized for backup power in the event that they are not able to be occupied after a disaster.

3. **Facilities scheduled for upgrade or improvement in the next five years.** Facilities that are likely to be upgraded or retrofitted in the next five years should be prioritized for solar and storage at the time of retrofit. Guidelines should be required in each department with authority over these facilities to ensure that solar and storage are evaluated and implemented at the time of facility upgrade.

4. **Facilities with good solar access.** To screen for solar and storage suitability, roof area and adjacent parking lot area were examined. Solar deployment requires a large area on which solar arrays can be constructed to maximize exposure to the sun. Initial screening rules out those sites without sufficient exposed area for solar access. This measure ruled out approximately 50% of the critical facilities for San Francisco. Implementing solar and storage on these facilities would require leasing or borrowing solar area from adjacent structures. Some recommendations on adapting the results of this study to these facilities are provided within the conclusions of this roadmap. The remaining facilities are not automatically suitable; on-site investigation is necessary to evaluate structural suitability for solar development.

5. **Facilities that are colocated.** Colocated facilities can provide both technical and community benefits via a microgrid and should be prioritized for solar and storage deployment. Microgrids, as the term implies, are small groups of buildings that are connected together with an electrical grid that can separate from the normal electrical grid that connects to the utility provider. Microgrids are capable of taking generated and stored power from any of the buildings and distributing it elsewhere across the microgrid. Technically, colocation of facilities allows solar and storage assets to be shared, increasing cost efficiency. Colocation can also enable a facility without sufficient roof space for solar to still be provided with a resilient power source.

   One of the initial goals of the Solar and Storage for Resilience Project was to identify one or more microgrids as case studies. However, in mapping potential project sites, the team quickly determined that microgrids should be planned around communities of critical services to generate resilient design. Rather than providing extra capacity, resilient microgrids should include or center on areas with colocated services required after a disaster, such as open space, medical services, and grocery or food provision. The location of services should drive resilient microgrid development rather than the technical benefits during continuous operation.

   Numerous sites in San Francisco were found to meet this colocation requirement for microgrids. One example is shown in Figure 4.

Map data © 2017 Google

Figure 4: Close-up of one potential microgrid area showing the proximity of buildings (yellow) and lack of public rights-of-way in the microgrid boundary (orange)

Step 4: Choose Sites

While it would be ideal to install solar and storage in every shelter, the reality of financing and municipal budgeting creates a large barrier to installing solar across all critical facilities. Furthermore, to ensure technical feasibility and build awareness of the benefits of solar and storage for resilience across city departments, case studies are required. It is therefore important to prioritize the list of candidate facilities to identify those that provide the greatest benefit to the entire community and city government. Because the long-term success of the deployment strategy may rest on initial implementation, it was key to select pilot study sites that address the priorities of key stakeholders in CCSF and the community. To identify appropriate sites, SFE engaged the following:

- Office of the Mayor
- Fire Department
- Police Department
- Neighborhood Empowerment Network
- SFDEM
- Office of Resilience and Recovery

Using these departments as a filter, the project team began to shorten the list of critical facilities established as candidates for solar and storage to those facilities where it would be practical for design and implementation. To further reduce the list, the Board of Supervisors were engaged. From the beginning, the planning strategy targeted one site in each district of the 11 members of the Board of Supervisors, plus one extra site. Because San Francisco's districts each elect their own supervisor to represent their district, locating at least one priority site in each district helps demonstrate to all supervisors and the electorate the value of the project. SFE and SFDEM shortlisted three to five projects in each district and then sought input from the supervisors directly, as well as Neighborhood Empowerment Network, an organization that bridges the gap between city administrators and local community leaders. With the help of both groups, the project planning team selected one to two facilities in each district for detailed study and consideration for pilot implementation. The 18 selected buildings are listed in the table below, and their locations are shown in Figure 5.

Schools	Recreation Centers	Libraries	Other
Marina Middle School	Hamilton Recreation Center	Marina Library	Providence Baptist Church
John O'Connell High School	Moscone Recreation Center	North Beach Branch Library	Maxine Hall Health Center
Francisco Middle School	Joseph Lee Recreation Center	Western Addition Library	
George Washington High School	Minnie and Lovie Ward Recreation Center	Visitacion Valley Branch Library	
St. Ignatius College Preparatory	Harvey Milk Center for the Arts		
Thurgood Marshall High School			
AP Giannini Middle School			

Figure 5: Shelters used for load analysis for solar and storage evaluation

Step 5: Site Investigation

Once sites for resilient backup power were selected, site investigation was required to fully understand the emergency power loads for the site and confirm the appropriateness for solar and storage. The mapping exercise provided a good foundation for screening sites for solar and storage readiness, but elements of electrical capacity, structural integrity, site space for batteries, and true emergency electrical load must be determined on-site. For this study, confirming appropriateness of each site required on-site investigation. In the future, these assessments could be combined into routine maintenance and building evaluation and the results stored within the critical facility database. Incorporating these assessments into each department's maintenance procedures is a tangible action that should be pursued.

Building on the information stored in the critical facility database, site investigations helped clarify the following:

- Intent of the facility's operation after a disaster, number of occupants expected, hours of operation, and expected period of use
- Actual anticipated electrical loads in disaster situations
- Potential space and roof construction quality for solar panels
- Appropriateness of existing electrical infrastructure and distribution for solar and storage integration
- Existing emergency backup generators / alternative generation

SFDEM arranged site investigations for the buildings identified as candidate. In future expansion of solar and storage projects, site visits should be arranged by the agency with direct oversight of the facility or directly with the facility manager. It is advantageous to tour the facilities with both an on-site facilities manager/engineer and the intended manager of the facility during emergency and disaster operation. This will ensure access to all the information needed to assess the current electrical systems and determine the needs in an emergency system.

Building Load Assessment

Though SFDEM provided some information on emergency electrical requirements for critical facilities, the composition of the load was not known. Understanding how the load changes in relation to time of day during critical operation is very helpful in sizing solar and storage systems. Therefore, site investigations were used to gain a greater understanding of the building load. Prior to site investigations, whenever possible, historic energy consumption and information on facility use after an emergency were used to gain a preliminary understanding of energy use. These were very helpful in creating load profiles for each of the 18 facilities. Shelter use was characterized in the San Francisco shelter database and electricity use from historic energy bills. For those sites without historic electric bill records, downloading energy data through the Green Button program was an option. Green Button allows a facility owner to download their facility's historic electricity consumption securely from the utility.[10]

The information gathered from the site investigations and the facility utility bills was helpful in constructing building load profiles for the 18 facilities being studied for solar and storage. Load profiles were essential to understanding how the proposed generation systems would meet the critical need after an event.

[10] http://www.greenbuttondata.org

Appliances

- Will there be cooking, refrigeration, coffee machines, copiers, radios, washers/dryers, dishwashers, etc.?
- What are the usage estimates?
- Will there be phone charging? If yes, how many phones are expected?

Lighting

- Where is lighting required? Is all lighting required or is there designated emergency lighting?
- What is the load? Will it be reduced during daylight hours or controlled by occupancy?
- Which areas will be lit and for what hours of the day?

Communications

- Are communications required?
- What server racks will be required? What is the rating of the server racks?
- Is Wi-Fi needed?

Computers

- Are computers required?
- How many are expected to be used and between what hours?
- Are they laptops, PCs, single monitor, dual monitor?

HVAC

- Is heating/cooling required?
- Is the heating gas or electric?
- Will the communications room require cooling to be maintained?

Hot Water

- Is hot water needed?
- Is the hot water unit gas or electric?
- What is the power consumption?

Operations

- What purpose will the building serve in a disaster situation?
- How many occupants are expected? Are they staff, displaced residents, injured, or living in the building?
- Between what hours will the building be occupied?

Solar PV

- Is the roof structurally sound and accessible? Is there a parking lot or other free space suitable for solar?
- Does the building or site have access to sunlight or is it shaded?
- Is the building likely to withstand a disaster?

Existing

- Is the current system set up to provide separate emergency power?
- Are the panels/loads which will need to be powered all on the emergency circuits?
- How do they currently switch to backup power? Manual/automatic?

Figure 6: Questions to ask during a site visit to help identify loads

Two methods were developed to generate a load profile for a facility:

- **Using actual meter data from the building, complemented by site investigation:** This requires that meter or utility bill data be available for the prior year of facility operation and that the facility would have essentially the same use profile under emergency operations, and a scaling factor can be applied (e.g., 10%). A good starting point for accessing historic data is the Green Button program, through which building owners can download their electrical use data. Where possible, actual meter data is the most accurate representation of the expected emergency load where buildings operate in a similar manner in an emergency. For instance, a fire station is likely to retain the same use patterns. If the facility manager knows that some loads may be added or removed in emergency operation, the meter or bill data can be adjusted to account for this.
- **Using load estimations and time-of-use predictions based on site investigation:** Where billing or meter data are unavailable, or it is known that the emergency operation of the building will differ significantly from the normal operation, the load must be constructed from information gathered in the site investigation. Documenting existing equipment and use, and discussing how it will be used during an emergency with the facility manager provides the information necessary to construction the load profile. The daily profile may differ by weekday and weekend, and it may also change in emergency operation.

Regardless of the approach used to construct the emergency load, the site investigation is helpful to confirm the parameters of the emergency load, including lighting and equipment requirements, and to confirm the expected operating schedule following a disaster. For each site visit, a worksheet encompassing questions to understand these aspects of the building was used. Some of these questions are shown in Figure 6.

No matter which method was used, the final load shape was required as an hourly profile. This is necessary to properly evaluate the relationship of daytime and nighttime load, and the probability of balancing the load with solar generation and storage on cloudy days. To generate hourly load profiles, information from the shelter database and site investigations was used to create archetypal loads by shelter space use. Relationships were derived for appliance density and anticipated usage in each similar space type; similarity was determined by expected function in an emergency.

To assist evaluators and designers in identifying the emergency loads of similar uses in critical facilities found in the shelter database, hourly load archetypes of common critical facilities have been provided for three building types that represented the majority of shelters in the database. Similar facilities can also be represented through these archetypes. Archetypes, shown in Figure 7, were created for recreation centers, libraries, and schools.

Archetypes can be helpful for evaluators taking either approach to estimating building load. In cases where only monthly energy bill data are available, choosing the archetype most similar to the facility being investigated and then scaling the monthly energy consumption to meet the bill data can provide a good estimate of facility energy use. Paired with adjustments to the underlying assumptions of the archetype based on site investigation, a reasonably accurate model of loads can be devised.

Similarly, if the load must be constructed using equipment estimates and time-of-use predictions, the archetype can be used as the starting point. Individual equipment properties can be altered based on the equipment identified while walking through the facility. Unless schedules have been otherwise noted in walking through the facility, equipment and occupancy schedules from the archetype can be used.

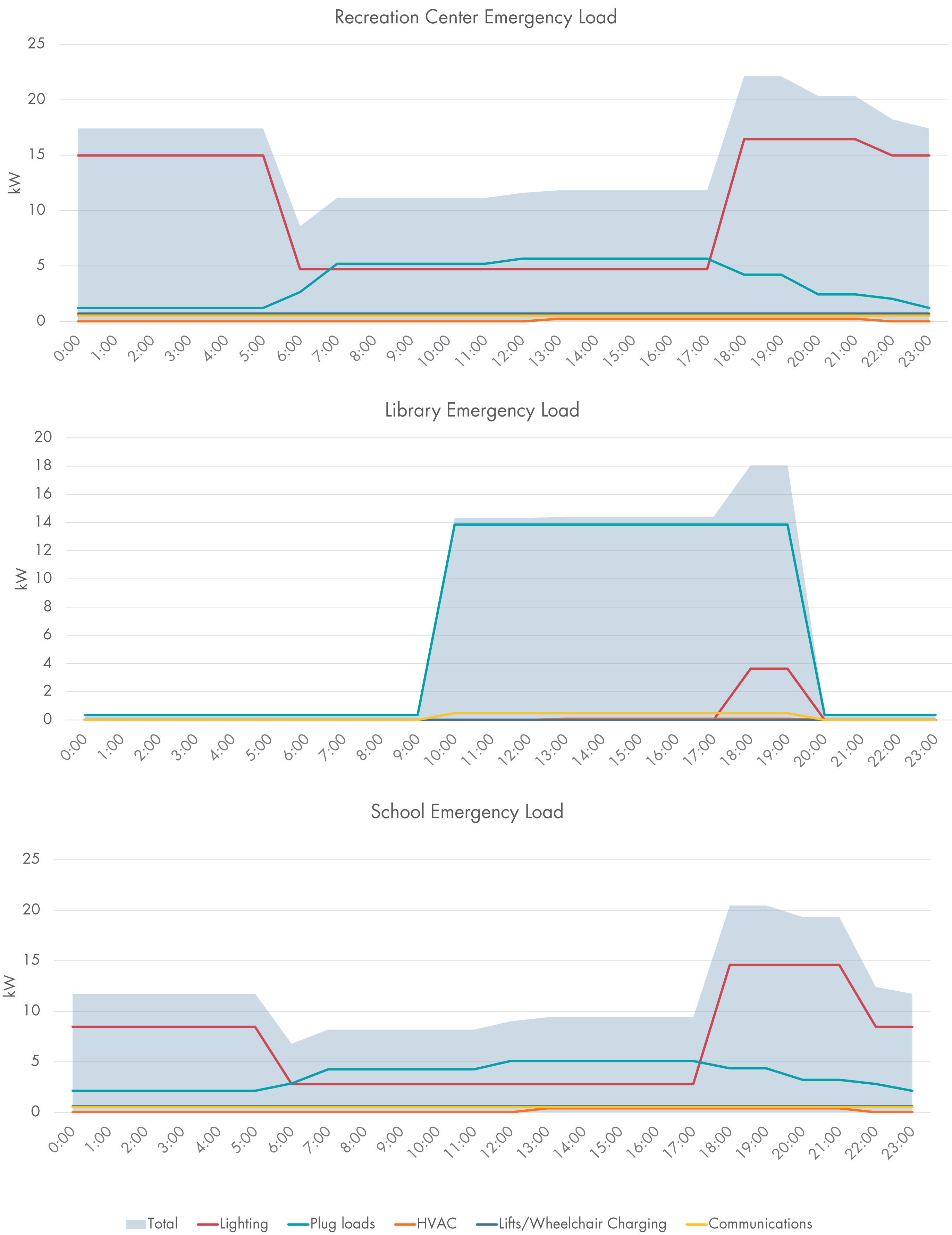


Figure 7: Sample load profiles for three common building types

As shown in Figure 7, the loads were divided by end use to help understand and adjust the composition of each end load by facility. Five categories of loads were identified as critical to understand in detail for any given building: heating, ventilation, and air-conditioning (HVAC); lighting; communications; Americans with Disabilities Act (ADA)–required loads; and plug loads. For most buildings, HVAC will likely be limited in emergency operation but may be required to ensure that the shelter does not add stress to inhabitants as it becomes too hot or too cold. Lighting will also vary by space but can be predicted as a minimum required lighting for a particular site. ADA-required loads include lifts and wheelchair charging, and should be prioritized to ensure equitable shelter access. Communications requirements may vary by building depending on the services a facility is anticipated to perform. Plug loads are likely to exhibit the greatest variation and will depend on whether medical services, sleeping, or other uses are anticipated.

Determining On-Site Solar Potential

For the 18 case studies, evaluation of the load was paired with an evaluation of the on-site generation and storage potential. In general, rooftop PV arrays were preferred where roof space was available. Roofs usually have fewer shading challenges than ground-level open space and keep surrounding area open for other uses. Prior to visiting a building, the project team used satellite imagery to make an initial assessment of rooftop solar potential. Satellite data provide a quick assessment of which parts of the roof are accessible for solar and can easily alert designers to any portions of the roof used for greenery, skylights, or other functions that are incompatible with rooftop solar. Measurements of the rooftop area can then be made using the original project drawings or the area tool in Google Earth to

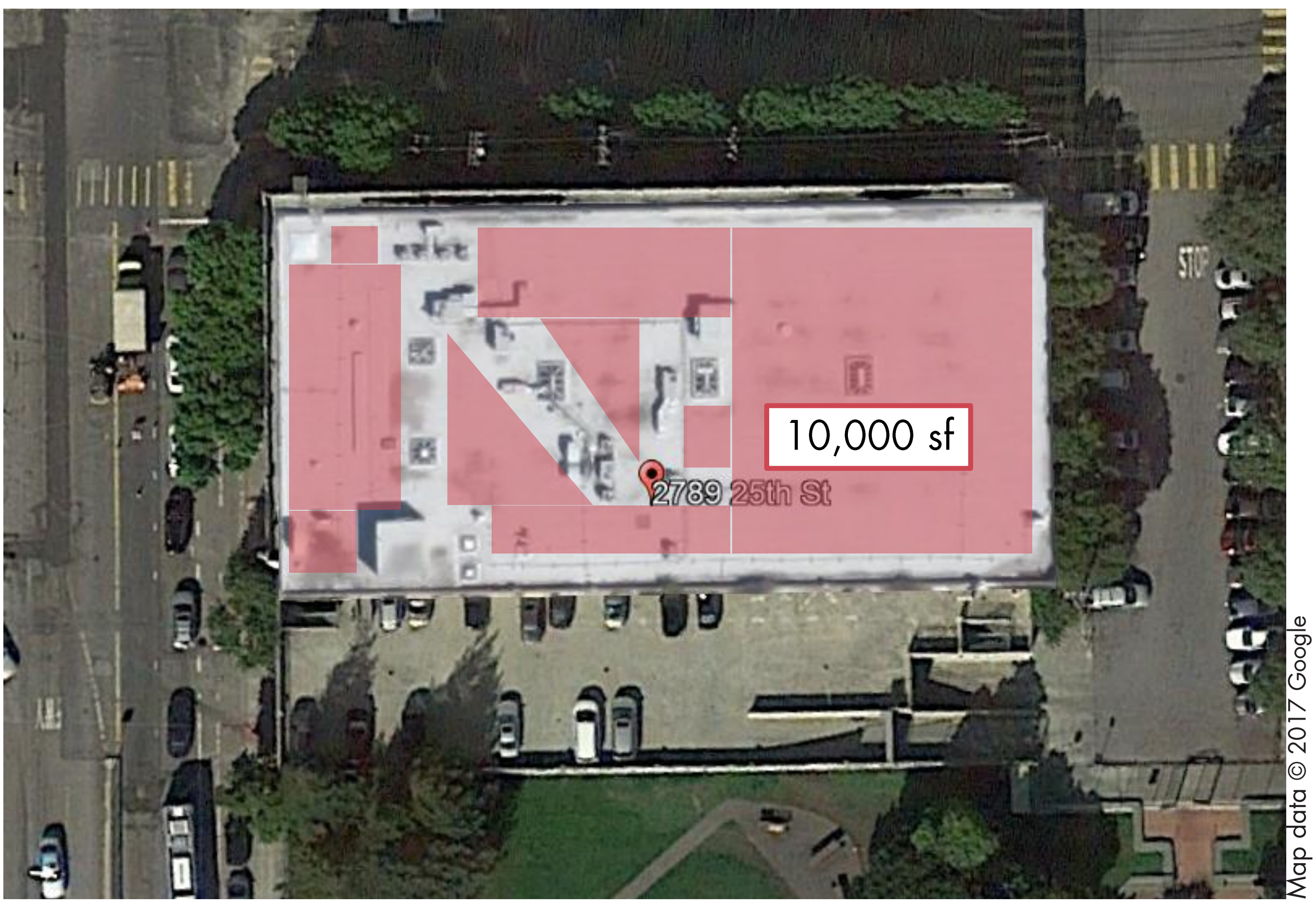


Figure 8: Diagram showing quick evaluation of roof area, from which solar area can be calculated

provide a starting point for calculating rooftop solar capacity, as shown in Figure 8. Project Sunroof, a free service from Google, can also provide a quick assessment of the area available on the roof for photovoltaics (PV). These estimates must be confirmed through detailed site investigation.

