AUTOMATED DEMAND RESPONSE AND RESILIENCY

PROOF OF CONCEPT REPORT

Prepared for

City of Medford

and

Massachusetts Department of Energy Resources

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INTRODUCTION

PROJECT BACKGROUND

The City of Medford is involved in an automated demand reduction and an operating resiliency pilot project sponsored in part by two DOER Grants, funding from the City, and in-kind labor support from National Grid. The goal is a comprehensive project which incorporates battery energy storage, electric demand management, energy conservation and solar Photo-Voltaic (PV) technologies in two city buildings, Andrews Middle School and the Department of Public Works (DPW). These technologies improve resiliency in the event of a loss of grid power, provide dispatchable peak demand load reduction and result in reduction of demand on the utility distribution system and create energy related cost savings and new revenue streams for the City of Medford, as well as reduce emissions and environmental impact. The proposed project will deploy enough renewable energy production, energy storage, energy conservation, and demand response strategies to substantially reduce these building's demand on the grid during demand response periods. These same technologies together will also enable renewable solar PV systems to power the building when off-grid, provide up to a few hours of additional backup power, and manage building loads to maximize off-grid power supply to these facilities during an extended power outage.

In 2017 B2Q Associates Inc was awarded a grant from the DOER to implement automatic demand response and energy conservation at the Andrews Middle School and the Department of Public Works (DPW) buildings in the City of Medford. The demand response sequences will include HVAC and lighting system load reductions combined with discharging energy from on-site battery storage. The energy conservation measures include lighting system LED conversions and the addition of controls, revised control sequences of operation for the HVAC systems, and the installation of Monitoring-Based Commissioning (MBCx) software for the purposes of commissioning and monitoring the operation of the HVAC systems.

In 2014 the City of Medford was awarded a grant from the DOER to procure and install battery storage for Andrews Middle School and Department of Public Works (DPW) at City of Medford for the purpose of improving resiliency during a loss of grid power. At the time the automated demand response grant was released for proposals (2016), the City had not yet started the design or installation of the battery storage-based resiliency projects. One of the reasons for the delay in getting started with the resiliency project was a concern that the original design intent and project budget had not been properly vetted and aligned.

Additionally, the City of Medford was also evaluating entering into purchased power agreement(s) with solar system developer(s) for solar PV system installations at both of these buildings. The City recognized the complexity and interconnectedness of the two electrical infrastructure projects. It was understood that the installation of battery storage for the purpose of improved resiliency would require related electrical system changes in order to integrate the batteries with existing infrastructure including the existing standby generator, the future solar PV system, and the interconnect to the electrical grid.

The intent of this project is to pilot and demonstrate how automated demand response technology, energy conservation, resiliency technologies and renewable energy systems can be designed to work together and complement each other both in normal operation and in islanding mode (during emergencies when power from the utility grid is unavailable).

Purpose of this Proof of Concept Report

In recognition of the uniqueness and complexity of designing and implementing the two DOER grants as well as the potential integration of the solar PV systems, B2Q proposed to confirm the technical and economic feasibility of the project through a Proof of Concept Study. The purpose of this report is to present the findings of the Proof of Concept Study including confirmation of the design intent and budget, and to identify project boundaries and critical success factors, as well as to present lessons learned to date.

EXECUTIVE SUMMARY

The project effort is currently at the end of the investigation phase and deep into the design phase, and the results indicate that the project is ready and can move successfully to implementation. The objective of the investigation and proof of concept is to review and confirm the technical and economic feasibility of implementing these technologies in a resilient "mini" microgrid peak demand response system at two project sites, the Andrews Middle School and the Department of Public Works (DPW). The results of the investigation confirm that HVAC controls, lighting controls, energy conservation, solar PV, and battery energy storage can be successfully integrated for both automated demand response and resiliency within the allocated budget. The investigation and design has not identified any factors which would indicate the project goals are unachievable. Accordingly, B2Q recommends that all aspects of the project continue to implementation.

The project team encountered a number of complicated aspects associated with this project which have been overcome, in order to advance the project to implementation. These challenges can be used as lessons learned to inform future projects and are discussed as such later in this section. In general, the challenges we have encountered are: 1) complexity of engineering and need to coordinate technical details and operating sequences for each technology and automated demand response, as well as the "mini" microgrid resiliency system as a whole; 2) coordination of the communications methodology and protocols needed to integrate all systems; 3) coordinating multiple projects with various schedules, sources of funding, project management and constituents; and 4) working within limited budgets and multiple funding sources with different requirements driving technology design and capacity. Addressing these interactive issues is paramount to enable the integrated system to function as designed for both on and off grid scenarios, automated peak demand response, resiliency, and to achieve the project goals.

Medford has also encountered challenges specific to the solar PV aspects of the project at the Andrews School and the DPW. At the DPW, issues with the solar PPA related to the timing of the phase-out of the DOER's current solar financial incentives program, SREC-II and the anticipation of its replacement with the SMART program, and the coordination for the installation of the solar PV followed by the battery energy storage system as two separate projects which must be technically integrated, have contributed to delays in procurement and construction. Additionally, the need to follow public procurement law has added layers of complexity that would not be encountered if this was being implemented at a privately-owned location. However, these issues have been overcome in the last few months and construction of the solar PV array at the DPW is approved and slated for September 2018. At the Andrews school, the age and condition of the roof must be addressed prior to the installation of solar PV, and there are concerns of soil contamination at the site which are currently being evaluated by Medford to determine the feasibility of a carport solar system. Medford is anticipating making a determination on the path forward by June 2018.

The City of Medford is strongly supporting all aspects of this project with both facilities and has dedicated staff and resources at many levels. Direct support and participation by the host municipality are key to the success of this type of project and should not be overlooked for future projects. We would like to acknowledge Medford's staff efforts, and in particular Alicia Hunt, as without her and the City's support this project would not be possible.