Beyond confirming availability of roof area for solar PV, site investigation is required to evaluate the condition of the roof. Quality of the roof construction, ability to withstand penetrations, shading impact, and slope should be investigated to determine which areas of the roof are in fact suitable for solar.

If not enough roof area is available or if the roof is unsuitable for solar panels, other areas on the property can provide additional PV-generation space. Parking lots, car ports, empty lots, and any adjacent City-owned unused land can provide opportunity for ground-mounted PV to augment or replace rooftop-mounted systems. These structures have the additional advantage of providing shading to pedestrians or cars, and some shelter after a disaster. As with roof area, estimates of the area available on these sites can be made from area takeoffs of satellite images.

One example where ground area was required for solar availability was found at the Waller Street Park Police Station. For this site, through a combination of satellite imagery analysis and conversation with the building managers, the project team concluded that the condition of the roof was not favorable for solar panels. Surrounding the police station, however, is a large parking area that could incorporate PV shading structures. The land to the south of the site is also currently not serving any useful purpose and is city-owned. Ground-mounted PV, storage, or parking shading structures could be an option in this location, as shown in Figure 9.

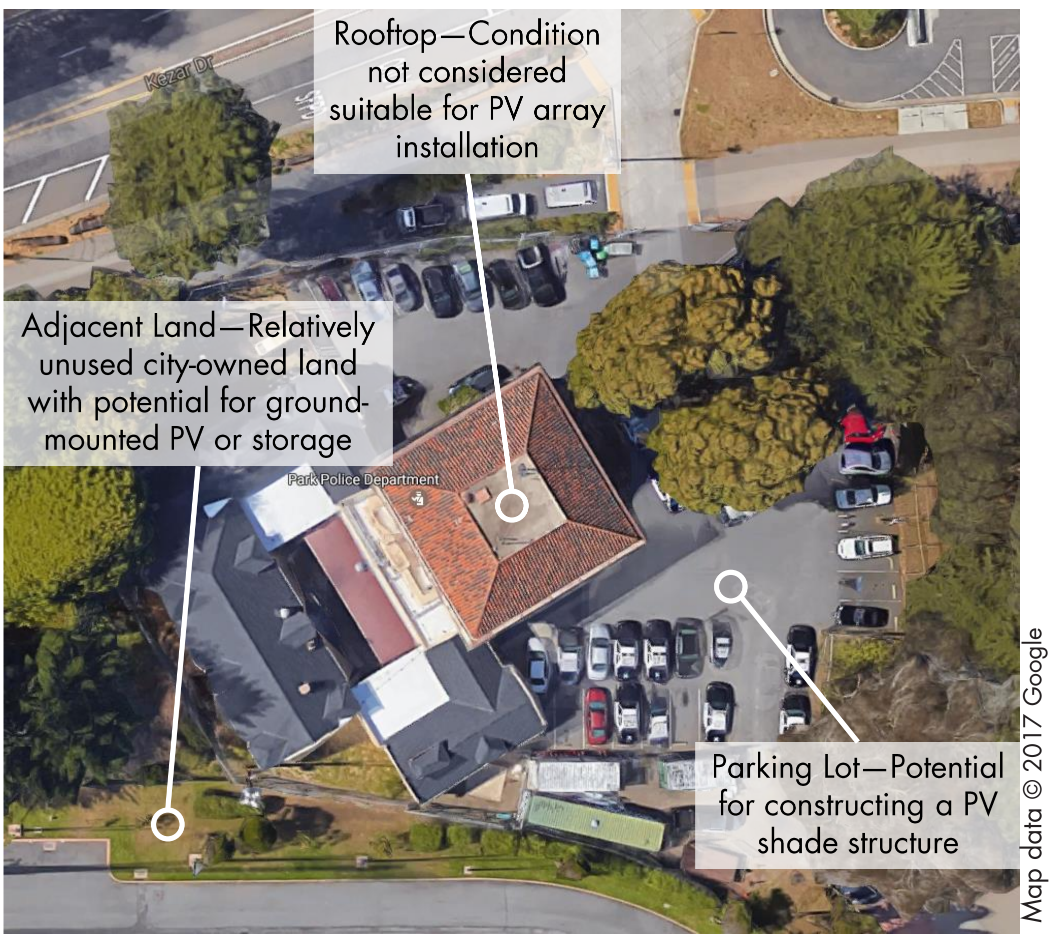


Figure 9: Solar potential for 1899 Waller Street; the image shows how adjacent land can also be identified for solar potential

Determining Storage Potential

The final aspect of site readiness determined during the site investigations was the potential for on-site battery storage. On-site battery storage potential is much more flexible than solar, but specific requirements must be met. Locations for battery storage should be enclosed and well-ventilated, and may be located indoors or outoors. Outdoor installations should be within a rated enclosure and may require a setback from the building and adequate space for ventilation The battery should reside in an area of the site that is not prone to flooding or other damage in the event of a disaster. Ideally, the batteries should be located near the inverter and the solar panels to minimize loss between the solar and battery network, and to facilitate system maintenance. Depending on the type of battery and the nature of the facility where it is to be installed, other requirements may apply.

During the site walk for each facility, the facility managers for each building helped identify possible locations where batteries may be installed, as well as the floor area available for battery installation. From these assessments, information on battery sizes and capacities from manufacturers were used to determine the maximum allowable size of on-site storage. Battery size and capacity in relation to the space available did not prove to be a limiting factor in any of the cases examined, but it is feasible that this could be limiting in other sites.

Evaluating Electrical System and Backup Power

The readiness of the electrical system for solar and storage should be assessed, especially for retrofits of older buildings. Typically, retrofit buildings fall into two categories: newer buildings with segregated emergency loads and panel space to accommodate solar and storage, and older buildings without segregated emergency loads or panel space. If the building already has a backup generator or power system, it also likely falls into the former case. For newer buildings, addition of a solar and storage system is entirely feasible. For older buildings, retrofitting a solar and storage system will have a significantly higher cost as additional electrical work is required. Without load segregation, the size of the system may also need to be larger; otherwise, performance after a disaster may rely on building operators using electricity for only critical functions rather than allowing the building to operate normally.

In addition to the panel space and load segregation, space also had to be identified for the inverter and charge controller. These can be mounted in the electrical room or elsewhere in or around the building. Identifying capacity in conduits and electrical chases from the likely PV location to the electrical room was also key. New chases can be added, but this would increase the cost of the installation. Finally, the electrical meter was evaluated to determine whether it is capable of collecting interval data and net metering of solar production. If such a meter is not installed, an upgrade would be required.

The project team also investigated existing emergency power generation as these systems may play a role in a microgrid or to augment a stand-alone solar and storage system. Knowing the capacity and condition of the generator helped to determine whether this was an option. The maintenance history of the generator and the amount of on-site fuel storage can also help in sizing new equipment and in determining when the existing backup may become obsolete. Scheduling future evaluations of buildings for resilient solar and storage, to coincide with the generator replacement schedule offers a good opportunity for resilient solar and storage to be integrated to the building.

Deciding Between a Microgrid or Stand-Alone System

Prior to sizing any resources for the buildings, a decision must be made regarding whether the building would have a stand-alone solar and storage backup system or be part of a microgrid connecting several buildings to one another. This decision is based on an assessment of the following:

- Proximity of other critical facilities
- Policy barriers to microgrid development in the jurisdiction of the critical facilities
- Technical barriers to microgrid development in the specific location of the facilities
- Availability of solar and storage resources at individual buildings

Proximity and availability of solar and storage resources are discussed below. Barriers to microgrids are discussed in detail in Appendix A.

Proximity of Other Critical Facilities

During the course of this study, it was found that the main reason a microgrid may be advantageous for a given project is the proximity of buildings requiring power after a disaster. While planning for disaster resilience is not often the impetus for microgrid development, it has become clear that microgrids are most effective for resilient infrastructure when planned in areas with multiple critical facilities within a one- to two-block radius. As discussed in Step 3, mapping buildings using GIS or a browser-based mapping service (e.g., Google Maps) provided an initial screening for where these colocated services may exist. Figure 4 shows an example of this high-level identification.

Where all of the buildings have the same critical load and where each has sufficient solar and storage area, a microgrid may not be advantageous. For the greatest benefit from a microgrid, diversity of loads is beneficial. When loads are different, the peaks of individual loads can offset and reduce the required solar or storage sizing. When loads are identical across buildings, connecting buildings in a microgrid may introduce unnecessary cost, loss, and risk to the system for only a marginal improvement in the overall system resilience. Except where the added resilience of a microgrid is beneficial, in these cases stand-alone systems may be a better solution.

Availability of Solar and Storage Resources

Microgrids may also be driven by lack of availability of roof area or battery installation at one or several facilities. In cases where individual buildings may not have sufficient solar area or space for battery installation, creating a microgrid that connects several facilities could be a necessary option. Connecting multiple buildings together allows the solar area or storage area on all buildings to be shared in meeting the combined load. When no additional critical facilities are present, parking lots, parks, and other open spaces can provide areas for additional solar generation that feed back to the critical facility. It may also be possible to set up a microgrid arrangement with a nearby private facility. Though more difficult, if the private owner installs solar and/or storage, they could benefit from the asset in normal operation while allowing the critical facility to use the resources after a disaster. This can be guaranteed through an availability payment, roof or building lease, or other contract structure.

Step 6: Design Solar and Storage

After identifying the loads of the facility and the suitability for solar and storage, the next step was to determine the size of solar and storage to meet the backup needs of the facility. Sizing is based on balancing the expected duration of the outage with critical load requirements and the expected weather during the disruption. To assist in sizing, Arup has created SolarResilient, a tool that uses the inputs identified in the previous steps of site and facility analysis to generate estimated solar and storage needs.[12] The intent of the tool is to provide building owners and managers with an estimate of the PV and battery capacities required to provide a desired level of resilience. The recommended capacities are translated into rooftop and parking lot area for a PV array, and interior or exterior space for the battery system. This gives the facility manager an idea of what system sizes are feasible for their building.

This section provides a brief overview of the tool — a more detailed description of the tool and its use is available in Appendix B.

Using the Online Sizing Tool

The SolarResilient tool has three pathways for analysis to help facility managers understand the solar and storage potential of the building:

- **Quick:** The user inputs the annual electricity peak demand of the building, the location, and the desired outage duration and percentage of the total electrical load to be supported during a disaster event. The tool creates an hourly emergency load profile based off an electrical load profile for a typical office building in the chosen climate zone, scaled to match the entered peak demand and desired load percentage. Other building types are not modeled.
- **Standard:** The user uploads the actual electricity profile for the building. These data must contain hourly or 15-minute data for a full year starting at midnight on January 1, to match the hourly PV data used in the calculations. The user also enters the desired timeframe and percentage of the total electrical load to be supported during a disaster event. The tool creates an hourly emergency load profile by multiplying the uploaded electricity data with the emergency load percentage.
- **Detailed:** This is the most accurate method. The user enters the following information about each load type that will be running during a disaster event:
  - Wattage per fixture/appliance/device
  - Quantity
  - Diversity (% of the time each fixture/appliance is used)
  - Daily schedule (start and stop hours)
  - Annual schedule (start and stop months)

  The tool uses this information to create an hourly emergency load profile for a full year.

The output of the SolarResilient tool provides the capacity of both solar and storage required to meet the input conditions. Solar panel output is calculated using the building location to identify incident solar power from the National Renewable Energy Laboratory's National Solar Radiation Database.

[12] http://solarresilient.org/

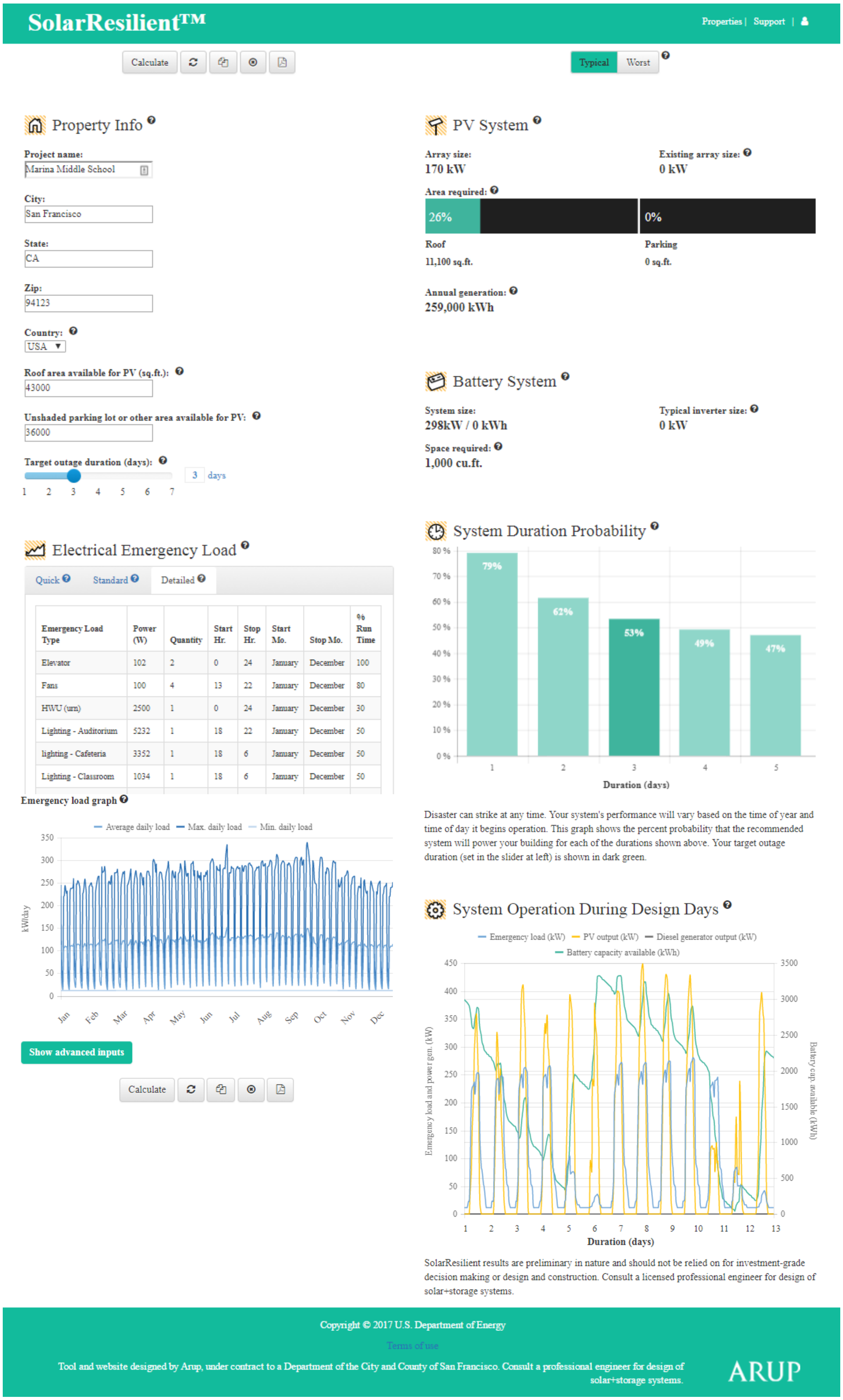


Figure 10: Solar and storage sizing tool developed by Arup

Multiple scenarios can be run to test input parameters and determine which best serve the site needs. The tool also displays the percentage of available solar roof and site area that must be used to meet the required backup criteria. Learning from the case studies tested in this study, the project team found that in cases where the required area exceeded the available area, a few strategies could be pursued:

1. Different inputs could be tested with the tool to find a good compromise for a backup system that balances area and critical load. This could involve shrinking the peak load, shortening the duration of the outage that can be weathered, or managing average rather than worst-case performance.
2. The load profile could be reassessed to ensure that it accurately represents the facility being simulated. Furthermore, the critical loads could be double-checked to ensure that they are truly critical. In future projects, this may involve a follow-up meeting with the facility manager to explore whether any loads can be eliminated or reduced to balance power provision with critical need.
3. If the area required is greater than that available for only the worst-case scenario, management plans could be created for the facility under both worst-case and average post-disaster scenarios. Knowing which loads should be reduced if generation and storage do not meet the average expectation helps prevent the unexpected loss of power at the facility after an event.
4. If additional area was truly needed to provide the level of backup required for the facility, the team could revisit whether a microgrid incorporating nearby buildings was possible. Using the ground or roof area of nearby facilities could be the best alternative for meeting the critical backup need.

Sizing Results for the Case Study Buildings

The 18 case study buildings (including 3 studied as a microgrid) were evaluated using SolarResilient. Systems were sized for a typical and worst-case three-day outage. These results are in the table below.

	Typical Assessment			Worst Case Assessment		
Building	**PV Size (kW)**	**Battery Size (kW)**	**Battery Size (kWh)**	**PV Size (kW)**	**Battery Size (kW)**	**Battery Size (kWh)**
Hamilton Recreation Center	54	83	330	130	103	410
Marina Microgrid (3 Total Buildings)	190	333	1,330	460	420	1,680
John O'Connell High School	130	183	730	320	238	950
Francisco Middle School	71	105	420	170	135	540
George Washington High School	140	240	960	130	103	410
AP Giannini Middle School	110	188	750	270	228	910
St. Ignatius College Preparatory	97	140	560	240	180	720
Joseph Lee Recreation Center	20	25	100	51	38	150
Providence Baptist Church	40	60	240	98	75	300
Minnie and Lovie Ward Recreation Center	53	73	290	130	95	380
Maxine Hall Health Center	30*	9	36	30*	100	400
North Beach Branch Library	15 (12*)	33	130	54 (12*)	48	192
Western Addition Branch Library	27	25	100	66	38	150
Harvey Milk Center for the Arts	45	55	220	110	80	320
Visitaction Valley Branch Library	20	19	76	50	28	110
Thurgood Marshall High School	87*	63	250	87*	123	460
*Denotes existing PV						

As the sizing data indicate, for the worst predicted outage, the battery size changes by less than 20% while the PV system roughly doubles. This is expected, given that the worst case assumes three days with limited solar resource. Since PV also provides a more guaranteed return on investment, upsizing PV arrays can provide a greater return during normal use, while providing added resilience in the case of an outage.

The previous table details the sizing parameters based on the loads identified at each building. A different but important sizing criteria may be to size the solar and storage system to best capture the federal investment tax credit (ITC). In this case, sizing may be different because to capture this credit, energy storage must be charged with a minimum of 75% solar energy. To demonstrate the difference in sizing to meet the ITC requirements, an analysis was carried out to determine the maximum size of battery (in kW, assuming a 1, 2 and 4 hour battery) with a fixed 100 kW PV array size that would be charged 75% with solar. For any size (kW) battery, the PV energy output necessary to overcome the 75% threshold is ultimately limited by two factors.

- Battery duration (kWh)
- Number of battery operation cycles in each day

The PV charging requirements may limit the number of cycles that can occur in any day, especially for long duration (e.g. 4 hour) batteries. Availability for the battery to perform any ancillary services may be limited based on coincidence with PV charging. The results from the analysis are shown below.

Battery Duration	1 Hour	2 Hour	4 Hour
1 Cycle per Day	320 kW	160 kW	80 kW
2 Cycles per Day	160 kW	80 kW	40 kW
3 Cycles per Day	106 kW	53 kW	Not possible
4 Cycles per Day	80 kW	40 kW	Not possible

The number of cycles that the battery will be operating (for demand charge reduction and ancillary services) results in differing PV to storage ratios. For example, if the battery was required to operate for 2 cycles per day, then for every 100 kW of PV installed a one hour battery would be sized for 320 kW/320 kWh, a two hour system for 160 kW/320 kWh, and a four hour system for 80 kW/320 kWh. The number of cycles that the battery will be required to operate should be investigated during the design process.

The results from these 18 buildings were extrapolated to 67 shelters in San Francisco to calculate the total PV and battery size requirements for all shelters within the city. The project team calculated PV and battery requirements by space type within recreation centers, schools, and libraries from the 18 buildings studied in detail. These values were then multiplied by the total square footages of each space type within the 67 buildings to determine total PV and battery requirements. These values are shown in the table below.

Space Type	Area (sf)	System Profile	Dormitory (% sf)	Evacuation (% sf)	Library (% sf)	PV (kW)	Battery (kW)
Clubhouse	23,348	Recreation Center	40%	43%	0%	85	150
College/Adult Education	5,940	School	8%	14%	0%	6	10
Convention Facility	1,425,000	School	8%	14%	0%	1,331	2,392
K–12 School	2,530,591	School	8%	14%	0%	2,364	4,248
Other Recreational Building	5,000	Recreation Center	40%	43%	0%	18	32
Performance Hall	1,061,450	School	8%	14%	0%	991	1,782
Recreation Center	277,895	Recreation Center	40%	43%	0%	1,006	1,789
Library	571,281	Library	0%	0%	80%	2,384	2,468
Grand Total	**5,900,505**					**8,180**	**12,870**

Step 7: Project Finance

Ideally, every facility or group of facilities that is identified as a candidate for resilient backup power would have a pathway to size and install solar and storage. However, budgeting and financing are often barriers to wider adoption of solar and storage at critical facilities. San Francisco is no exception to this rule. Departmental budgets often do not allow for widespread adoption of resilient solar and storage deployment, and no capital budget is currently available for upgrading the resilience of critical infrastructure. Typical financing methods of bonds and taxes may require voter approval, creating a lengthier process for deploying resilient infrastructure. Therefore, exploring effective and innovative budgeting and financing techniques for solar and storage was determined to be a key component in improving the resilience of San Francisco's critical facilities.

Aside from the challenges of municipal financing, solar and storage financing is a complicated undertaking for several reasons:

- Returns are determined by electricity rates, which vary by facility and energy provider, and have uncertainty in future escalation. Typically rates are set for at most three years in the future with no guarantee of stability beyond the end of the current rate case.
- San Francisco has multiple options for incentivizing solar and storage due to its position as a customer of the San Francisco Public Utilities Commission (SFPUC). Furthermore, should the city choose to partner with a private entity, additional funding mechanisms would be available (e.g., feed-in tariff, net metering, income tax refund).
- Energy storage financing options are still developing as the California Energy Commission, California Public Utilities Commission (CPUC), and utilities (e.g., SFPUC, Pacific Gas and Electric [PG&E]) identify the best mechanisms for storage interactions on the retail and wholesale markets.
- Several options for design, construction, ownership, and maintenance of solar and storage systems are used in the marketplace currently.

As a result of this variability in financing options, the optimal financing choice for San Francisco depends on whether a single building is being evaluated or a portfolio of buildings is being considered. For single buildings, addition of solar and storage can likely be accomplished through direct procurement by the city department through capital planning or at the time of building renovation. If capital is unavailable, a power purchase agreement with a third-party provider could provide a zero-capital approach to installing solar and storage.

For a portfolio of buildings, financing is more complex, requiring different mechanisms for obtaining capital and sharing risk and return. In the case of the 8.2 MW of solar and 12.9 MW of storage required to serve the 67 shelter buildings in San Francisco, two financing models were compared:

- **Design-bid-build (DBB)**: DBB is the traditional mode of project delivery — the CCSF contracts the design of a project, bids the design to local contractors, and finances the construction. The city retains ownership of all assets and takes on all risk in each phase of the project. Project capital must be sourced using the owner's debt and equity alone.
- **Public-private partnership (P3)**: In a P3, the city would seek a private-sector partner to share the financing and risk of the project in all phases, relying on the private-sector partner to provide most of the initial capital in exchange for allowing the partner to operate the installation for a set number of years as a means to recover the initial capital expense. At the end of the operation period, the private partner hands the asset over to the city.

P3 models have been applied to municipal assets in a variety of contexts, including toll roads, bridges, railways, and other major infrastructure. In these cases, P3s have been shown to reduce risk and provide a viable vehicle for executing large projects with high capital requirements on a limited budget.

Delivery Type	Positives/Benefits	Negatives/Risks
DBB	• City maintains control of project, able to require certain means and methods to achieve the desired outcome, both in terms of aesthetics and performance. • City has access to low-cost financing due do its strong bond rating. • City can leverage existing operations and maintenance staff, and experience with implementing previous capital projects (solar only).	• Significant risks related to design and construction that could lead to schedule delays and cost overruns, risks associated with delivery on time and on budget. • City would have to dedicate bonding capacity to the project that could otherwise be used for projects more central to the City's core missions. • City may not have sufficient bandwidth to properly manage the entire life cycle of the project (from design and construction through operation); City would likely have to supplement existing staff in terms of numbers and expertise.
P3	• Passes responsibility and risks to third parties whose primary business is to design, build, and operate facilities; enables the City to focus on its primary business: providing public services to taxpayers. • Avoids potential construction cost overruns and delays. • Leverages best practices in operations and maintenance industry to save costs. • Dedicated industry players have the ability to optimize the interface between systems (storage and solar) and the market. • Preserves bonding capacity and avoids need for large up-front payments to cover capital costs. • Benefits from oversight from private financing institutions to further ensure that the project is constructed on time and on budget, and performs according to contract specifications. • Able to take advantage of savings from tax equity structures by attracting entities that can leverage the federal investment tax credit (ITC) and Modified Accelerated Cost Recovery System, which is also known as accelerated depreciation.	• City loses some amount of control over the direction of the project (means and methods). • Significant repercussions to the City if private partner fails to manage market interface. • Private finance typically has more expensive cost of capital. • Difficulty in drawing boundaries around what remains the city's responsibility and what assets should be the responsibility of the developer. • Potentially high transaction costs relative to project size (P3 projects benefit from economies of scale in terms of transaction costs relative to capital expenditures).

While P3 models for infrastructure are well known, P3 models for distributed solar and storage development are not as well documented. The closest analogue are power purchase agreements for single buildings, which are similar to P3 models but on a smaller scale. Expanding this approach to distributed solar and storage in multiple city-owned buildings could have significant potential but would require a new model. Figures 11 and 12 show how a P3 model could be applied to solar and storage deployment.

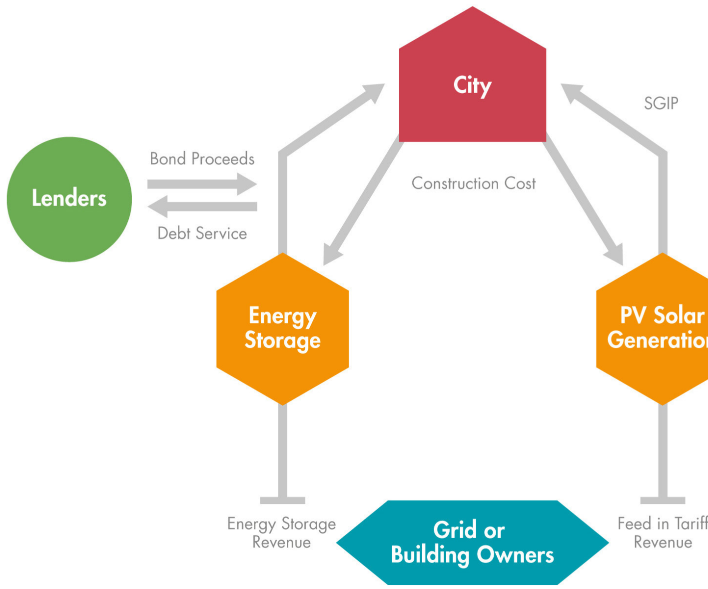


Figure 11: Design-bid-build structure for procuring solar and storage for San Francisco

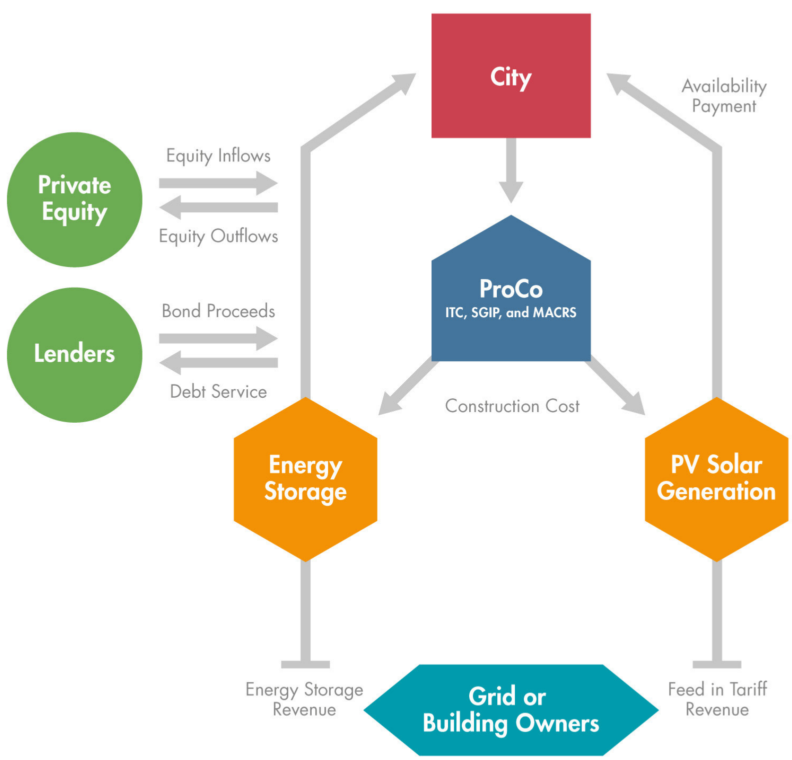


Figure 12: Public-private partnership structure for procuring solar and storage for San Francisco

In addition to a new model for deploying solar and storage, whether under a DBB or a P3 structure, the project would require a mechanism by which both the CCSF and any private partner could achieve a guaranteed return. Currently, market mechanisms for solar and storage revenue for either the city or a private entity are limited to the following:

- **Net metering**: In hours when the solar array is overproducing, credits are accrued for the building owner. These credits are used to offset payment of electricity costs in other hours when the facility demands more electricity than is being produced.
- **Feed-in tariff (FIT)**: The utility pays a flat rate for solar generation to the owner of the panels while charging a different rate (or a tiered rate) for consumption. Two meters are required for the customer facility to monitor both energy use and production.
- **Demand charge reduction**: Solar and storage assets can be used to offset peak demand in the customer facility, thereby reducing the amount spent by the facility on the peak-demand charge. This operation is entirely behind the meter.
- **Investment tax credit (ITC)**: Currently, a federal tax rebate is available for investment in solar and storage. The rebate is available only to private entities and is up to 30% of the total capital cost of the solar and storage system. To capture the ITC, it is important to note that the battery must be charged with a minimum of 75% of the energy coming from the PV. This affects the PV and battery sizing ratio.
- **Self-Generation Incentive Program (SGIP)**: CPUC has introduced the SGIP, which provides incentives for solar and storage projects throughout the state. The incentives are based on a first-come, first-served application process and apply to the capital cost of both solar and storage.

An analysis of the best economic packages for San Francisco's proposed shelter solar and storage portfolio showed that the highest return combination of incentives would utilize a FIT, SGIP, and ITC (with a private partner). This was based on current electricity rates and FIT rates from SFPUC, the power provider for the sites studied. Additional analysis of this choice is provided in the Preliminary Financial Analysis Report, which is available at the Solar and Storage for Resilience project website.[13] The choice of incentive packages is unique to each project, however, and should be evaluated for any future efforts based on current rates.

Evaluating the performance of the solar and storage requirements for the 67 shelters in San Francisco under a DBB and a P3 model, the project team found that the city would be responsible for a significantly lower portion of the capital expense under a P3 but would incur an annual payment to the private entity for ownership and maintenance. Evaluating these structures over a 20-year lifetime shows that a P3 would save the city on total cost for deploying solar and storage systems.

[13] https://sfenvironment.org/solar-energy-storage-for-resiliency

Step 8: Construction and Operations

The final step of the resilient solar and storage process is to execute the work. Though financing has not yet been secured for the entire portfolio of resilient solar and storage projects, several of the projects documented in this study are moving toward pilot development and design. To assist in these and future resilient solar and storage efforts, recommendations for project development, construction, operations, and maintenance were devised.

For any department in the city seeking to deploy solar and storage, finding the right engineer and contractor can be a challenge. Prior experience with local firms may provide a great starting point to identify those with particular expertise in solar and storage design and deployment. Engaging SF Planning or SFE may help other departments identify such contractors, and as resilient solar and storage projects are completed, tracking which firms performed the work and the ultimate quality will help build a portfolio of qualified companies across the city government. Whether recommended firms exist or not, each project should be bid through a competitive process that emphasizes cost and quality to ensure the best overall project execution. Within the guidelines of the city's procurement process, it is important to ask in the proposal for examples of similar projects to assess the ability of the firm to adequately perform the work. With the booming solar market in Northern California, San Francisco should also have no shortage of local contractors experienced in solar and storage projects.

Once the project designer is chosen, they should jointly consider the solar and storage technologies to be used. Today, more choices than ever exist for solar and storage products, so understanding what factors drive a decision is helpful in realizing the best possible design. For solar panels, some considerations are:

- Manufacturer location (e.g., is there a preference for domestic technologies?)
- Ease of installation (this may be specific to the project and whether it is roof- or ground-mounted)
- Aesthetics
- Degradation over time
- Technology type (e.g., silicon, cadmium telluride)

For storage, the key consideration is the type of battery chosen. Battery technologies vary significantly in their longevity and efficiency, so working with the engineer to choose the right one is important. In addition, battery technologies are currently changing more rapidly than solar, and new options may be available. Similarly, in recent years restrictions on certain battery types or their installation locations have been introduced by national and local authorities. Make sure that the designer is familiar with the latest guidelines and best practices prior to specifying a particular technology. In general, some things to consider when specifying batteries are as follows:

- **Depth of discharge**: One of the main differentiators in battery technologies is how much each is intended to discharge. Those that discharge more of their nominal power tend to be more expensive, but fewer of them are required to provide the same actual power output. Deep discharging of many batteries degrades them faster, so managing the depth of discharge is important in prolonging longevity.

- **Expected lifetime**: Batteries degrade significantly faster than solar panels, so choosing a technology with a longer life even at a higher capital cost may improve the lifetime economics of the project.
- **Round-trip efficiency**: Batteries lose some power in charging and discharging — this is known as the round-trip efficiency. Minimizing this loss helps ensure that the battery provides the most value to the owner.

Once a project partner and candidate technologies are selected and design is underway, permitting and approvals present the next hurdles. Utilizing the stakeholder network and champions documented in Step 1 of this process can help each department in the city ensure that the projects can be completed. Furthermore, experience has shown that it is very helpful to discuss early with fire and building inspectors what the project plans to achieve and how it plans to be isolated from the grid after a disaster. With microgrid projects in particular it is necessary to engage in this dialogue early since city officials may not be familiar with projects where multiple buildings are isolated after a disaster. Additional design reviews with city officials and coordination between fire officials, utility stakeholders, and building code officials may be necessary.

After the project is designed and approved, construction should be fairly straightforward, especially given the local solar installation experience in San Francisco. The contractor should ensure that their work will not disturb facility operation, and with the exception of tying to the grid, there should be no interruption to power service to the building. The owner and engineer should verify that the system has been connected and installed properly, and that the performance matches what is expected for the project. Monitoring of the system for the first three to six months after installation will ensure that both are providing the expected capacity, which is important for post-disaster operation.

Operations

As noted in the introduction, two of the primary advantages of solar and storage over generator-based backup systems are their lower maintenance requirements and ability to operate continuously to reduce cost and emissions associated with the building. Operation of these systems tends to be self-regulating but can take one of several forms depending on the financial incentives the project is trying to capture.

In normal grid-connected operation under a typical tariff or a time-of-use rate, if the batteries are not continuously charged and discharged, the system will utilize the power generated by the PV system to reduce the electricity imported from the utility grid, saving the facility money especially during times of peak use. This type of operation is exemplified in Figure 13.