Summary of Project Components

This pilot project leverages existing systems and new technologies for both resiliency and peak demand response. Although described separately, the systems will operate together for peak demand response and during a resiliency event. The subsections below summarize the project components and technologies at each site, the reasoning for including them in this pilot project, and the peak demand response and resiliency impact at each site.

Andrews Lighting LED Upgrades and Controls

The existing lighting systems at the Andrews school are primarily first generation T8 fluorescent without any automated controls or occupancy sensors. The existing lighting systems use approximately 38% of the building's annual electric energy (kWh) use and comprise 16% of the building connected electrical load (kW). The simple payback of upgrading the building lighting systems to LED with controls was estimated to be approximately 10 years after utility incentives from National Grid. In addition, a new control system would be capable of communicating with other building systems for the purposes of specialized peak demand response and resiliency operation. Because of the favorable economics and the ability to communicate with other systems for peak demand response and resiliency, Medford chose to allocate funding for the LED and control upgrades as a co-pay for the Peak Demand Response Grant with B2Q and the DOER.

When complete, this project component will result in a facility-wide lighting system upgrade to LED with a new lighting control system, integrated with automated demand response and resiliency supervisory controls. The upgrade will result in annual energy savings of 148,186 kWh, a passive peak demand savings of 57.5 kW, with potential of up to 11.3kW additional load shedding capacity available on dispatch for peak demand response. This will result in an estimated annual energy cost-savings of $23,672, with the potential to generate an additional $1,858 annually through demand response programs.

Andrews Building Automation System Upgrades

The existing Building Automation System (BAS) at the Andrews school controls all major HVAC equipment and was most recently upgraded in 2010. The building HVAC systems use nearly 50% of the buildings annual electric energy and comprise 65% of the total building connected electric load. In addition to the peak demand impact of managing the HVAC loads through the BAS, the need for specialized control sequences for resiliency mode is apparent to manage the HVAC system impact on the building's off-grid energy resources. The HVAC control sequences implemented in the BAS for peak demand response serve a dual-role, as they are re-used for resiliency operation as a specialized case on select equipment that is operating during resiliency mode. The BAS control upgrades in this project are designed to achieve a 37kW demand reduction as a dispatchable asset, resulting in a potential annual revenue of $5,539 through demand response programs.

DPW Building Automation and Lighting System Upgrades

The DPW was constructed in 2015 and therefore has a contemporary BAS, LED lighting, and lighting control system. The building HVAC loads use approximately 32% of the DPW's annual electric energy and comprise 40% of the total building connected load. Similar to the Andrews school, the peak demand response sequences at the DPW will be re-used for resiliency operation. However, at the DPW the lighting control system will be integrated into the BAS to augment the existing system capabilities. The lighting integration to the BAS will also give building managers a user interface for managing the lighting control system as an added benefit. Together, the BAS HVAC and lighting control demand response sequences will shed 10.3 kW of dispatchable load, potentially generating $1,674 in annual revenue.

AUTOMATED DEMAND RESPONSE

Automated Demand Response (ADR) systems are integrated into this project to make it easier for facilities to participate in demand response programs automatically through a Curtailment Service Provider (CSP), reducing the need for human involvement to generate DR revenue. The ADR system consists of a networked universal controller integrated with all dispatchable demand response assets. The CSP will dispatch the building to curtail during peak demand response events, and the ADR systems will signal to the BAS, lighting controls, and batteries to curtail building load for the duration of the event.

BATTERY SYSTEMS

Medford was awarded a CCERI grant from the DOER for a Battery Energy Storage System (BESS) in 2014. However, they had not moved ahead with the project because a feasibility analysis had not been performed. In considering the impact of a BESS on potential demand response, Medford and B2Q developed the concept for a mutually beneficial system that could support resilient activities at both sites and be used for demand response for a few days of the year to offset load on the utility electric grid and generate revenue for the city. The impact on resilient off-grid operation in particular is to form the local electric grid and enable solar PV systems to generate electricity when disconnected from the utility grid. A secondary benefit during off-grid operation is to use the battery on its own to provide short-term power to building systems when solar PV and fossil fuel generators are not available. The BESS similarly could offset 20kW or more at the DPW and 50kW or more at the Andrews school, the maximum peak demand response capacity being dependent on the BESS energy storage capacity, discussed in the following sections. Through demand response, a BESS at the DPW could generate $2,470 or more of annual revenue, while a BESS at the Andrews school could generate $8,235 or more in annual DR revenue.

SOLAR PV

Medford was already pursuing a solar PV Power-Purchase Agreement (PPA) at both the DPW and the Andrews school at the commencement of this project and had awarded a contract to Solect for an installation at the DPW based on energy conservation and cost-savings impact. Medford, B2Q, and Solect worked together to coordinate the 180kW AC solar PV system for off-grid use, preparing for the future BESS installation to support off-grid solar generation. Together, the solar PV and the BESS will be capable of powering the building when it is disconnected from the grid. The solar PV installation at the Andrews school is also being actively pursued by Medford for similar benefits and resiliency integration.

MONITORING-BASED COMMISSIONING

Monitoring-Based Commissioning (MBCx) is a tool used to optimize the efficiency of building HVAC systems, continuously extracting system data for real-time performance monitoring and fault detection. This technology will be used at the DPW and the Andrews school to maximize the building efficiency by identifying potential HVAC problems that could be wasting energy, as undetected problems could hamper peak demand response load shedding capability and waste energy reserves during a resiliency event.

Project Status

The project schedule is approximately 3-6 months behind the schedule proposed at the time of kick-off. The delays are a result of the impact of challenges listed above on the investigation, design and procurement, which have been overcome. Presently all technologies are in the design or procurement phase and are moving towards implementation, with the exception of the Solar PV at Andrews, which is expected to be combined with the battery energy storage procurement at that site. The current status of each technology and the schedule moving forward is identified in the Table 1 below. It should be noted that the technology implementation schedule may be impacted by contractor construction schedules and equipment lead times.