Another strategy during normal operation is to employ load shifting for demand management by utilizing the batteries. This involves storing the energy generated by the PV in the batteries and discharging them to the loads at times that provide the most financial advantages or help to relieve peak pressure on the utility. Typically this operation occurs if high demand charges are experienced by the building. This type of operation is shown in Figure 14.

Operation during an emergency is also important to understand. During a grid outage or disaster situation, the buildings will transition to island-mode and rely entirely on the PV array production and the battery storage. The loads must be controlled automatically or manually to decrease to the critical services only to conserve power and extend the availability of energy for critical use for the maximum time period possible. The power generated by the PV will be used to serve the loads directly and charge the batteries when excess power is available. In times of low or no solar power, production the loads will be supplied from the batteries. This type of operation is shown in Figure 15.

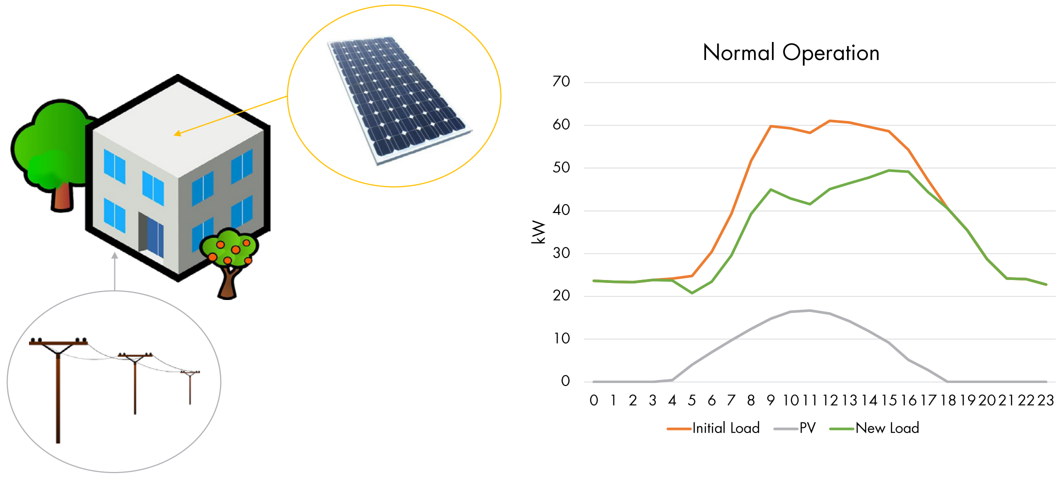


Figure 13: Normal operation of solar and storage assets

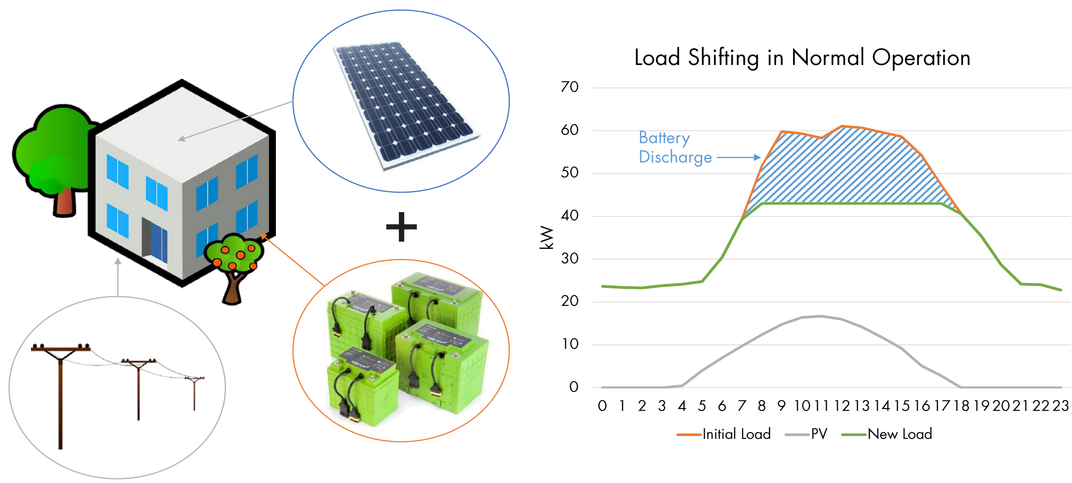


Figure 14: Load shifting operation of solar and storage assets

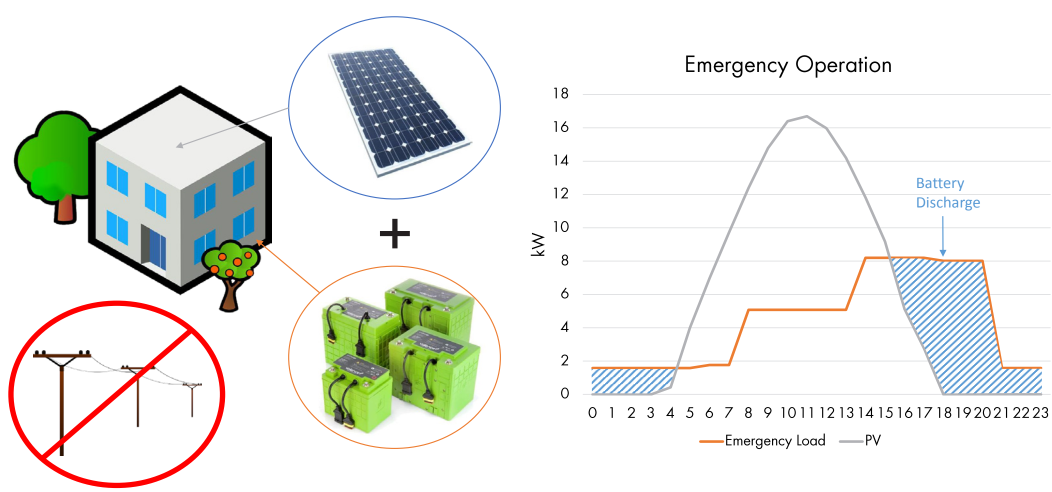


Figure 15: Emergency operation of solar and storage assets

One final consideration for normal operation of a resilient solar and storage system is maintaining the level of charge in the batteries. Since a disaster can strike at any time, managing the level of charge in the batteries to ensure an adequate supply of power in the event of an emergency is essential. In normal operation for non-backup systems, battery operation is determined by price signals from the utility such that the private owner reduces costs in times of peak demand or high energy rates. While this can be done with a backup system as well, the depth of discharge should be limited to ensure that the batteries always maintain enough charge to satisfy the minimum critical load. This is especially true after daylight hours when the battery would be the only source of resilient power in the event of a disaster. Understanding the anticipated depth of discharge for each project should be accomplished with the project engineer and tested under a variety of load and discharge scenarios to ensure that the storage is appropriately designed and sized for resilient operation.

Maintenance

Maintenance of both the solar and storage components is minimal — this is one of the key advantages of these technologies. The primary maintenance activity required for both components is ensuring that they are kept clean and operating at their full potential. This requires monitoring the power output of the panels and batteries on a regular basis and comparing the operational characteristics to historic averages to detect any drop in performance. For solar panels, a drop in power usually means that the panels are dirty. In general, solar panels should be cleaned every 6 to 12 months or whenever an average power exceeds about 5% of the overall panel capacity for a prolonged period. Keeping the panels clean will ensure that the facility is getting the most from its investment. In some cases, a power drop may be caused by shading from nearby trees instead of the accumulation of dirt. This usually can be seen by a drop in the power from one or a few panels rather than a drop in all of the panels. If this is the case, pruning of nearby vegetation can help restore the panels to full power operation. In the case of exceptional power reduction from one or more panels, the manufacturer should be engaged as they typically provide a 25-year warranty on their solar panels.

For batteries, it is important to monitor both the stored energy and voltage. As noted previously, batteries degrade much more quickly than solar panels, especially if discharged frequently and deeply. Since the capacity of battery storage is a key factor in providing post-disaster resilience, the battery bank should not be permitted to degrade to a point where it will provide insufficient backup after an event. Monitoring the change over time in the battery output voltage and the total energy stored in the batteries will help ensure that, in the event of a disaster, the full expected backup storage is available.

Post-Disaster Building Management

An important aspect of disaster preparation is creating a post-disaster building management plan. Without a systematic way to manage energy consumption after an event, the usefulness of a resilient backup system can be negated. Some facilities may already have such a plan in place, but the installation of a solar and storage backup system is the perfect time to review, update, or create such a plan.

A post-disaster energy management plan should include the following:

- **Inspection procedure and responsibility**: As part of evaluating the safety of the building after an event, the solar and storage components and connections should be inspected for any damage. The inspector should check for loose connections, damaged components, and any shock or fire hazards that may have resulted from the disaster. In addition, if flooding is experienced, the inspector should ensure that all components are dry and elevated above water level. Solar panels in particular may be exposed to damage during a disaster. If a panel is cracked or the glass damaged, the system is still able to operate safely, though it will produce less power.
- **Control of building loads**: Responsibility should be designated for reducing the running energy of the building to just the critical loads that were determined and agreed on during the initial sizing and walkthrough of the facility. Since the solar and storage system is sized to handle only these loads, any extraneous power needs should be immediately curtailed to ensure that the building can operate as continuously as possible until power is restored. In cases where even critical loads can be temporarily suspended or reduced (e.g., reducing lighting during daylight hours), these steps should be taken as well to help store and conserve power.
- **Monitoring of power output and consumption**: One member of the post-disaster operations team should routinely monitor building power consumption, storage levels, and panel production. This will help ensure that power production and consumption are balanced, guaranteeing the operation of the facility until primary power can be restored. If consumption exceeds production, additional curtailment of building loads may be necessary. If production exceeds consumption, once the batteries are fully charged it may be possible to use excess production for additional loads such as phone or device charging. In addition, continuous monitoring of power output and use will help identify any reduction in system capacity due to damage sustained in the event.
- **Communication with the local utility**: After building operation has been guaranteed and backup power has been restored, a member of the post-disaster management team should contact SFPUC to find out when to expect restoration of primary power. Knowing how long the utility expects the facility to be without primary power will help managers plan adequately to keep critical operations running.

Detailed Case Studies

Four case studies of critical buildings in San Francisco were used to demonstrate the process of sizing and designing solar and storage resilient backup power. They encompass different use cases and surroundings to demonstrate how to adapt the approach in this roadmap to different facility and site conditions. The following cases were explored:

- Case 1 – Thurgood Marshall High School
- Case 2 – Marina Microgrid (School, Library, and Recreational Center)
- Case 3 – Hamilton Recreational Center
- Case 4 – Maxine Hall Health Center

The site areas for these four case studies are shown in Figures 16 through 19.

Figure 16: Thurgood Marshall High School

Figure 17: Marina Microgrid

Figure 18: Hamilton Recreational Center

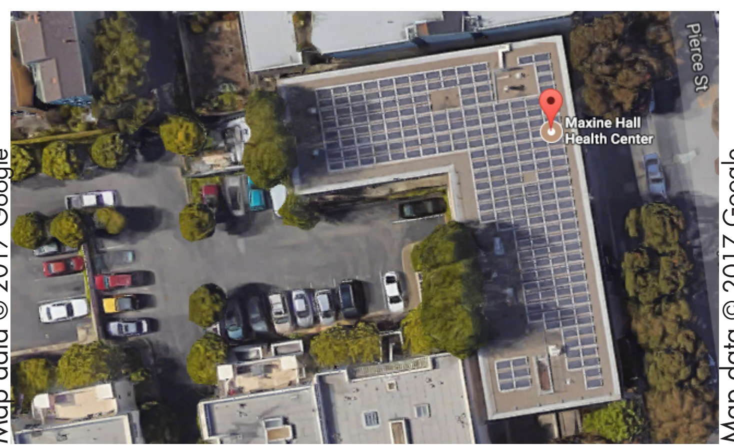


Figure 19: Maxine Hall Health Center

Thurgood Marshall was developed to a greater level of detail than other sites and a concept design was produced. As this concept design may be of value to readers, it is included within this case study.

The project team developed a number of assumptions that were used to perform a consistent analysis methodology for all of the case studies carried out. These assumptions are presented in Appendix C.

Thurgood Marshall High School

Thurgood Marshall High School (TMHS) was constructed in 1958 and is identified as a potential shelter. The site has an 87kW PV array that was installed in 2015.

Name	Thurgood Marshall High School
Street Address	45 Conkling Street
City	San Francisco
State	CA
Zip Code	94124
Normal Usage	School
Number of Floors	3
Sleeping Capacity	65 sf/person
Temporary Evacuation Capacity	20 sf/person
Data Source	SF Emergency Shelter Database
In Shelter Database	Yes
Emergency Usage	Shelter/Evacuation
Generation Assets	87 kW PV array — does not operate in the absence of the grid

- **Intent of Operations/Interior and Exterior Spaces:** TMHS is a potential designated shelter, as such there is a well-defined use case for the building. Each of the spaces has been assessed and assigned a use. The number of people who may sleep at the building or can be provided with temporary (under 8 hours) evacuation shelter is defined. Not all of the school is planned to be used when the facility operates as a shelter. The interior and exterior areas tabulated are the identified areas at this facility for emergency use.

Interior Spaces		**Emergency Space Use**							**Occupancy**	
Space	**Area (sf)**	**Dormitory**	**Dining**	**Office**	**Interview**	**DHS**	**Kids Area**	**Rec/Meeting**	**Dormitory**	**Evacuation**
Auditorium	4,600							✓		230
Cafeteria	3,720		✓							186
Main Office	1,400			✓	✓	✓				
Gym	7,860	✓							121	393
Counseling Offices	1,175			✓	✓	✓	✓	✓		59
Classrooms/Misc.	2,800		✓		✓	✓	✓	✓		140
Classrooms/Misc. (No Windows)	1,800		✓		✓	✓	✓	✓		90
Classrooms	1,800		✓		✓	✓				90
Corridor Nighttime	5,070									
Corridor Evening	4,430									
Total	**34,655**								**121**	**1,188**

Exterior Spaces	Emergency Space Use — Available for Camping		
Space Category	**Space**	**Area (sf)**	**Occupancy**
Exterior	Field	40,000	615

Figures 20-23 are provided to show some of the emergency use spaces.

Photo © Arup

Figure 20: TMHS Auditorium

Photo © Arup

Figure 21: TMHS Gym

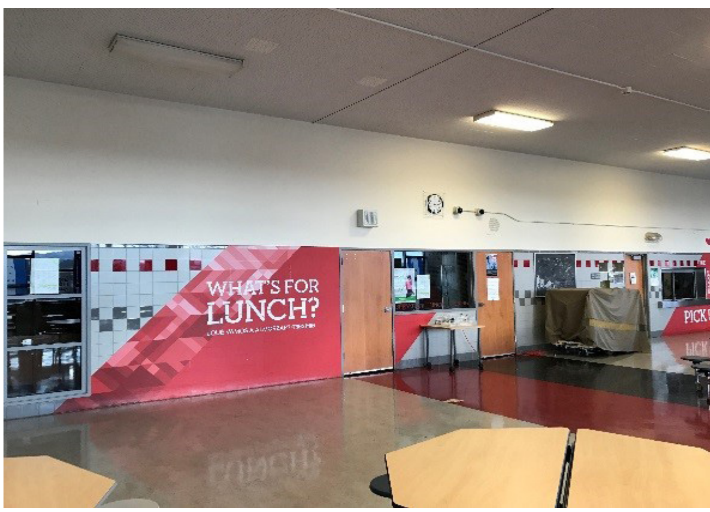


Photo © Arup

Figure 22: TMHS Cafeteria

Photo © Arup

Figure 23: TMHS Basement Classroom

- **Electrical Loads:** Electrical loads were developed for the site based on the assumptions in Appendix C and specific identified items based on the site visit. The load is shown in Figure 24.

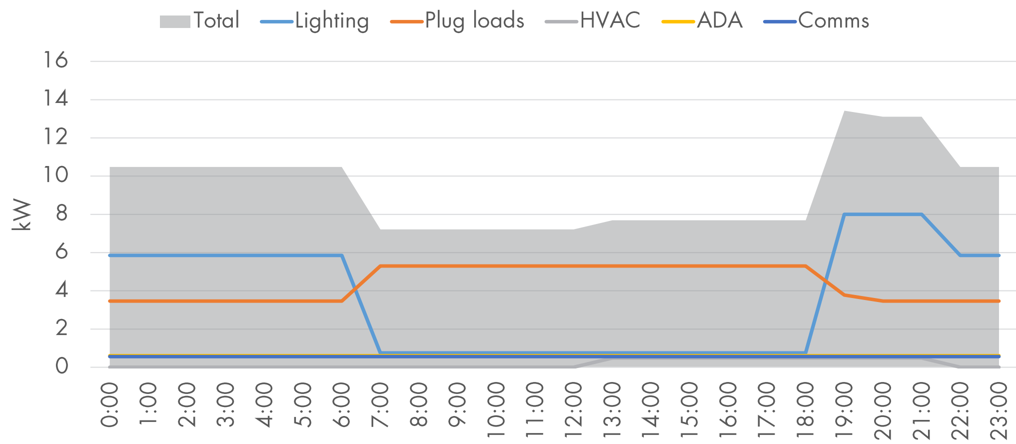


Figure 24: Typical 24-hour electrical profile of TMHS

- **Proposed Equipment Capacity:** The SolarResilient online tool was used to size the equipment required at this site. As this site already has an 87kW PV array installed, it was assessed in the tool how much extra PV would be needed to meet the identified resilience needs. It was found that during the typical and worst case assessment that between 0kW and 11kW of new PV respectively were proposed. As such it was decided to select the option to not install any new PV in the analysis tool as installing such a small amount of extra PV is a small project in the commercial sector to such a new PV array and may not attract competitive bids. For this assessment we allowed the tool to slightly upsize the battery (by 11kW/40kWh) to compensate for the lost PV capacity. Should this project move to the bid stage, we would present both options (adding more PV or upsizing the battery) in the bid documents and select the best option for the project once bids are received. The results of the sizing exercises are shown in the table.

	Existing PV (kW)	New PV Required (kW)	Roof Area for New PV (sf)	Parking Area for New PV (sf)	Battery Size (Power, kW)	Battery Size (Energy, kWh)	Inverter Size (kW)	Battery Space Required (cu. ft.)
Typical	87	0	0	0	63	250	43	540
Worst-Case	87	0	0	0	123	490	83	1,000

- **Equipment Space:** During the site visit, potential space requirements for the battery and associated electrical infrastructure was identified. The most suitable location found at TMHS was a long (>100′) and wide (>12′) corridor, adjacent to the main electrical and PV inverter rooms. This location was selected for the proximity to the key electrical infrastructure, the ability to install batteries in this location and fence the infrastructure off, the lack of use of this corridor by the students (used by maintenance staff) and existing spare conduits between this location and the main electrical room. The corridor is 12′ wide and 6′ would be reserved for the batteries and electrical infrastructure and 6′ reserved as free space to allow for the passage of people and goods. Existing items that are stored here would be relocated to a designated storage room.

Electrical Option Description	Assessment Results	Notes
Segregate emergency loads onto their own defined electrical panels, when a grid outage occurs, automate the transfer from grid power to emergency power and back to the grid. No manual interventions needed.	This option is cost prohibitive at TMHS as the existing electrical infrastructure is not separated and is shared throughout the school. To separate the loads would require a major school re-wiring project and major disruption.	This solution would be the optimum solution for a new build or major renovation.
Install an Automatic Transfer Switch (ATS) to switch between grid power and solar/storage loads. Use the existing electrical infrastructure to distribute emergency power and have an operations plan to manually switch off all of the circuit breakers that do not feed emergency loads and then switch them back on when the grid returns.	Due to the physical size of the school, split over 3 floors, there are a large number of electrical panels, each serving multiple areas. This makes such a manual plan cumbersome to undertake. However, the main reason that this is not a suitable option is the age of the electrical infrastructure – several areas of the school use fuse type electrical panels were circuits are not easily/safely switched.	This solution works well when the electrical equipment is easy to operate, there are a limited number of electrical panels and when there are on-site facilities staff to perform these tasks.
Install an ATS to switch between grid power and solar/storage loads. Add festival / event style downstream power distribution to allow temporary power distribution equipment to be brought into the rooms that need it during an emergency.	This option is most suited to this particular application and is described in more detail in this chapter.	This solution works well for retrofits of buildings with aging electrical infrastructure and where transfer of power to emergency loads is only expected to be required during a major event such as an earthquake. It is not suitable to provide power regularly to emergency loads such as during the typical minor (if any) power outages that may be experienced over a year.

Photo © Arup

Figure 25: Proposed location for battery installation

Photo © Arup

Figure 26: Distribution panel to basement classroom — fuse type panel; difficult to isolate individual circuits easily

The electrical design for emergency power is as follows:

- In Normal Operation PV and Battery are Grid Tied and provide power to all loads
- During a Grid Outage – ATS transfers PV/Battery to an Emergency Power 'Tap Box'
- Each room to be provided with power has a 208/120V, 50A "Spider Box"
- Extension cords transport power from Tap Box to Spider Boxes
- Plug loads are connected to Spider Box. Typically 6 receptacles per Spider Box.
- Lighting via LED pole lighting - daisy chained via local extension cords – existing lighting not used.

Figure 27: Emergency power "tap box"

Figure 28: Extension wiring

Figure 29: Emergency power "spider box"

Figure 30: Temporary lighting

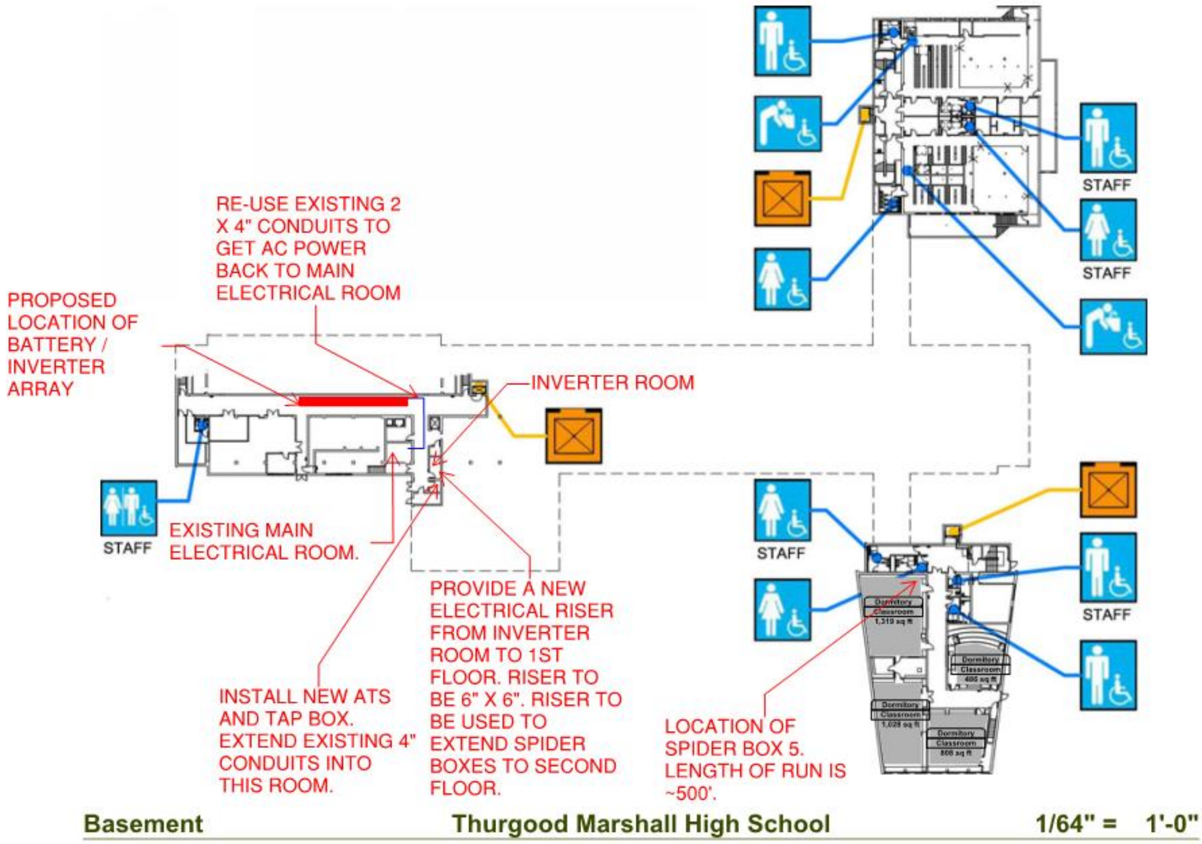


Figure 32: Basement location plan of key electrical infrastructure

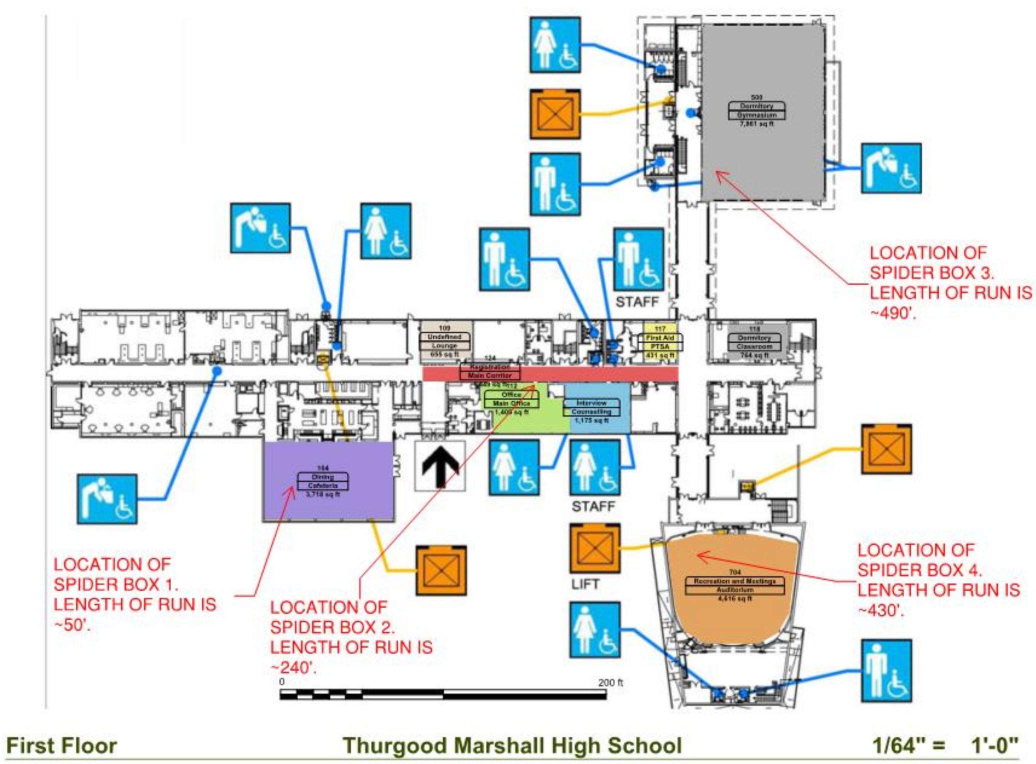
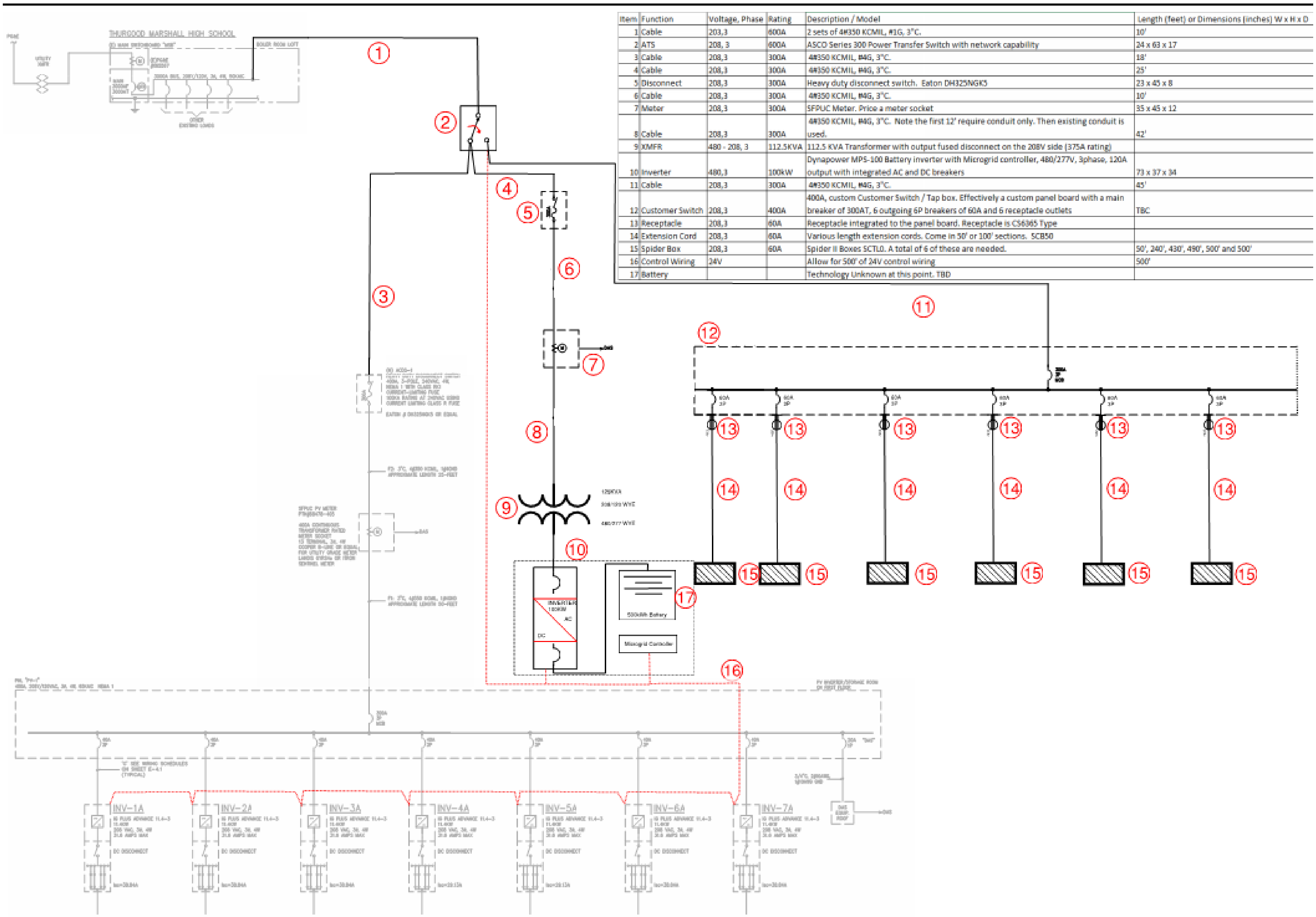


Figure 31: First floor location plan of key electrical infrastructure



Item	Function	Voltage, Phase	Rating	Description / Model	Length (feet) or Dimensions (inches) W x H x D
1	Cable	203,3	600A	2 sets of 4#350 KCMIL, #1G, 3"C.	10'
2	ATS	208, 3	600A	ASCO Series 300 Power Transfer Switch with network capability	24 x 63 x 17
3	Cable	208,3	300A	4#350 KCMIL, #4G, 3"C.	18'
4	Cable	208,3	300A	4#350 KCMIL, #4G, 3"C.	25'
5	Disconnect	208,3	300A	Heavy duty disconnect switch. Eaton DH325NGK5	23 x 45 x 8
6	Cable	208,3	300A	4#350 KCMIL, #4G, 3"C.	10'
7	Meter	208,3	300A	SFPUC Meter. Price a meter socket	35 x 45 x 12
8	Cable	208,3	300A	4#350 KCMIL, #4G, 3"C. Note the first 12' require conduit only. Then existing conduit is used.	42'
9	XMFR	480 - 208, 3	112.5KVA	112.5 KVA Transformer with output fused disconnect on the 208V side (375A rating)	
10	Inverter	480,3	100kW	Dynapower MPS-100 Battery inverter with Microgrid controller, 480/277V, 3phase, 120A output with integrated AC and DC breakers	73 x 37 x 34
11	Cable	208,3	300A	4#350 KCMIL, #4G, 3"C.	45'
12	Customer Switch	208,3	400A	400A, custom Customer Switch / Tap box. Effectively a custom panel board with a main breaker of 300AT, 6 outgoing 6P breakers of 60A and 6 receptacle outlets	TBC
13	Receptacle	208,3	60A	Receptacle integrated to the panel board. Receptacle is CS6365 Type	
14	Extension Cord	208,3	60A	Various length extension cords. Come in 50' or 100' sections. SCB50	
15	Spider Box	208,3	60A	Spider II Boxes SCTL0. A total of 6 of these are needed.	50', 240', 430', 490', 500' and 500'
16	Control Wiring	24V		Allow for 500' of 24V control wiring	500'
17	Battery			Technology Unknown at this point. TBD	

Figure 32: Concept electrical one line diagram — grayed out is existing equipment, bold is new equipment

EXISTING CONDITIONS				$ 15,110
Site Protection	1	EA	8000	$ 8,000
Small demolition and repair work	1	EA	7110	$ 7,110
ELECTRICAL EQUIPMENT				$ 95,755.70
ATS				$ 6,777
ASCO Series 300 Power Transfer Switch with network capability, 24 x 63 x 17	1	EA	$ 6,777	$ 6,777
Battery				$ -
Technology Unknown at this point.	1	EA		$ -
Cable				$ 5,525
2 sets of 4#350 KCMIL, #1G, 3"C.	10	FT	$ 25	$ 254
4#350 KCMIL, #4G, 3"C.	18	FT	$ 39	$ 711
4#350 KCMIL, #4G, 3"C.	25	FT	$ 39	$ 987
4#350 KCMIL, #4G, 3"C.	10	FT	$ 39	$ 395
4#350 KCMIL, #4G, 3"C	12	FT	$ 39	$ 474
4#350 KCMIL, #4G, 3"C not conduit	30	FT	$ 31	$ 928
4#350 KCMIL, #4G, 3"C.	45	FT	$ 39	$ 1,776
Control Wiring				$ 1,134
Allow for 500' of 24V control wiring in non-metalic conduit	500	FT	$ 2	$ 1,134
Customer Switch				$ 8,772
400A, custom Customer Switch / Tap box. Effectively a custom panel board with a main breaker of 300AT, 6 outgoing 3P breakers of 60A and 6 receptacle outlets	1	EA	$ 8,772	$ 8,772
Disconnect				$ 4,061
Heavy duty disconnect switch. Eaton DH325NGK5	1	EA	$ 4,061	$ 4,061
Extension Cord				$ 1,900
Various length extension cords. SCB50	50	FT	$ 13	$ 633
Various length extension cords. SCB50	100	FT	$ 13	$ 1,267
Inverter				$ 58,500
Dynapower MPS-100 Battery inverter with Microgrid controller, 480/277V, 3phase, 120A output with integrated AC and DC breakers, 73 x 37 x 34	1	EA	$ 58,500	$ 58,500
Meter				$ 826
SFPUC Meter. Meter socket, 35 x 45 x 12	1	EA	$ 826	$ 826
Receptacle				$ 1,537
Receptacle integrated to the panel board. Receptacle is CS6365 Type	6	EA	$ 256	$ 1,537
Lighting				$ 20,400
120V 2 x 50W LED fixture. A total of 34 of these are needed.	34	EA	$ 600	$ 20,400
Spider Box				$ 15,054
Spider II Boxes SCTL0. A total of 6 of these are needed.	6	EA	$ 2,509	$ 15,054
Cable set				$ 27,995
Cable Sets for Spider II Box SCB50	50	FT	$ 13	$ 633
Cable Sets for Spider II Box SCB50	240	FT	$ 13	$ 3,040
Cable Sets for Spider II Box SCB50	430	FT	$ 13	$ 5,447
Cable Sets for Spider II Box SCB50	490	FT	$ 13	$ 6,207
Cable Sets for Spider II Box SCB50	500	FT	$ 13	$ 6,334
Cable Sets for Spider II Box SCB50	500	FT	$ 13	$ 6,334
XMFR				$ 6,723
112.5 KVA Transformer with output fused disconnect on the 208V side (375A	1	EA	$ 6,723	$ 6,723
SUB SCHOOL				**$ 63,449**
SUB TOTAL CONTRACTOR				**$ 110,866**
CONTRACTOR'S COSTS				$ 35,477
Contractors OH&Profit	20%			$ 22,173.14
Design Maturity	10%			$ 13,304
	-30%	LOW		$ 147,314
TOTAL CONSTRUCTION COST		**MOST LIKELY**		**$ 210,449**
	50%	HIGH		$ 315,673

Figure 33: Concept rough order of magnitude cost for install

Hamilton Recreation Center

Hamilton Recreational Center (HRC) was constructed in 1953 and was renovated in 2009/10. The facility is identified as a potential shelter.