Project Component	**Current Status**	**Key Milestones**
Andrews Lighting LED Upgrades and Controls	Construction Phase	Estimated Completion August 2018 Demand Response Impact: Summer 2018
BAS DR and Systems Integration	Andrews: Construction Phase DPW: Contracting with BAS Vendor	Andrews BAS vendor under contract DPW Contract phase to start April 2018 Estimated Completion June-July 2018 Demand Response Impact: Summer 2018
DR Program	Enrolled	Medford and CPower have signed contracts Both sites are enrolled in DR programs Demand Response Impact: Summer 2018
Grid Dispatch	Construction phase	Grid dispatch hardware on order Estimated Completion June 2018 Demand Response Impact: Summer 2018
Battery Systems	Procurement Andrews: 90% DPW: Complete	Andrews Bid phase to commence August 2018 Estimated installation Feb 2019 - June 2019 DPW Bid phase to commence in May 2018 Estimated installation Dec 2018 – April 2019 Note: battery schedules are subject to supplier lead times and may vary. Demand Response Impact: Summer 2019
Solar PV Systems	Andrews: Project Development phase DPW: Solect Under PPA contract.	Andrews: Medford to determine path forward spring/summer 2018. Likely to be combined with battery systems procurement. DPW: Construction expected to begin September 2018 / with SMART program timing.

Table 1 DOER and City of Medford Automated Demand Response and Resiliency Project Status and Key Milestones.

Project Budget

Overview of Current Integrated Project Budget

The Table 2 below presents a summary of the most recent opinion of costs for implementation of each technology. This project has encountered budgetary constraints which have been addressed by modifying the scope and/or capacity of each technology. The budget constraints primarily impact the Battery Energy Storage System (BESS) and the BAS demand response and integration costs. The BESS can be implemented with the current budget, and most of the project goals (described in the next section) can be met, however the installed capacity will be less than optimal for off-grid capabilities, and funding must be shared from the DPW to the Andrews Middle School. The approach to the battery system capacity vs. budget within the existing funding constraints is noted in the Table 2. Additional funding could increase the BESS capacity that can be implemented, optimizing the energy storage system size for resiliency. We strongly recommend the project administrators consider increasing project funding to achieve all project goals and maximize the local resiliency impact and off-grid benefits, as well as to capture the most relevant data of optimized system sizing for feedback into future projects and programs. Battery system budget and funding are discussed further in the next subsection.

	Andrews Middle School			DPW			Total Project Andrews + DPW	
Technology	Budget	Current Estimate[3]	Difference	Budget	Current Estimate[3]	Difference	Current Estimate[3]	Difference
Automated Demand Response Signal Reciever/Controller	$6,950	$6,950	$0	$6,950	$6,950	$0	$13,900	$0
LED Lighting and Controls Retrofit	$335,000	$291,000	$44,000	$10,000	$10,000	$0	$301,000	$44,000
BAS DR and Integration	$56,600	$60,000	($3,400)	$10,000	$10,000	$0	$70,000	($3,400)
MBCx	$14,953	$14,953	$0	$3,738	$3,738	$0	$18,691	$0
Batteries[1,2]	$458,352	$489,280	($30,928)	$458,350	$427,361	$30,989	$916,641	$61
TOTAL	$871,855	$862,183	$9,672	$489,039	$458,049	$30,989	$1,320,232	$40,661

Notes

1 Battery systems will be be bid with a lower base-bid capacity so proposals can meet budget.
2 Bidders will be asked to offer alternative pricing for larger battery capacity to maximize budget in competitive bid.
3 Current estimate is based on most recent quotes, proposals, and bids.

Table 2 DOER and City of Medford Resiliency and Demand Response opinion of costs compared to budget for Andrews Middle School and DPW.

BAS DR and integration costs at Andrews are 6% greater than the budget, although the project contingency will be able to absorb this small increase. However, it should be noted that the contractor's original proposal was for $75,000, which included a significantly improved user interface for peak demand response and providing real-time data to the MBCx system for all HVAC systems on the BAS. Due to the budgetary constraints, the reduced BAS integration scope will use older/existing graphics for the user interface and will allow approximately 500 BAS points to be available for MBCx. This is limiting the energy analytic and fault detection deployment to approximately 50% of the HVAC equipment in the school. Conversely to the BESS and BAS integration, the low bidder for the Andrews LED Lighting & Controls retrofit was lower than the project budget, which may allow Medford greater flexibility within the funding set aside for their capital request.

RESILIENCY GRANT PROJECT BUDGET AND FUNDING[1]

The resiliency project total costs for various relevant battery energy storage capacities are shown in the Table 3 & Table 4, below and compared to the CCERI Grant funding. The project team developed a base project for each site that will accomplish most of the project goals described in the following section, if funding is shared between Andrews Middle School and DPW. The opinions of probable construction cost used in this analysis were developed from budget quotes provided by multiple battery vendors. It can be seen in the Table 3 below that at a minimum, a BESS can be installed at the DPW within the project budget. It can also be seen that a BESS with enough capacity cannot be installed at the Andrews school within the current allocated funding for that site. Costs are notably higher for the Andrews site because it requires larger battery capacity than the DPW due to its higher load and more complicated electrical modifications to add specific loads necessary for emergency shelter operations.

The DOER CEERI grants funding the batteries are structured as two separate grants to Medford of equal value, one for each site, which limits the ability to appropriately match funding to the requirements of each project. However, when the viewed as a comprehensive project with two sites, it is anticipated that a BESS that meets most of the project goals (please refer to following section "Comparison to Project Goals") can be installed within the current funding that is available. If the funding is shifted between the two project sites both projects can be achieved that meet most of the project goals. One means to balance funding more evenly between the two sites is to shift all consultant costs for the feasibility study, engineering design and bid, and commissioning from the Andrews to the DPW. It can be seen that although shifting these costs to the DPW improves the difference between the Andrews grant allocation and the project cost opinion, there is still a gap.