Name	Hamilton Recreation Center
Street Address	1900 Geary St
City	San Francisco
State	CA
Zip Code	94109
Normal Usage	Recreation Center
Total Square Feet/Emergency Use Square Feet	16,988/7,100
Number of Floors	1
Sleeping Capacity	65 sf/person
Temporary Evacuation Capacity	20 sf/person
Data Source	SF Emergency Shelter Database
In Shelter Database	Yes
Emergency Usage	Shelter/Evacuation
Generation Assets	None

- **Intent of Operations/Interior and Exterior Spaces:** HRC is a potential designated shelter, as such there is a well-defined use case for the building. Each of the spaces has been assessed and assigned a use. The number of people who may sleep at the building or can be provided with temporary (under 8 hours) evacuation shelter is defined. Not all of the recreational center is planned to be used when the facility operates as a shelter. The interior and exterior areas tabulated are the identified areas at this facility for emergency use.

Interior Spaces		**Emergency Space Use**							**Occupancy**	
Space	**Area (sf)**	**Dormitory**	**Dining**	**Office**	**Interview**	**DHS**	**Kids Area**	**Rec/Meeting**	**Dormitory**	**Evacuation**
Auditorium	2,000	✓	✓			✓		✓	31	100
Main Office	5,000	✓	✓			✓		✓	77	250
Gym	100			✓	✓				31	100
Total	**7,100**								**108**	**350**

Exterior Spaces	**Emergency Space Use — Available for Camping**		
Space Category	**Space**	**Area (sf)**	**Occupancy**
Exterior	Path	7,000	108
Exterior	Field	42,000	646
Exterior	Tennis Courts	18,000	277

Figures 34 through 37 are provided to show some of the emergency use spaces.

Photo © Arup

Figure 34: HRC Auditorium (1 of 2 rooms)

Photo © Arup

Figure 35: HRC Gym

Photo © Arup

Figure 36: HRC modern main electrical distribution

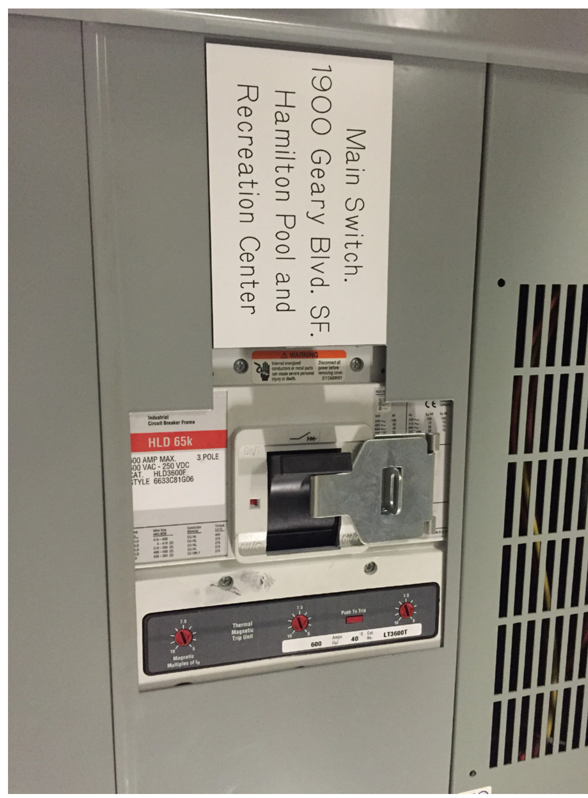


Photo © Arup

Figure 37: HRC new main electrical circuit breaker

- **Electrical Loads:** Electrical loads were developed for the site based on the assumptions in Appendix C and specific identified items based on the site visit. The load is shown in Figure 38.

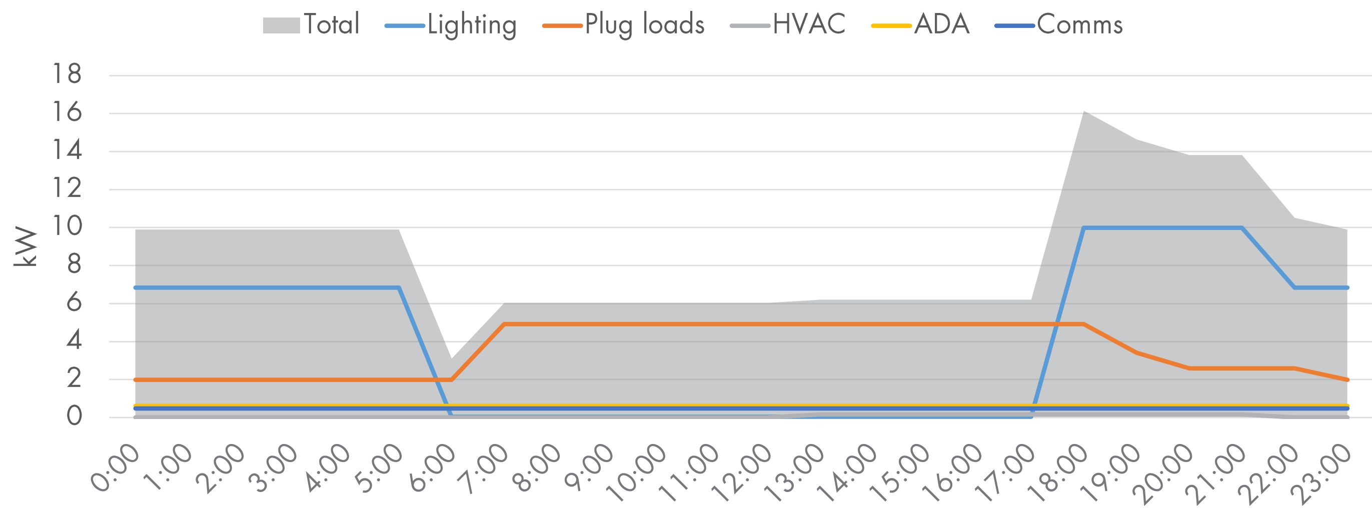


Figure 38: Typical 24-hour electrical profile of HRC

- **Proposed Equipment Capacity:** The SolarResilient online tool was used to size the equipment required at this site. Both the typical and worst case assessments are presented here.

	Existing PV (kW)	New PV Required (kW)	Roof Area for New PV (sf)	Parking Area for New PV (sf)	Battery Size (Power, kW)	Battery Size (Energy, kWh)	Inverter Size (kW)	Battery Space Required (cu. ft.)
Typical	0	54	3,600	0	83	330	84	280
Worst-Case	0	130	8,900	0	103	410	106	350

- **Equipment Space:** During the site visit, potential space requirements for the PV and battery and associated electrical infrastructure was identified. The suitable roof space for PV is approximately 9,000 sq.ft. The most suitable location found at HRC for energy storage is an outdoor strip of land that's located outside of the existing electrical room. There is room for the inverters for PV and storage and associated interconnection equipment in the basement electrical room.
- **Electrical Infrastructure:** HRC has recently been renovated and all of the electrical infrastructure serving the site replaced with modern, adequately rated equipment. The recreational center is fairly small with all of the electrical panels located within 4 areas of the building. The areas that are to be used in an emergency do not have separate electrical panels, however the panels do not serve large areas of the building. As such the electrical interconnection strategy is to install an Automatic Transfer Switch (ATS) to switch between grid power and solar/storage loads. PV and storage may share inverters and be Direct Current (DC) coupled, or each have their own inverter and be Alternating Current (AC) coupled. It is proposed to use the existing electrical infrastructure to distribute emergency power and have an operations plan to manually switch off all of the color coded circuit breakers that do not feed emergency loads and then switch them back on when the grid returns. Due to the sites size and modern, safe equipment this is the most cost effective solution at this site.

Figure 39: Proposed equipment areas — white rectangles are identified PV areas, and yellow is the storage location

- **Direct Current System:** In addition to the above electrical topology, Bosch also reviewed this site in relation to their DC microgrid system. The Bosch system takes a holistic approach to energy by combining PV, storage and DC loads such as LED lighting into a system that can island from the grid. As DC generation sources and building loads are becoming more prevalent in buildings, removing the need for power conversion devices provide higher efficiency and reliability of these products. For this site, there would also be an AC/DC conversion added to provide power to AC loads that the building requires in an emergency e.g. selected plug loads for cell phone charging. Under the Bosch proposal, the high energy consuming light fixtures in the Gym and Pool area would be replaced with LED equivalents. This reduces the system losses also as PV can directly power the lights and battery charging. The losses from the entire DC system are assumed to be roughly 3-5%. There is a slight loss from DC solar PV from using a DC driver to power the DC LED fixtures.

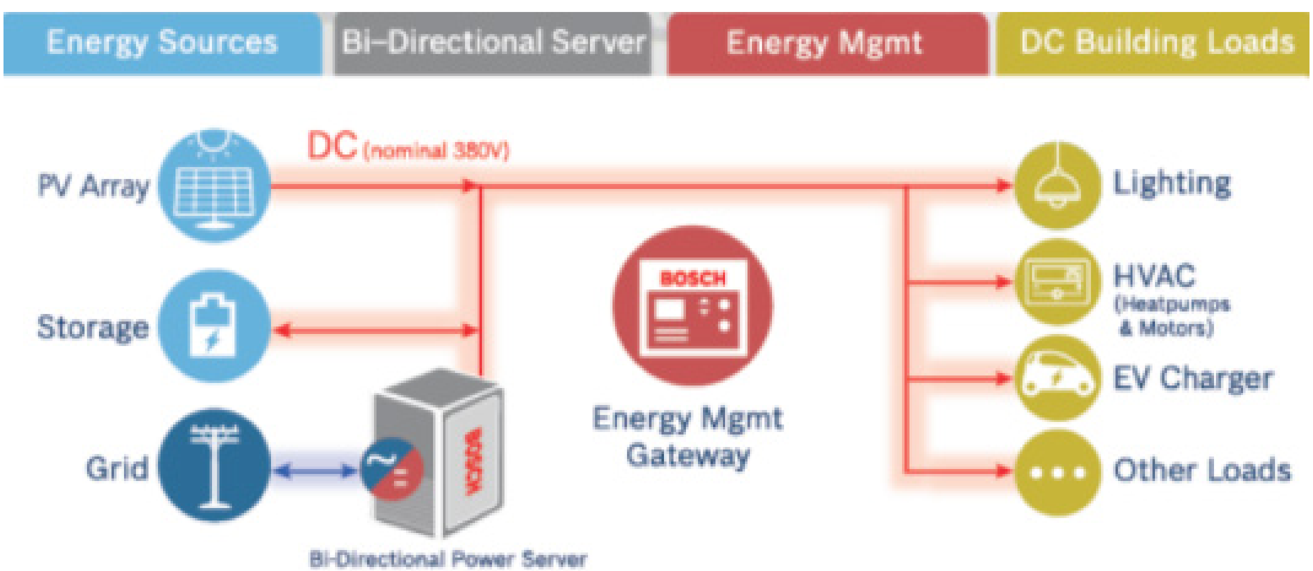


Figure 40: Bosch DC microgrid setup (Image from Bosch)

The PV arrays are used to directly power the LED fixtures on DC while the storage can provide energy management to the facility. Both systems can export to the utility, if needed. In emergency mode, the Bosch bi-directional Powerserver islands from the grid upon loss of utility voltage. There will be a transfer switch to connect the critical AC emergency load panel onto the DC microgrid network. The PV arrays and storage system continue to power the DC LED fixtures and the critical AC emergency load panel through the Powerserver. When utility voltage returns the Powerserver re-connects to PG&E without the need for the systems to sync as DC has a unity power factor. This is a cost-effective approach to resiliency as the Powerserver acts as the disconnect from the grid to isolate the DC devices.

As a result of using DC LED lighting in a DC microgrid, the approximate total energy savings from 36 metal halide fixtures to DC LED fixtures is about 31,000 kWh/year. Assuming electricity rate of $0.15/kWh equals $4,650 per year in energy savings and helps the business case of the system, the more fixtures that a particular facility has, the greater the energy savings. This solution can be a viable option to provide cost effective generation, efficiency, and resiliency benefits.

Marina Microgrid

Marina Middle School (MMS) was constructed in 1936 and is identified as a potential shelter. Marina Library (ML) was constructed in 1936, it is not a designated shelter. Marina Recreational Center (MRC) was constructed in 1936, it is not a designated shelter.

MMS is a designated shelter and is located adjacent to ML and MRC. There is also a large park which has been identified as a potential camping area adjacent to the buildings. As such for this case study it was decided to work with the local utility, PG&E to determine the suitability of joining all of these buildings together as a microgrid. The host site would be MMS which would supply power to the other buildings in the event of an emergency.

Name	Marina Middle School	Marina Library	Marina Recreational Center
Street Address	3500 Fillmore St	1890 Chestnut St	1798 Chestnut St
City	San Francisco	San Francisco	San Francisco
State	CA	CA	CA
Zip Code	94123	94123	94123
Normal Usage	School	Library	Recreational Center
Total Square Feet/Emergency Use Square Feet	152,900/24,000	7,633/5,900	6,650/4,700
Number of Floors	3	1	1
Sleeping Capacity	65 sf/person	None	None
Temporary Evacuation Capacity	20 sf/person	Based on desk count	20 sf/person
Data Source	SF Emergency Shelter Database	Site Visit	Site Visit
In Shelter Database	Yes	No	No
Emergency Usage	Shelter/Evacuation	Library Use	Evacuation
Generation Assets	None	None	None

- **Intent of Operations/Interior and Exterior Spaces:** MMS is a potential designated shelter, as such there is a well-defined use case for the building. Each of the spaces has been assessed and assigned a use. The number of people who may sleep at the building or can be provided with temporary (under 8 hours) evacuation shelter is defined. Not all of the school is planned to be used when the facility operates as a shelter. The interior and exterior areas tabulated are the identified areas at this facility for emergency use.

Interior Spaces		Emergency Space Use							Occupancy	
Space	**Area (sf)**	**Dormitory**	**Dining**	**Office**	**Interview**	**DHS**	**Kids Area**	**Rec/ Meeting**	**Dormitory**	**Evacuation**
Auditorium	6,540									
Cafeteria	3,724		✓							186
Office	1,231			✓	✓	✓				
Gym	8,582	✓							132	429
Conference Room	1,321			✓	✓	✓	✓	✓		66
Room 104	1,292		✓		✓	✓	✓	✓		65
Room 171	1,200		✓		✓	✓				
Total	**23,890**								**132**	**746**

Exterior Spaces	Emergency Space Use — Available for Camping		
Space Category	**Space**	**Area (sf)**	**Occupancy**
Exterior	Courtyard	90,000	1,385
Exterior	Baseball Court	180,000	2,769
Exterior	Tennis Courts	36,000	554
Exterior	Lawn	32,000	492

There are significant outdoor spaces identified at this facility. Outdoor spaces are provided with night lighting to ensure that the spaces are safe. Due to the large outdoor areas, this adds a lot of load to this particular microgrid.

Both ML and MRC have not been identified as shelters to date. As such assumptions have been made for this case study that are consistent with how these buildings may operate if they were to become occupied as a shelter in an emergency. A site visit was used to confirm the assumptions.

Interior Spaces		Occupancy	
Space	**Area (sf)**	**Library**	**Recreational Center**
Main Library	2,500	48	
Kids Library Area	1,700	31	
Office	1,000	6	
Media	700		
Recreational Center Gym + Fitness Rooms	4,700		235

Figures 41-44 are provided to show some of the emergency use spaces.

Photo © Arup

Figure 41: Marina Middle School

Photo © Arup

Figure 42: Marina Library

Photo © Arup

Figure 43: Recreational Center Exterior

Photo © Arup

Figure 44: Recreational Center Fitness Room

- **Electrical Loads:** Electrical loads were developed for the site based on the assumptions in Appendix C and specific identified items based on the site visit. The load is shown in Figure 45.

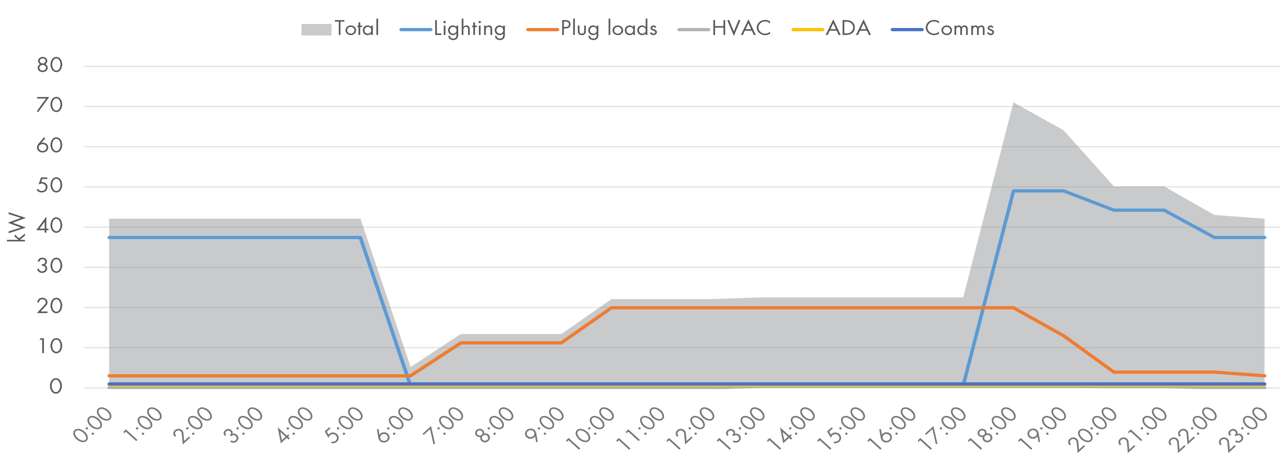


Figure 45: Typical 24-hour electrical profile of all the microgrid properties

- **Equipment Space:** During the site visit, potential space requirements for the PV and battery and associated electrical infrastructure was identified. The host site for the microgrid components is MMS, due to the large, unobstructed roof where PV can be arranged south facing, the number of people who would be using the site and the large electrical load during an emergency. The suitable roof space for PV is approximately 20,000 sq.ft. There is a large parking lot at MMS and up to 13,500 sq.ft of suitable space was identified for parking lot PV. The most suitable location found at MMS for energy storage is within a shipping container adjacent to the proposed parking lot PV.

Figure 46: Proposed equipment areas — white rectangles are identified PV areas, blue is parking lot PV, and yellow is the storage location

- **Proposed Equipment Capacity:** The SolarResilient online tool was used to size the equipment required at this site. Both the typical and worst case assessments are presented here. As can be seen from the assessment, the worst case assessment required more PV area than is available. The Marina Microgrid has made an allowance for large scale outdoor lighting (33kW). In order to provide a worst case assessment for this site that is feasible, we would need to reduce this exterior lighting to 28kW which in turn reduces the PV size to 420kW and then fits in the allocated space. Should there be a use-case without exterior lighting then the PV and Storage requirements and significantly reduced. For a worst case assessment, PV is reduced to 240kW and storage to 140kW/560kWh when exterior lighting is excluded.