[1] Please note that the project cost and funding analysis presented in this subsection only applies to the resiliency aspects of the project, and that costs associated with the demand response aspects of the project are therefore excluded.

Resiliency Grant Funding

	Andrews	DPW	Total Both Sites
CCERI Resiliency Grant Funding + Medford Copay	$458,352	$458,350	$916,703
Base Project Cost Opinion	$573,558	$343,084	$916,641
Net Base Project Cost and Grant Funding	-$115,205	$115,267	$61
Base Project Cost Opinion with Consultant Costs[1] Shifted all to DPW	$489,280	$427,361	$916,641
Net Shifted Base Cost and Grant Funding	-$30,928	$30,989	$61

Notes

1 Consultant costs include: Feasibility Study, Design & Bid, Cx

Table 3 The resiliency project total costs for various relevant battery energy storage capacities compared to the CCERI Grant funding

It is noteworthy that Medford's current understanding is that CCERI grant funding cannot be used for a down payment on a lease arrangement. However, if using the CCERI grant funds for a down payment on a lease agreement were a possibility, federal tax incentives such as the ITC or MACRS could be leveraged as a pass-through reduction in vendor costs to Medford and could significantly reduce the funding required. In a competitive bid for a leased solar PV plus energy storage system, the value of the tax credit to Medford could be on the order of $100,000 - $300,000.

Table 4 below presents project cost opinions developed for various battery sizes relevant to each project site. It can be seen that the DPW project needs only a modest funding increase to achieve the project goals compared to the Andrews project. As described above, the Base Project will accomplish most of the project goals described in the following section and provide approximately one hour of battery-only off-grid backup power, while the Increased Off-Grid Backup option represents increased battery capacity that will provide approximately two hours of battery-only off-grid backup power. The Increased Off-Grid Backup option is presented as an alternative option with capacity in between the base project and the Meets All Project Goals option (which provides 3 hours or more of battery-only off-grid backup power). We strongly recommend the program administrators consider increasing the grant allocation for both sites to maximize resiliency and meet project goals. We also recommend that the program administrators review the policy on using grant funding as down payment for lease agreements, as the associated tax credits could significantly reduce project costs and increase the overall value to Medford and the Commonwealth.

Andrews Energy Storage Capacity and Resiliency Project Costs

Description	Energy Storage Capacity kWh	Battery-Only Off Grid Duration[2] hours	Opinion of Project Cost $	All-In Cost per kWh Installed $/kWh	Estimated Funding Increase Required[3] $
Base Project[1]	250	1	$573,558	$2,294	$115,205
CCERI Documents Allocation	389	1-2	$656,528	$1,688	$198,175
Increased Off-Grid Backup	425	2	$676,109	$1,591	$217,757
Meets All Project Goals	650	3	$834,521	$1,284	$376,169

DPW Energy Storage Capacity and Resiliency Project Costs

Description	Energy Storage Capacity kWh	Battery-Only Off Grid Duration[2] hours	Opinion of Project Cost $	All-In Cost per kWh Installed $/kWh	Estimated Funding Increase Required[3] $
Base Project[1]	85	1	$343,084	$4,036	--
Increased Off-Grid Backup	170	2	$422,638	$2,486	--
Meets All Project Goals	250	3	$487,497	$1,950	$29,146
CCERI Documents Allocation	389	5	$555,809	$1,429	$97,459

Notes

1 Base Project does not account for any costs shifted between sites.

2 Battery-Only Off Grid Duration assumes that the battery is fully charged and under peak resiliency loads for each project site.

3 Estimated Funding Increase Required does not include any contingency.

Table 4 The resiliency project total costs detailed for various relevant battery energy storage capacities compared to the CCERI Grant funding

Comparison to Project Goals

Peak Demand Response Goals

The table below presents a comparison of the proposed implementation strategy from the proof of concept analysis to the project goals proposed with the Peak Demand Response grant application for each aspect of the project.

Project Aspect	**Goals Proposed with Grant Application**	**Proposed Implementation from Proof of Concept**	**Comments and Recommendations**
Automated Demand Response	Integrate dispatchable ADR with HVAC controls, lighting controls, battery energy storage systems	Use EnergyIQ ADR signal receiver/controller and enroll with CPower to participate automatically in demand response programs. Integrate dispatchable ADR with HVAC controls, lighting controls, battery energy storage systems	This project aspect is technically feasible. The ADR signal receiver/controller costs approximately $7,000 per site, meter upgrade is approximately $3,500 per site. B2Q recommends to proceed with ADR at both project sites.
HVAC Demand Response	Create programming in the Building Automation System at both sites to reduce HVAC loads by a combined 56kW during summer peak periods and 16kW during winter peak periods.	Create programming in the Building Automation System to reduce HVAC loads during summer peak periods by 27.2kW at Andrews and 6.5 kW at DPW, and during winter peak periods by 8.4kW at Andrews and 4.0 kW at DPW.	This project aspect is technically feasible and all DR savings are dispatchable. Costs increase for the quantity and complexity of DR sequences. Additional demand savings could be realized by optimizing sequences during commissioning and occupant tolerance of turning off cooling equipment during DR events. B2Q recommends to proceed and optimize BAS demand response sequences at both project sites.
Andrews LED Lighting and Controls Upgrades	Medford commits to facility-wide LED lighting conversion to realize approximately 180,000kWh electric savings, 85kW of installed capacity demand savings and an additional 12kW of dispatchable demand savings.	Proposed new upgrades combined with 2017 GC lighting project will complete facility-wide LED upgrade and achieve energy and demand savings. Dispatchable demand savings are estimated to be 13.2kW, exceeding the goals proposed by the grant.	This project is technically feasible and currently in the construction phase. Demand savings are based on dimming to pre-set levels. Actual savings that can be realized are a function of how occupants respond to short-term dimming levels. Medford is proceeding with with LED lighting and controls upgrades at the Andrews school.

Peak Demand Response Goals (Cont.)

Project Aspect	**Goals Proposed with Grant Application**	**Proposed Implementation from Proof of Concept**	**Comments and Recommendations**
Battery Energy Storage System	Use Battery Energy Storage System being installed under resiliency grant for participating in ISO-NE and National Grid demand response programs. Battery systems at both sites combined could offset 50kW – 100kW of load during a 4-hour demand response event.	Battery energy storage systems can readily integrate with automated demand response controls. Andrews proposed batteries could offset 50kW of load and DPW proposed batteries could offset 15kW of load during a 4-hour DR event. Meeting the battery energy storage system demand response goals proposed for the grant.	This project aspect is technically feasible and all demand response savings are dispatchable. Battery demand response savings are estimated based on a 250kWh battery at Andrews school and a 85kWh battery at DPW. An increase in battery energy capacity would similarly increase the ability to offset greater load for demand response and would be preferred.
Energy Conservation	Use Monitoring-Based Commissioning to gather system data and identify opportunities to improve building energy performance. Anticipated 22,500 kWh and 4,500 therms savings.	Use FacilityConneX to integrate with BAS and supervisory controller for battery energy storage system to gather data. FacilityConneX will run analytics to identify opportunities for improvements. Due to the nature of using real-time analytics to identify energy savings, confirmation of grant savings goals is pending installation and analytic results.	This project aspect is technically feasible and key to gathering operational project data and maximizing energy efficiency. FacilityConnex is under contact and proceeding with implementation.

Resiliency Goals

The table below presents a comparison of the proposed implementation strategy from the proof of concept analysis to the project goals proposed with the CCERI grant application for each aspect of the project.

Project Aspect	**Goals Proposed with Grant Application**	**Proposed Implementation from Proof of Concept**	**Comments and Recommendations**
Battery Energy Storage System Technology Selection	DOER CCERI technical assistance study by Cadmus proposed using Sealed Lead Acid (SLA) batteries. CCERI grant is based on SLA batteries.	This proof of concept review selects LI-ion for the battery technology based on the following key factors: • SLA batteries have a slow rate of charge compared to LI-ion batteries. • LI-ion batteries have a longer life than SLA batteries. • LI-ion has higher round-trip efficiency (discharge/charge efficiency) than SLA. • LI-ion batteries have very stable discharge voltage while the SLA battery voltage drops consistently during discharge. • LI-ion is cleaner and safer for the environment than SLA because LI-ion does not contain lead. • LI-ion batteries are more flexible in how they are used and can be discharged lower than 50% with limited adverse impacts to battery life. Compared to SLA batteries which cannot be discharged below 50% of rated capacity without potentially significant impacts on cycle life.	Although the project budget can only support a smaller LI-ion battery compared to an SLA battery, from an equipment lifecycle perspective, the LI-ion benefits outweigh the limitations and cost. In particular, the discharge of the SLA batteries is typically limited to 50% of capacity while LI-ion batteries can discharge below 50% with limited adverse effects resulting in an equivalent cost per usable kWh is between the technologies. Furthermore, the DOER CCERI technical assistance study by Cadmus notes that Medford should consider alternative battery technologies to the SLA. B2Q recommends that Medford proceed with LI-ion batteries.

Resiliency Goals (cont.)

Project Aspect	Goals Proposed with Grant Application	Proposed Implementation from Proof of Concept	Comments and Recommendations
Battery Energy Storage System Sizing	B2Q estimated battery system capacity of 200kWh at Andrews and 100kWh at DPW for comprehensive project proposal to Medford. CCERI grant funding breakdown proposed battery system capacity of 389kWh at each site using Sealed Lead Acid (SLA) batteries.	Proof of concept sizing within the current budgetary constraints results in a Base Project of a 250kWh battery at Andrews and a 85kWh battery at DPW to match building loads during a resiliency event and to enable off-grid capabilities. This sizing is similar to the sizing originally proposed by B2Q in our grant proposal to Medford and DOER. Due to the difference in technology costs, the selected LI-ion batteries cannot meet the capacity goal set by the CCERI grant funding for SLA batteries. Battery capacity of 250 kWh for DPW and 650kWh for Andrews would meet all project goals.	It is important to note that DPW was under construction at the time of the application submission for the CCERI grant. As a result, at that time there was no actual data on building energy consumption that could be used for battery sizing. After metering the DPW electrical systems and review of actual building energy consumption data, it was determined that the DPW could meet the project goals with a smaller battery energy storage capacity. Although funding could be shared between sites to accomplish the Base Project, we recommend program administrators consider increasing funding at both sites so batteries with enough capacity to meet all project goals can be installed.
Provide Emergency Power to DPW Critical Operations and Andrews Emergency Shelter	Provide approximately 3 hours of emergency power	Provide emergency power using LI-ion batteries for approximately 1 hour at both sites.	The energy storage capacity of the LI-ion batteries is less than the size used to develop the discharge duration goal for the CCERI grant. Increased funding would enable this goal to be met, as shown in the previous section. However, it should also be considered that because the emergency generators can power the facility for significantly longer, the impact of adding battery energy storage is maximized when it is used in conjunction with solar PV to enable off-grid renewable generation during the day (described below).

Resiliency Goals (cont.)