	Existing PV (kW)	New PV Required (kW)	Roof Area for New PV (sf)	Parking Area for New PV (sf)	Battery Size (Power, kW)	Battery Size (Energy, kWh)	Inverter Size (kW)	Battery Space Required (cu. ft.)
Typical	0	190	12,600	0	333	1,330	335	1,100
Worst-Case	0	460	20,000	18,300	420	1,680	401	1,400

- **Microgrid Considerations:** In order to investigate the feasibility of connecting the three buildings as a microgrid the local utility, PG&E were engaged to discuss the various options for connecting buildings. In some cases, it may be possible to connect buildings via private wires, but this would be an exception to the norm. For this assessment, we worked with the utility to determine the various distribution topologies and understand how a microgrid may operate with behind the meter generation assets. These topologies are described in Appendix A.

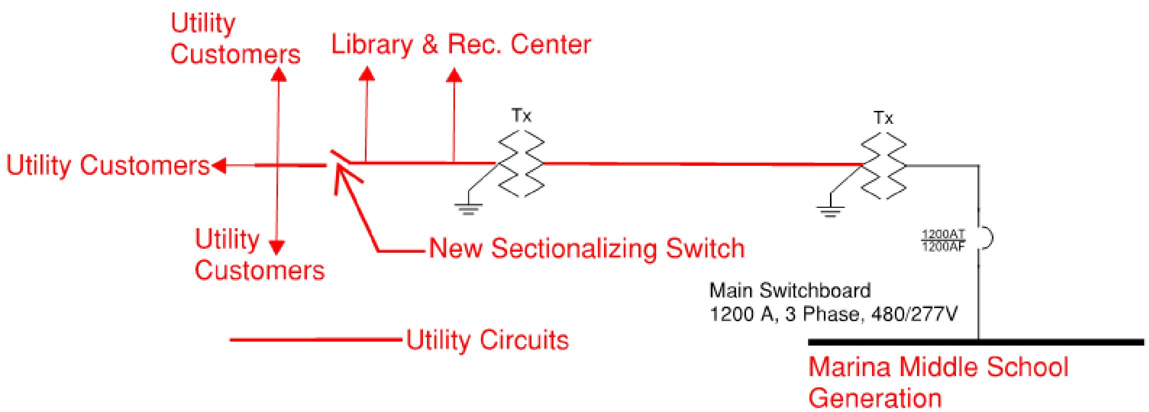


Figure 47: Marina microgrid distribution topology

For the Marina Microgrid all storage and generation assets would be located at MMS. The utility confirmed that the buildings are on the same feeder but different feeder branches. MMS is supplied at 480V and then a utility distribution transformer connects the site to the utility distribution network. That same utility distribution network connects to another utility transformer where ML and MRC are supplied, along with a significant number of other utility customers.

In normal operation the PV / storage operates in parallel with the grid and may export to the utility. In emergency mode, the generation and storage is tripped. The utility would then need to isolate all of the existing customers from the microgrid circuit. Once this is complete the utility would remove the generation interlock at the microgrid host site to allow microgrid operations safely. The battery reforms the microgrid, adding PV when stable, power is exported via the isolated utility infrastructure. When utility voltage returns and is stable PV/Storage is again tripped off to allow re-connection to the utility and the other customers on the circuit.

In discussions with the utility, a microgrid is technically feasible for this development. However, it's costly and operationally very challenging for the utility with the current automated distribution network. Cost aside, the main challenge for a microgrid in this location is how the microgrid could safely operate in an emergency and also allow the utility to fairly restore other customers in the area. A microgrid in the Marina area is unlikely to move forward due to both cost (it was cheaper to install solar/storage at each site) and primarily the operations constraints. During an event such as an earthquake the response from a utility is to restore power fairly to all areas of the city as fast and as safely as possible. Having a separate piece of the distribution network with its own rules would likely complicate the restoration effort. This is true with current grid infrastructure, as distributions systems are upgraded in the future and more automatic is put in place, several of the cost and operational barriers may be removed in the future.

Maxine Hall Health Center

Maxine Hall Health Center (MHHC) was constructed in 1953 and was renovated in 2009/10. The facility is identified as a potential shelter.

Name	Maxine Hall
Street Address	1301 Pierce St
City	San Francisco
State	CA
Zip Code	94115
Normal Usage	Medical Center
Number of Floors	1
Sleeping Capacity	N/A
Temporary Evacuation Capacity	N/A
Data Source	Site Visit
In Shelter Database	No
Emergency Usage	Health Center
Generation Assets	30 kW of existing PV

- **Intent of Operations/Interior and Exterior Spaces:** MHHC provided health services to San Francisco residents. These services include primary care, prenatal care, behavioral health, and psychiatrist services. The building is a two story building. All patient care occurs on the first floor with office space on the second. During an extended grid outage, only patient care services will be provided and the second floor will not be used.

  Arup performed a site visit of the patient care areas to determine the electrical load of the building. Electrical loads typically consisted of lighting, plug loads, computers, refrigeration and medical equipment. The majority of the medical equipment is battery operated equipment. As such the equipment datasheets were reviewed along with the operation schedule to determine how long the battery would last and how much power the device would consume to charge. MHHC was assumed to operate primarily between the hours of 8am and 5pm during a grid outage.

Figures 48 through 51 are provided to show some of the emergency use spaces.

Photo © Arup

Figure 48: Existing 30 kW PV array

Photo © Arup

Figure 49: Typical exam room

Photo © Arup

Figure 50: Basement area

Photo © Arup

Figure 51: PV inverters

- **Electrical Loads:** Electrical loads were developed for the site primarily based on the site visit and discussions with the center to determine how the facility would be operated in an extended outage. The load is shown in Figure 52.

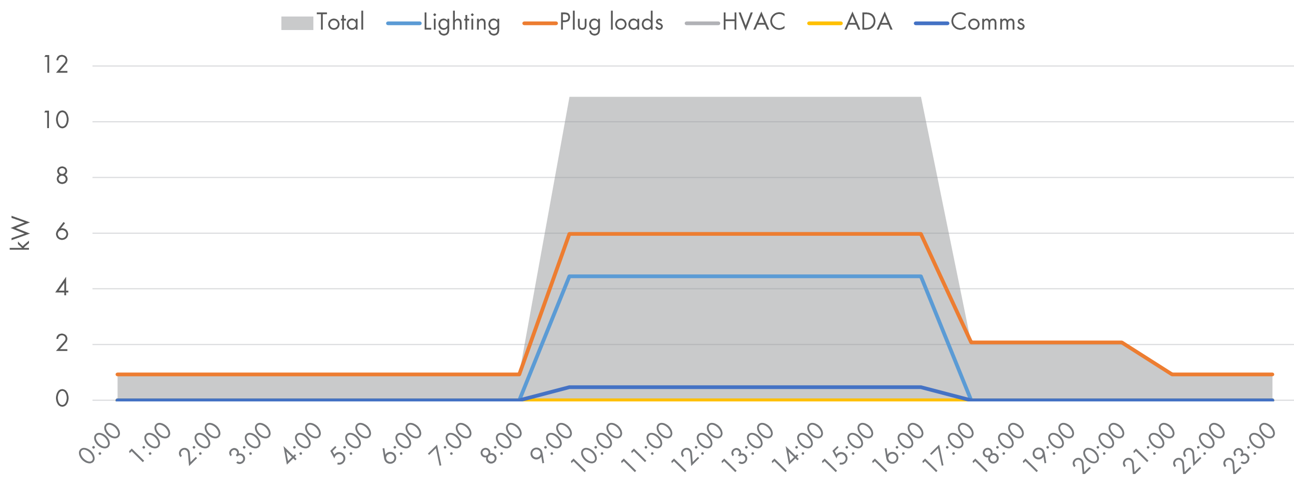


Figure 52: Typical 24-hour electrical profile of MHHC

- **Proposed Equipment Capacity:** The SolarResilient online tool was used to size the equipment required at this site. There is no room for additional PV at the site so the PV has been capped at the existing 30kW level. Both the typical and worst case assessments are presented here.

	Existing PV (kW)	New PV Required (kW)	Roof Area for New PV (sf)	Parking Area for New PV (sf)	Battery Size (Power, kW)	Battery Size (Energy, kWh)	Inverter Size (kW)	Battery Space Required (cu. ft.)
Typical	30	0	0	0	9	36	9	30
Worst-Case	30	0	0	0	100	400	15	340

- **Equipment Space:** During the site visit, potential space requirements for battery and associated electrical infrastructure was identified. There is suitable space in the basement for all of the electrical equipment adjacent to the existing main electrical and PV infrastructure is located.
- **Electrical Infrastructure:** MHHC is a small facility with a fairly simple electrical distribution system. There are electrical panels serving the first floor and second floor. The existing PV system was installed ten years ago and as such will soon be due for an inverter replacement. It is recommended that when the inverter replacement take place, either battery storage be added and coupled as a single system or separate inverters are added that can communicate with a battery to form a microgrid. The areas that are to be used in an emergency do not have separate electrical panels, however the panels do not serve large areas of the building. As such the electrical interconnection strategy is to install an Automatic Transfer Switch (ATS) to switch between grid power and emergency loads. PV and storage may share inverters and be DC coupled, or each have their own inverter and be AC coupled. It is proposed to use the existing electrical infrastructure to distribute emergency power and have an operations plan to manually switch off all of the color coded circuit breakers that do not feed emergency loads and then switch them back on when the grid returns. Due to the sites size this is the most cost effective solution at this site.

Conclusion and Key Recommendations

San Francisco's drive to develop resilient solar and storage systems for its critical facilities and shelters has made enormous strides through the work documented in this roadmap. However, following on this work, several steps remain to evaluate, finance, and install sustainable, resilient backup power throughout the city. One of the first efforts that can be made is to build a baseline understanding of the critical power needs and characteristics of all emergency and shelter facilities in San Francisco. To this end, each department can incorporate as part of its routine maintenance and reporting the following steps from this roadmap:

- Build a coalition within the department in support of resilient solar and storage
- Maintain and update the list of critical facilities under the department's jurisdiction and their power needs
- Walk through each facility to determine critical load and solar/storage suitability, and record this information in the database of critical facilities
- Identify microgrid opportunities near the facility (if available)
- Perform a preliminary estimate of the solar and storage needs using the SolarResilient tool
- Create a list of qualified solar contractors the department has previously used and share with SFE and other champions for resilient solar and storage across the city government
- Identify early any pertinent approvals or regulations in the department that might impede solar and storage deployment to avoid roadblocks to when a project can begin
- Create post-disaster building energy management plans
- Identify opportunities to include resilient solar and storage in capital financing or facility improvements in the future and discuss with department leadership

Beyond individual project development, the exercise of planning resilient solar and storage facilities can aid in the overall development of more resilient plans and emergency procedures for San Francisco. The first steps of identifying facilities and their power needs is the gateway to institutionalizing sustainable, resilient development of backup power. With power needs and current backup strategies identified, the city can take advantage of planned improvements to facilities to install solar and storage rather than address all facilities immediately. Moreover, the findings of critical facility needs, locations, and critical loads can be incorporated into city-wide emergency plans and hazard mitigation plans. The map of critical facilities can assist immediately after a disaster as well in meeting FEMA aid requirements. Finally, the management of critical facility loads should be immediately incorporated into all facility Emergency Action Plans, whether powered by solar and storage or not. Establishing a procedure for managing energy consumption and prolonging critical fuel sources is a key step to effective provision of relief services after a disaster.

More prospectively, findings from evaluating critical facilities can be incorporated into new plans and ordinances for San Francisco. Solar and storage is a viable solution for post-disaster backup power management, and this should be incorporated into standards for all new public buildings that serve a critical need. In addition, planning for new developments or public facilities should aim to colocate critical services where possible to create more opportunities for resilient microgrids and a community-centered "one-stop shop" for post-disaster relief. Additionally, since solar and storage provide a benefit in normal operation, city departments can be required to examine building solar and storage systems when undertaking a capital planning process in order to both lower their costs and create resilient post-disaster facilities.

Finally, by leveraging the challenge of resilience as a vehicle for greater solar and storage deployment city-wide, a host of benefits can be realized for the city. Deploying resilient solar and storage in underserved neighborhoods can provide an educational and social benefit, as well as further democratize solar and storage by proving it as more than a luxury for the wealthy or middle class. These technologies can provide sustainable power so that all facilities receive clean, resilient backup during non-disaster scenarios. This reduces the environmental footprint of the city as a whole and helps drive us toward a 100% clean, renewable future.

What's Next?

Evaluating and piloting resilient solar and storage across San Francisco is a big accomplishment, but it is only the beginning. Transitioning all critical facilities to more sustainable and resilient backup power will take a long time, and the effort of many stakeholders within City Hall and the community. However, all departments and citizens can agree that the ultimate goal of enabling effective post-disaster management and smooth, sustainable power provision is worth the challenge. So the question becomes not one of if, but one of how, and how to accelerate the transition to clean, sustainable, resilient backup power. To this end, a few policy actions can be extremely helpful:

- **Require critical power management plans for all new and existing city facilities**: While not directly tied to building new solar and storage facilities, cultivating a culture of resilient power management within the municipal leadership can build a coalition that pushes for better, more sustainable backup power sources. Requiring all critical facilities to assess their power needs and create a power management plan for after a disaster will both assist in post-disaster recovery and build an awareness of how vulnerable existing power systems may be. Understanding power needs, sources, and their risks is the first step to improving the critical power system of any public building. Furthermore, this information should be shared among all agencies so all agencies can more effectively plan for recovery after a disaster.
- **Incorporate solar and storage as requirements for new public and critical facilities**: Installing solar and storage has the lowest added cost and disruption when buildings are initially constructed or undergoing renovation through a capital planning process. If providing resilient backup power is an important goal for the city, incorporating solar and storage should be institutionalized across all departments in capital planning exercises. The same method described in this roadmap can be applied at project inception or major renovations to ensure that all new facilities are equipped with resilient solar and storage from day one. Furthermore, grouping critical facilities in new developments increases the potential of using microgrid-based solutions to provide solar and storage resilient power.
- **Install mechanisms to ease the financial barriers for solar and storage solutions**: As solar panel and battery costs decrease, the soft costs of solar and storage systems make up a greater share of the total cost. These include parameters over which the city has control including permitting, inspection, and financing. Creating mechanisms across municipal departments to reduce the impact of costs and fees on solar and storage developments can get some projects over the barrier from infeasible to feasible. For municipal projects, acquiring financing may be the challenge. Enabling partnerships with third party companies that can take advantage of tax incentives and provide financing is one way to ease the financial barriers. Another is to bundle multiple projects when applying for a loan. This reduces perceived risk for the bank and is likely to result in a lower interest rate.

- **Build a cross-departmental coalition for resilient solar and storage**: The experience of San Francisco, the first resilient solar and storage pilot city, illuminated the need for creating a coalition of resilience champions in different departments. This group of individuals from within each agency were instrumental in pushing for solar and storage in their department's facilities. Though not policy, building a coalition and leveraging them to work within their own departments to ease barriers, create incentives, and identify key opportunities to install new solar and storage facilities can be stronger than any official policy in advancing the solar and storage cause.

The vulnerabilities associated with traditional energy transmission and distribution are a weakness with potentially profound implications for the recovery and stability of a city after a major natural disaster. It is only natural to seek a solution that pays for itself, is reliable, and requires no fuel other than the sun. Solar and storage as a resilient power source is the future of post-disaster power management. It is clean, reliable, low maintenance, cost-effective, safe, and can be easily expanded serve microgrids as well as individual buildings. As the climate becomes less predictable and more severe, ensuring that cities have reliable backup power is imperative, and solar and storage is the solution.

Need More Help?

To discuss how best to get started down the path to solar and storage resilient facilities, please email the City and County of San Francisco Department of the Environment at environment@sfgov.org (Attn: Distributed Energy Resources Coordinator – Solar + Storage).

Appendix A: Barriers to Microgrids

Policy Barriers to Microgrids

Even when critical facilities are in close proximity, microgrids may not be feasible due to policy or technical barriers. Policy barriers vary by jurisdiction and are changing rapidly, so it is important to investigate the latest policies from CPUC, SFPUC, PG&E, and CCSF and their impact on microgrid development prior to starting a project.

Several common policy barriers to microgrids are as follows:

- **Ownership**: In a community microgrid it needs to be decided who owns the various assets in the microgrid and who is responsible for maintaining them. Ownership structure and opt-out provisions for all parties involved must be negotiated up front to prevent challenges in operation from arising.
- **Rate Structures**: CPUC regulates how rates are set by utilities, but the commission has not yet released rate-setting procedures for microgrids. Rates determine the ability of a coalition of parties to finance, construct, and operate a microgrid. In the absence of regulation on microgrid rate-setting, microgrids spanning multiple customers will face significant challenges.
- **Franchise Rights**: CPUC and the Federal Energy Regulatory Commission (FERC) classify any corporation which sells electricity across a public street as a public utility. This then subjects the corporation to a gamut of regulatory rules and requirements, one of which is exclusivity. Currently, in California and many other states, public utilities have monopoly rights in a given service territory which prevents new entrants from operating in the same territory. Any ties between buildings that crosses a public street is disallowed by this provision. There is considerable litigation involved in trying to prove that the microgrid is not infringing on the utilities franchise rights but currently, getting around the issue may involve the microgrid owner paying the utility for the crossing.

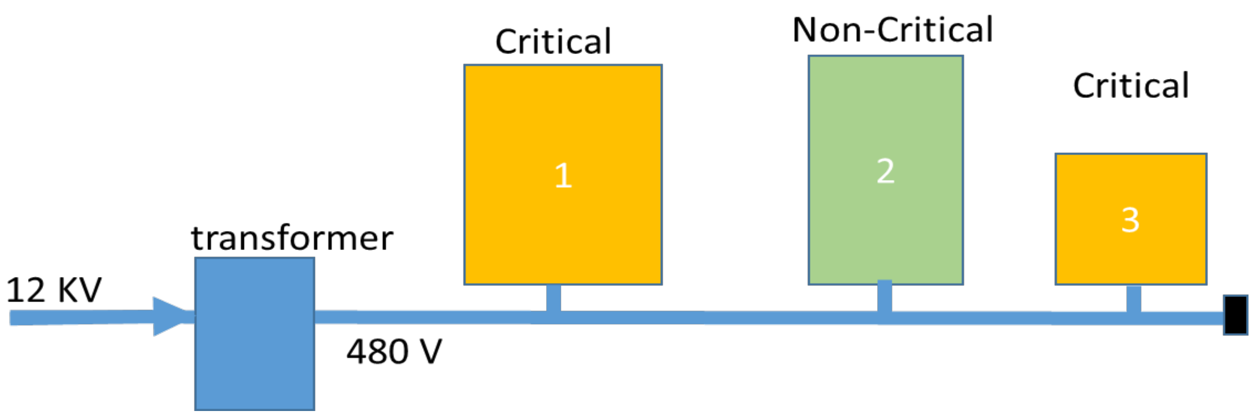
  In San Francisco only, SFPUC has the ability to cross PG&E's franchise rights and serve customers. However, this non-exclusivity for PG&E applies only to SFPUC and would still disallow any microgrids that cross PG&E rights-of-way. SFPUC could, however, create microgrids between buildings with a single master meter to all connected end-uses on the microgrids. A financing challenge with this approach, however, is that SFPUC historically has offered very low-priced, flat rates which do not offer the same financial incentives for private solar and storage development as PG&E's higher time-of-use rates.