Project Aspect	**Goals Proposed with Grant Application**	**Proposed Implementation from Proof of Concept**	**Comments and Recommendations**
Address Long Term Grid Outages	Address electricity grid failures of greater than 48 hours. Maximize Energy Resiliency.	The battery systems have "grid-forming" capabilities required to enable off-grid use of solar PV systems for power. This will allow the facilities to be completely powered by the renewable solar PV array when enough solar energy is present for generation. HVAC and lighting load management during a resiliency event will reduce the loads on the resilient power systems and extend off-grid power capabilities. Assuming a full tank of fuel, and not including any solar or energy storage, the Andrews school emergency generator can operate fully loaded to support resiliency shelter activities for approximately 12 hours, while the DPW emergency generator can power the building systems for approximately 90 hours to support critical facility operations. The System Supervisory Controller will manage all of these systems so they operate in concert to maximize facility performance and power duration during a resiliency event. Key loads will be added to the optional standby systems at Andrews in order to support resiliency activities when the facility is being used as a shelter.	In addition to the societal clean energy benefits from reducing reliance on fossil-fuel generators when grid power is not available, the added resiliency impact will maximize time between generator refueling. Maximizing the time between refueling the emergency generator is an important consideration for a resiliency event if fuel deliveries were delayed or unavailable, particularly if an event occurs at a time when the generator fuel tank is not full to capacity. The integrated system will be able to save up to an hour of fossil-fuel generator operation for every hour the solar systems are producing energy. It is recommended that Medford consider adding a reserve fuel tank at the Andrews School to extend off-grid shelter capabilities and increase reserves beyond 12 hours. Since the resiliency sequences will be automated by the System Supervisory Controller, the operations managers at both project sites will be able to focus on other priorities in a resiliency event. Currently, the Andrews school has only minimal, code-required equipment on the emergency systems, which would not be able to support operating the facility as a resilient community shelter. Adding key optional standby loads to the emergency systems as proposed in the proof of concept analysis, such as HVAC, 1st floor lighting and plug loads, and kitchen equipment, will make the facility capable of supporting shelter activities and enable it to be used during a resiliency event.

Lessons Learned

Key Benefits of ADR + Resiliency + Energy Conservation + PV Renewable Energy

From a technical perspective, based on these two buildings, there are no insurmountable issues which would prevent either ADR or battery storage-based resiliency from benefitting the owner and/or the Commonwealth. The hypothesis that battery-based resiliency projects and automated demand response programs are complimentary appears to be valid. ADR measures can be activated during normal grid power scenarios to lower the load on the grid, and these same measures can be activated during emergency events in an effort to prolong the source of the off-grid power (PV + batteries and/or standby generators). Energy conservation is also complimentary since lowering the demand for power whether the facility is connected to grid power or standby power is beneficial since it reduces the need for capacity from the grid or from the standby source(s) and it may prolong the source of standby power. Typically, when a facility with PV energy loses its connection to grid power, it disconnects and stops producing power. However, the inclusion of battery storage at a facility with PV's enables the PV system to operate without grid reference, by forming a local "grid" for the solar PV to reference. Since the PV's can operate using the grid-forming capabilities of the batteries as long as adequate irradiant solar energy is available (there's sufficient sunshine) and the capacity of the PV system is sufficient, the PV's can provide electricity to the building and keep the batteries charged.

This leads to a brief technical discussion regarding standby generators and their importance in facilities with battery storage systems which are being used for resiliency. The possibility of installing sufficient battery storage capacity to provide enough power to enable a typical facility to operate off grid for more than a few hours is currently cost prohibitive. Standby generators are much more cost effective.

Pairing solar PV + batteries and standby generation together results in significantly more resilient buildings, by enabling the buildings to operate off grid and without diesel deliveries for much longer as well as providing the capacity to have intermittent power once there is very little remaining diesel. During major disasters diesel deliveries can be significantly interrupted resulting idle generators. A system with battery storage and PV can at least recharge and provide periodic electricity to occupants, where a system with only a diesel generator is reliant on frequent, sometimes daily, diesel deliveries during extended periods of grid power outages.

Regarding new construction, we recommend that the Commonwealth provide some guidance to constituents regarding the benefits of designing traditional emergency generators to be sized and configured to serve much more than traditional emergency loads for longer periods of time. If these systems are used in combination with battery storage and PV systems, the overall impact is that there are now three sources of off grid power available to the host during a resiliency event. For existing facilities with emergency generators, reconfiguring the electrical system to convert the emergency system to serve optional standby loads is likely the lowest cost alternative standby power choice. This lowest cost alternative is possible as long as the existing electrical infrastructure can be reconfigured to serve the areas of refuge in the building without being completely rewired out to the subsystems. Additionally, in an effort to lower the future cost of increased resiliency and increase adoption of resilient technologies, we recommend that the Commonwealth and Authorities Having Jurisdiction (AHJs) introduce the concept of incorporating resiliency and/or preparing new construction building systems to incorporate future resiliency systems as a part of part of the Owner's Project Requirements and respective new construction Basis of Design.

It is also noteworthy that many relatively small facilities, such as those found in municipalities, are typically not staffed with personnel who have the training or time to properly initiate demand response every time an event is called. This means that unless the demand response load curtailment is automated, the economics and system benefits of demand response will be diminished. Furthermore, in the event of an emergency, these personnel will be further distracted with other priorities, and the resiliency benefits of demand response will not be realized. Therefore, it is our conclusion that in order for demand response programs to increase resiliency at municipal host facilities, the demand response programs must be automated.

Technical Considerations

Automated Demand Response

Site Considerations

Generally speaking, municipal facilities are often not considered for traditional demand response due to limited operational staff with the knowledge required to implement demand response strategies or the time to actively manage responding to load curtailment event notices. Older municipal buildings without mechanical ventilation and/or cooling and/or without Building Automation Systems have limited capability to participate in demand response programs since they have very little load to curtail and limited automation to control the loads that do exist. However, municipal facilities with working HVAC systems and BAS controls are good candidates for Automated Demand Response (ADR) because the BAS can be modified to integrate with ADR systems and configured to automate load shedding sequences based on a remote load curtailment signal. Therefore, ADR offers a means to leverage the load shedding opportunity in these types of facilities by reducing the need for staff to manage demand response actions during a load curtailment event. In order to reduce the cost of implementing ADR, the presence of an existing and functional building automation system is paramount to cost effectively deploying ADR initiatives.

Leveraging Resilient Technologies

Buildings with batteries that are installed for resiliency purposes are good candidates for participating in demand response programs through ADR. This allows facilities to make use of a resiliency asset to create additional value by creating a revenue stream using ADR. ADR can be integrated to signal batteries to discharge and offset load, requiring little oversight and management. ADR should not be considered for battery energy storage projects which are planning to use peak shaving, as peak shaving would significantly limit demand response revenues by maintaining a low baseline.

ADR Practical Considerations

As stated above, the best candidates for demand response programs in Massachusetts are facilities with a summer cooling load, variable occupancy, and in order to reduce the cost of implementing automated demand response, the presence of an existing and functional building automation system is paramount to cost effectively deploying automated demand response initiatives. Generally speaking the greater the base load, the better the opportunity to curtail meaningful quantities of electric load during DR events. Additionally, the presence of a functioning lighting control system will reduce the cost of implementing lighting-based DR strategies. Below is a summary of what we have learned to date from exploring the two different facilities in Medford:

1) The BAS in both facilities are functional and can be programmed with automated demand response sequences. The Andrews system is older and uses LON as its communication protocol, and although the existing BAS is fully capable of receiving external signals and implementing automated load curtailment for HVAC systems, LON is no longer used by contemporary lighting control systems. We initially envisioned the BAS being a single source of user interface and data storage for the new lighting system being deployed, however it is apparent that this would significantly increase the costs of the project because the BAS would have to be upgraded to BACNet (which is the communication protocol specified for the lighting controller and most used in contemporary lighting control systems) and this integration would require generating individual lighting system graphics on the BAS. Therefore, the new lighting control system was procured with a separate web-based user interface and the BAS and lighting control systems will receive separate signals to initiate ADR. At the DPW, both the existing BAS and the lighting controller are capable of BACNet communication at a very low cost and the two systems will be integrated into a signal user interface for ADR.

2) The cost of integrating the battery storage system into the demand response strategies appears to be incremental because we are coordinating both demand response and BESS initiatives. It is likely that if the design of these projects was not being coordinated then the cost of integrating the batteries in DR would be significantly higher. We cannot provide a definitive percent increase because it would be driven by engineering costs and system vendor and programming specific considerations.

Energy Conservation Practical Considerations

While energy conservation measures lower the peak building demand that is able to be part of an ADR initiative, energy conservation is an important aspect of the project for both energy resiliency and the building's peak demand impact on the utility grid. For example, the LED lighting and lighting controls retrofit at the Andrews school will reduce the installed lighting load by approximately 50kW, approximately 50% of the current installed load, and a passive load reduction on the utility grid at all times. The lighting controls portion of the upgrade also enables the building lighting systems to be leveraged for demand response. This benefits resiliency as well by reducing the electrical load needed to power a critical part of the building infrastructure systems required during a resiliency event, thereby reducing the cost of making the building resilient in a significant and impactful manner.

Through the investigation, we have identified a number of other energy efficiency opportunities such as VFDs on fans and pumps and improving normal HVAC operating sequences, which are not in the budget but should be considered for implementation by Medford to not only passively reduce building demand, but also to enable the HVAC system to be further leveraged for increased ADR capabilities. Additionally, through the use of the Monitoring-Based Commissioning (MBCx) software, the operation of the facility will be continuously monitored to identify previously unknown opportunities for energy conservation and to prevent failures that may go unnoticed from impacting the building's performance during both peak demand response events and resiliency events.

Battery Energy Storage System Practical Considerations

System Sizing Considerations

Sizing and designing battery storage systems and solar systems separately for an existing facility is a challenge and if the design of these systems is not coordinated, the cost of both will increase, possibly quite dramatically. This is exacerbated in projects where solar systems and battery systems are not provided by the same vendor and can also occur on projects where the solar and battery system designs are phased without forethought. We have experienced this first hand with the City of Medford who was already in the process of selecting a solar PV developer for a PPA agreement and installation. The solar PPA for the DPW was phased first, and after the PPA was executed, the installation was slowed down in order to coordinate the design of the battery system. In this case, the solar PV inverter controls and the grid interconnect had to be changed to accommodate the required interactions with the battery. Ideally solar PV and batteries should be designed together to maximize energy savings benefit and off-grid capabilities and minimize procurement and installation costs.

SUPERVISORY CONTROLS CONSIDERATIONS

The technology of System Supervisory Controllers (SSC) (aka microgrid controllers) is rapidly developing as the use of BESS increases. The costs of system supervisory controllers vary widely due to the nascence of the industry. Most controller vendors are designing controllers capable of managing large microgrids, therefore they have significantly more capability than the controller needed for a “mini-microgrid” like the Medford projects, while options for “mini-microgrid” controllers are sparse.

The controller selected should be considered in conjunction with the requirements of the resilient systems it is required to support. For example, a microgrid consisting of several buildings with variable loads and many Distributed Energy Resources (DER) and storage assets may require a sophisticated microgrid Programmable Logic Controller (PLC) to perform the duties of the system supervisory controller. However, a single building modified for resilient islanding mode may utilize on site DERs, energy storage, and energy demand management that could be managed by a simpler, less sophisticated PLC. The size and sophistication of the PLC has a significant cost impact, with simpler PLCs designed to manage smaller/building-level microgrids ranging from $35,000 to $75,000. Data gathered by B2Q indicates that PLCs designed to supervise larger microgrids can range from $100,000 to $250,000 or more. Unfortunately, the market for lower cost microgrid controllers is in its infancy, and competitive offerings for smaller single building and mini microgrids are very limited, therefore the cost of this one component has significant impact on the economic viability of these types of projects. The system supervisory controller for both site should be a less-sophisticated building-level PLC, as greater sophistication is not necessary to control the DERs of a single-building “mini” microgrid. This indicates an opportunity for the DOER and other agencies to sponsor and encourage a market transformation for mini-microgrid controller that could broadly impact the future costs for municipalities to implement resilient systems.