- **Utility Safety Concerns**: Utilities in California have historically also resisted the uptake of microgrids with valid safety concerns. Islanding, the ability to disconnect a building or group of buildings from the utility grid while maintaining power from on-site generation, represents a concern to the utilities. Having parts of the grid still energized amongst a widespread outage could potentially pose a safety risk. Work is ongoing in providing safety standards for microgrids. The 2017 National Electrical Code provides guidance for DC microgrid construction, and IEEE Standard 1547.4-2011 provides guidance on the design, operation, and integration of distributed resource island systems within the electric power grid, and IEEE Standard 1547.6-2011 provides guidance for interconnecting distributed resources within secondary distribution networks.

Technical Barriers to Microgrids

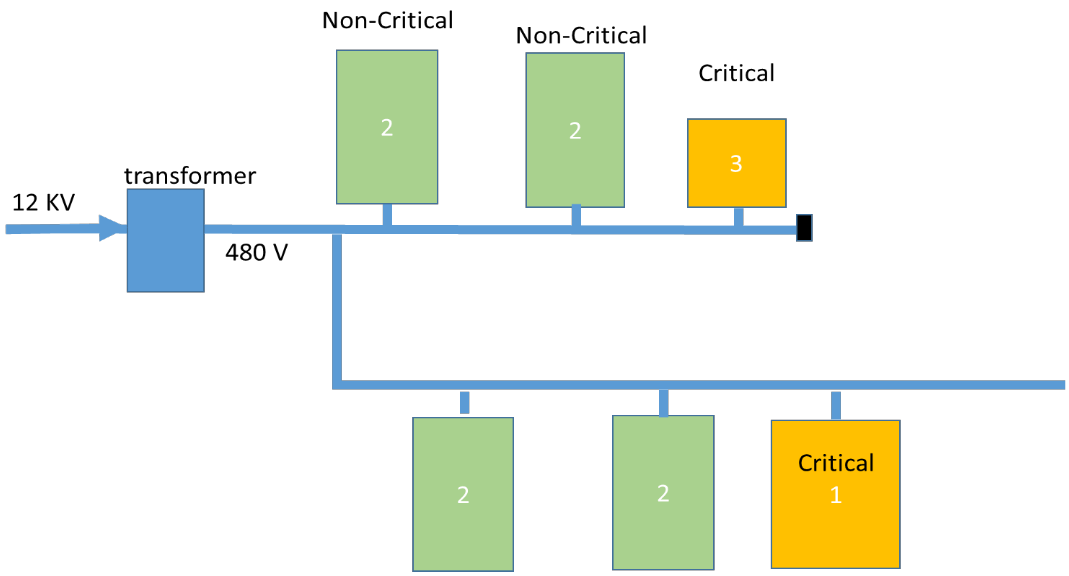
Even where the local utility or site layout may allow a microgrid, it is possible that additional technical barriers exist or that technical upgrades may be required to enable a microgrid. These are dependent on the architecture of the distribution system around the buildings being considered for a microgrid. Distribution architecture can be determined with the utility. For each distribution classification, the following should be considered:

- **Same Feeder, Same Branch**: This is the simplest case because both critical buildings are on the same distribution circuit and subsequent downstream branch circuit. In this example there is also a single building that does not have a critical load. In this instance there are a few options to allow microgrid operations – work with the non-critical building to offer services and make this a critical building meaning the utility can treat the branch circuit as a critical branch circuit and put in place protection and switching systems to isolate the wider utility distribution from the branch circuit. Should it not be possible to offer critical services from the non-critical building, work would be required such as a sectionalizing switch to isolate this building during microgrid operations. This would require an intervention and switching operations plan to be developed by the utility and clear instructions for power restoration strategies to be implemented.



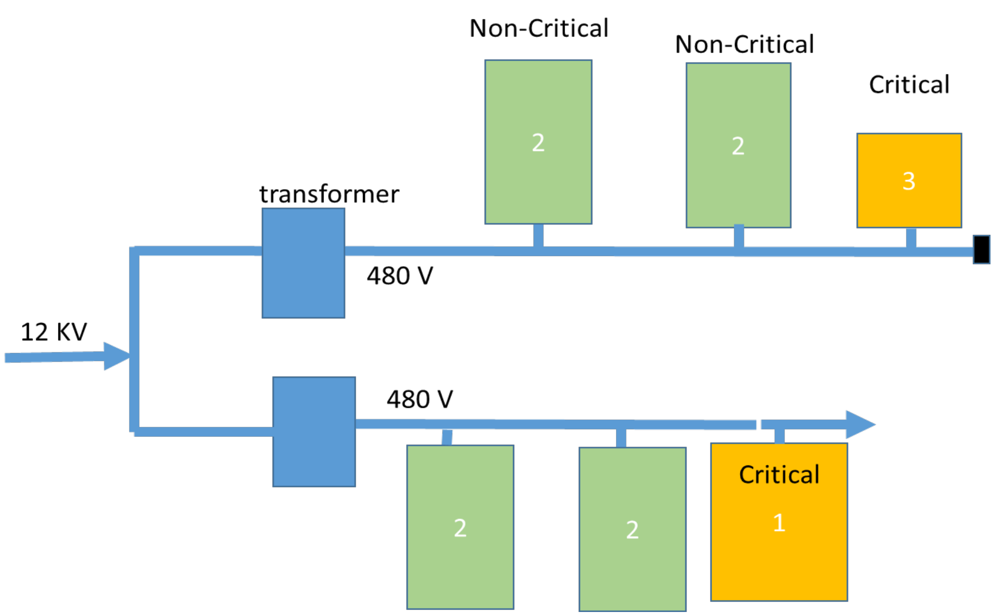
Microgrid Topology 1 – end of the same feeder branch

- **Same Feeder, Different Branch**: The second case adds complexity. The critical buildings are on the same utility distribution feeder, however they are on differing branch circuits with more non critical buildings. The mitigation options are similar to the first option, but the likelihood of easy implementation diminishes. To convert multiple non-critical buildings into critical buildings is unlikely – not only are there unlikely to be a significant concentration of critical-buildings in a city block / close proximity, but adding multiple buildings to the load the microgrid has to serve adds to the scale of the generation and storage needed. It has been assumed in the microgrid that all generation and storage is located at one host facility. If each building hosted generation and storage then these would all need to communicate and operate as one, not a trivial task. Should it not be possible to offer critical services from the non-critical buildings, work would be required such as a sectionalizing switch to isolate this building during microgrid operations. This would require an intervention and switching operations plan to be developed by the utility and clear, safe instructions for power restoration strategies to be implemented. In microgrid cases such as this, it may be better to have the storage asset in front of the meter and owned/operated by the utility. The utility can then be the orchestrator of the microgrid and control the storage dispatch. PV could still be behind the meter (or in front of) and provide the generation needed to sustain the microgrid with the utility compensating the generation owners for providing generation services during a grid outage. This would require new microgrid electricity rates to be offered by the utility and approved by local utility commissions, however this is of interest to the utilities that we have discussed this with, but is not a quick solution as new electricity rates take time to approve.



Microgrid Topology 2 – same feeder, different feed branch

- **Different Feeders**: The last scenario is where the microgrid needs to include buildings which are on completely different 12kV feeders. Again a new connection will need to be run between buildings making this another expensive option. Here, the likelihood of implementation diminishes.



Microgrid Topology 3 – different feeder, different feed branch

Appendix B: SolarResilient Online Tool Overview

The SolarResilient tool provides building owners and managers with an estimation of the PV and battery capacities required to provide a desired level resilience. The recommended capacities are translated into required roof top and parking lot area for the PV array, and basement or garage space for the battery system. The tool provides only a high-level estimation and should not be used as a basis for any system design. It can also account for existing PV and diesel generators, which reduces the capacity of additional solar and/or batteries required to meet the emergency load.

This section provides a summary of the tool's operation — full descriptions of the tool and important assumptions can be found on the website at solarresilient.org.

PV Model Overview

PV output for one year is estimated through NREL's tool PVWatts Calculator with a standard module; PV parameters can be changed by the user if desired. Unless alterations to the PV parameters are desired, the user needs only to enter the available roof space for PV (typically about 40-60% of the total roof area). From this, the software returns the amount of roof space required for the desired level of resilience assuming:

- **Rooftop Area**: 15W of PV per sq ft of unshaded roof
- **Parking Lot Area**: 9W of PV canopy per sq ft of unshaded parking lot

The PV system is sized to generate enough electricity (in kWh) to cover the net energy demand (emergency load minus any diesel generator or existing PV array output) during the target outage duration and any conversion losses in the solar and storage system.

Battery System Overview

SolarResilient allows the user to choose between 5 different battery technology options:

- **Lithium Ion (Li-ion)**: Commonly used in electric vehicles and stationary storage, Li-ion batteries are light-weight with a high energy density and can withstand deep discharges.
- **Advanced Lead-Acid**: This is a combination of the high-performance carbon ultracapacitor with the lead-negative electrode, and performs better than traditional lead acid batteries.
- **Flow**: Work like rechargeable fuel cells, and saver than traditional batteries. The electrolyte is separate from the power generation unit, so it is easy to scale up capacity.
- **Saltwater Ion**: Saltwater ion is safer and more sustainable than traditional batteries. It can withstand deep discharges and contains no heavy metals or toxic chemicals.

The battery system is sized based on four criteria:

- Discharge rate (in kW) required to meet the net load for every hour during the outage
- Charge rate (in kW) required to capture any excess PV output for every hour during the outage
- Discharge capacity (in kWh) required to provide enough energy during the hours with a positive net load each day during the outage. Extra capacity is added to compensate for the risk of the batteries being discharge at the start of the outage.
- Charge capacity (in kWh) required to capture all excess energy during the hours with an excess PV output each day during the outage.

Emergency Load Profile

The tool offers three different ways to estimate the hourly electricity profile during a disaster event.

- **Quick**: The user inputs the annual electricity peak demand of the building, the location of the building, and the desired outage duration and percentage of the total electrical load that the user wants to support during a disaster event. The tool creates an hourly emergency load profile based off an electrical load profile for a typical office building in the chosen climate zone, scaled to match the entered peak demand and desired load percentage.
- **Standard**: The user uploads the actual electricity profile for the building. This data must contain hourly or 15-minute data for a full year starting at 12 AM on January 1st. The user also enters the desired timeframe and percentage of the total electrical load that the user wants to support during a disaster event. The tool creates an hourly emergency load profile by multiplying the uploaded electricity data with the emergency load percentage.
- **Detailed**: The user enters following information about each emergency load type:
  - Wattage per fixture/appliance/device
  - Quantity
  - Diversity (% of the time each fixture/appliance is used)
  - Daily schedule (start and stop hours)
  - Annual schedule (start and stop months)

The tool uses this information to create an hourly emergency load profile for a full year. The sizing calculation is performed for a design week using the relationship between load and PV output.

The tool gives the user two design scenario options:

- **Typical**: Represents the average weekly PV to load ratio.
- **Worst**: Represents the lowest weekly PV to load ratio. This scenario is meant to calculate the largest system size needed to meet the resilience criterion.

The same design week and outage start day is used regardless of chosen target outage duration (1-7 days). From this, the tool calculates the probability that the calculated system will provide the desired resilience depending on when the disaster strikes. The variations are due to seasonal and daily changes in load and PV output.

Appendix C: Case Study Inputs

Case study general assumptions are presented in this Appendix and may be useful to readers as a starting point for load assessments.

Typical Use	Emergency Usage	From	To	Duration
Faith Based Organization	Shelter	12:00 AM	11:59 PM	23:59
Library	Internet Use and Reading	10:00 AM	8:00 PM	10:00
Medical Center	Medical Care	9:00 AM	5:00 PM	8:00
Recreation Center	Shelter	12:00 AM	11:59 PM	23:59
School	Shelter	12:00 AM	11:59 PM	23:59

Occupancy Capacity		
School, Recreation Center, Faith Based Organization	Dormitory	65 sf/person
School, Recreation Center, Faith Based Organization	Evacuation	20 sf/person
Library	Library	Chair/desk count
School, Rec Center	Exterior	65 sf/person

Load Category	Loads	Load W/item	Load W/sf	Percent Run Time	From	To	Duration
Plug Loads — Kitchen							
Plug Loads	Refrigerator	300		50%	12:00 AM	11:59 PM	23:59
Plug Loads	Freezer	400		50%	12:00 AM	11:59 PM	23:59
Plug Loads	Walk-in Fridge	580		100%	12:00 AM	11:59 PM	23:59
Plug Loads	Walk-in Freezer	1,640		100%	12:00 AM	11:59 PM	23:59
Plug Loads	Microwave	1,000		50%	7:00 AM	8:00 PM	13:00
Plug Loads	Coffee Maker	800		40%	7:00 AM	8:00 PM	13:00
Plug Loads	HWU (urn)	2,500		30%	12:00 AM	11:59 PM	23:59
Plug Loads — Other							
Plug Loads	Radio	250		100%	12:00 AM	11:59 PM	23:59
Plug Loads	Phone Charging (Evacuation)	5		25%	7:00 AM	7:00 PM	12:00
Plug Loads	Phone Charging (Dormitory)	5		13%	12:00 AM	11:59 PM	23:59
Plug Loads	Phone Charging (Exterior)	5		25%	7:00 AM	7:00 PM	12:00
Plug Loads	Phone Charging (Library)	5		25%	10:00 AM	8:00 PM	10:00

Load Category	Loads	Load W/item	Load W/sf	Percent Run Time	From	To	Duration
Plug Loads	Laptop	45		80%	7:00 AM	11:00 PM	16:00
Plug Loads	PC	200		80%	12:00 AM	11:59 PM	23:59
Plug Loads	TVs	200		100%	12:00 AM	11:59 PM	23:59
Facility							
Comms	Server Room (Racks)	600		70%	12:00 AM	11:59 PM	23:59
Comms	Wi-Fi — per Building	450		100%	12:00 AM	11:59 PM	23:59
Comms	Wi-Fi — per sf		0.0031	100%	12:00 AM	11:59 PM	23:59
HVAC	Fans	100		80%	1:00 PM	10:00 PM	9:00
ADA	Wheelchair Charging	720		42%	12:00 AM	11:59 PM	23:59
ADA	Stair Elevator — Standby	100		100%	12:00 AM	11:59 PM	23:59
ADA	Stair Elevator — Running	250		1%	12:00 AM	11:59 PM	23:59
Lighting							
Lighting	Exterior		0.1	100%	7:00 AM	7:00 PM	12:00
Lighting	Entrance		1	100%	7:00 AM	7:00 PM	12:00
Lighting	Atrium		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Auditorium		0.9	50%	6:00 PM	10:00 PM	4:00
Lighting	Cafeteria		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Classroom		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Conference Room		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Gym		0.9	50%	6:00 PM	10:00 PM	4:00
Lighting	Hallway		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Kitchen		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Library		0.8	50%	6:00 PM	8:00 PM	2:00
Lighting	Library Office		0.8	50%	10:00 AM	8:00 PM	10:00
Lighting	Library Hallway		0.8	50%	6:00 PM	8:00 PM	2:00
Lighting	Library Kitchen		0.8	50%	6:00 PM	8:00 PM	2:00
Lighting	Library Conference Room		0.8	50%	6:00 PM	8:00 PM	2:00
Lighting	Library Storage		0.8	50%	10:00 AM	8:00 PM	10:00
Lighting	Library Media		0.8	50%	6:00 PM	8:00 PM	2:00
Lighting	Locker		0.8	50%	12:00 AM	11:59 PM	23:59
Lighting	Lobby		0.8	50%	6:00 AM	6:00 PM	12:00

Load Category	Loads	Load W/item	Load W/sf	Percent Run Time	From	To	Duration
Lighting	Lounge		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Media		0.8	50%	6:00 AM	6:00 PM	12:00
Lighting	Medical Office		0.8	100%	9:00 AM	5:00 PM	8:00
Lighting	Medical Waiting Room		0.8	100%	9:00 AM	5:00 PM	8:00
Lighting	Office		0.8	50%	12:00 AM	11:59 PM	23:59
Lighting	Storage		0.8	50%	12:00 AM	11:59 PM	23:59
Lighting	Theater		0.9	50%	6:00 AM	6:00 PM	12:00
Lighting	Other		0.8	50%	12:00 AM	11:59 PM	23:59

Quantity Based on Dormitory Occupancy		
	Phone Charging (Dormitory)	00% of people over 24 hours for 3 hours per phone
	Laptops	5% of people at any one time
Faith Based Organization	PC	500 people/piece of equipment
Library	PC	Count people/piece of equipment
Recreation Center	PC	500 people/piece of equipment
School	PC	25 people/piece of equipment
	Wheelchair Charging	100 people/piece of equipment
	TVs	100 people/piece of equipment
	Server Racks	—
	Elevator (for Disabled)	750 people/piece of equipment

Quantity Based on Evacuation/Library Occupancy (Assumed 8 hours for first day only)	
Radio	500 people/piece of equipment
Phone Charging (Evacuation)	50% of evacuated people over 12 hours for 3 hours per phone
Fans	200 people/piece of equipment

Quantity Based on Exterior Occupancy (Assumed 8 hours for first day only)	
Phone Charging (Exterior)	100% of evacuated people over 12 hours for 3 hours per phone

Quantity Based on Square Footage	
Network Switches	300 W covering 90,000 sf
AP Controller	150 W per building
Router/Switch to Internet	300 kW per building

Wheelchair Charging	
Battery	60 Ah

Wheelchair Charging	
Time	10 hours per chair per day
Load	720 W

ADA Access Lift	
Hydraulic Lift	20 hp/15,000 W
Idle	100 W
Typical Trip Time	60 s/floor
Load	250 Wh per trip per floor
Runtime Diversity	0.25 trips per hour

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