EXISTING SYSTEMS AND INFRASTRUCTURE

Existing emergency system electrical infrastructure designs may limit the ability to be repurposed for resiliency due to costs. If emergency electrical systems are designed only for the code-required emergency systems, then they will not have the capacity to serve the building loads needed during a resiliency event. Often, emergency generators are lightly loaded, providing backup power only to systems that are mandated by code. Typically, emergency power is designed to provide power such that occupants will be able to safely evacuate a building that has lost power. Resiliency introduces the consideration of a facility need to remain occupied during extended power outages, changing the power demands on emergency systems. Integrating the ability to serve non-code mandated loads onto an emergency generation system introduces the concept of the systems capability to serve “optional stand-by loads”. The DPW building was designed for the emergency generator to serve the entire building, therefore the generator was sized for the entire building and there was no need to evaluate which additional loads need to be served during a resiliency event. However, the electrical system at Andrews was designed with a more traditional emergency power system, serving only part of the building loads. Therefore, for Andrews there was an evaluation of which parts of the building and which loads would be needed during and extended grid power outage. And the existing emergency generator was not designed to handle the loads of the systems which would be needed for a resiliency event. We met with Medford's Emergency Manager in order to better understand the power needs of the building if it is used as a longer-term shelter during emergencies. Based on this input we then evaluated the repositioning and design implications of meeting the intended Owners Project Requirements for optional standby loads. It is important to note that if the Andrews school had been originally designed as a shelter in place facility, it's electrical infrastructure would be been designed to support sheltering operations. This would reduce building electrical distribution and associated costs of re-circuiting to meet the needs of a shelter in place facility.

Site Selection

Site selection significantly impacts resiliency systems design, costs, and impact. When a municipality is preparing to embark on a resiliency project, a detailed site-selection process is recommended. The following site issues are relevant to this project which should be given consideration for future projects:

- Resiliency use-case (ie. Critical services or operations facility, community shelter, etc.)
- Limitations of the existing electrical systems and the location of the electrical service entrance (above ground and flood levels).
- Existing emergency electrical systems and emergency generator connected loads and fuel tank capacity
- Secondary electrical distribution system design and its impact on the cost of converting the building infrastructure to serve optional standby loads
- Potential site flood hazards
- Evaluation of the potential benefits of a larger microgrid encompassing more than one facility
- Feasibility of proposed location for energy storage and renewable generation resources, for example, if the solar PV system and/or BESS is to be roof-mounted, is the roof in good condition and is the structure capable of supporting an increased load (weight).
- Environmental and code considerations for the proposed DERs and energy storage system.

This list identifies key site selection issues relevant to this project. More comprehensive sources on this topic should be consulted for future project site selection, such as the "Mega-Shelter Planning Guide" by the International Association of Venue Managers (IAVM) and the American Red Cross, available for download at https://www.fema.gov/pdf/emergency/disasterhousing/mspg.pdf.

Technology Integration

Solar PV inverters need to be compatible with the SSC in order to operate off-grid. Confirming compatibility is especially important when the solar PV and BESS are being provided by different vendors and/or under different contracts. Furthermore, there are a number of solar PV inverters which are not capable of off-grid operation, even when coupled with batteries and supervisory controls.

Contemporary and common communication protocols between systems should be used wherever possible. Networking and systems integration costs should not be underestimated, and a PLC is essential to communicate and provide supervisory control over the other control systems. BACnet and Modbus are commonly used. Older communications protocols can prove difficult to manage and can have limited functionality without upgrades.

ECONOMIC CONSIDERATIONS

BATTERY ENERGY STORAGE ECONOMIC CONSIDERATIONS

The design and sizing of both battery energy storage and solar PV systems must be evaluated in order to maximize the potential solar and battery storage incentive programs available from state/federal agencies. It should be noted that in the case of municipal buildings, this integration significantly increases the complexity of the required procurement process. Solar PV procurement has become routine in municipalities but adding battery integration significantly increases the need for knowledgeable consultants to assist with the procurement process and adds a layer of complexity to understanding the financial cost benefits of the proposed systems. While the resiliency grant assumed that municipalities could contract for solar PV cost effectively, it was not clear at that time that an integrated procurement would be necessary to take advantage of federal tax credits or state incentives that currently exist, in addition to the technical need for integration. This results in a significantly more complex process that requires additional consulting support.

There are some specific complexities of the financial picture of solar and batteries in Massachusetts at this time that are adding additional complexity to the financing of a municipal solar PV and battery project, including this specific project:

1. In order to take advantage of the federal tax credit for battery storage, it must be owned by the same entity that owns the solar. This credit is 30% of the capital cost of installation and is significant. Specifically, on the order of $300,000 for both Medford sites combined. The original CCERI grant application assumed that Medford would be able to take advantage of the ITC.
2. In order to take advantage of the SMART adder for batteries, the battery must be owned by the entity that owns the solar.
3. The current structure of the resiliency grant and DOER policy is that the municipality must outright purchase the battery, therefore it is not possible to receive the benefit of either the 30% federal tax credit or the SMART adder for batteries. However, the grant is not large enough for an outright purchase of a battery system that would maximize the energy resiliency of the facilities and meet all project goals.
4. Medford's vendors have been told, but we have not yet confirmed, that the SMART battery adder cannot be taken for batteries paid for with a DOER grant.

In addition to the decision about rooftop versus carport solar for the Andrews School, the project is faced with the question about whether the battery should be financed through a PPA or owned. Financing the battery would be an overall savings to Massachusetts taxpayers since the installer would be able to take the ITC and pass through some of the savings to the city. For example, under a PPA financing scenario, Medford could put cash down to buy down the cost of the PPA, allowing the battery vendor to own the system and utilize the ITC value. If this could be done, the overall value to Medford and the Commonwealth tax payers could be maximized through leveraging the ITC and PPA financing structures. Furthermore, this added capital value could be used to increase the energy capacity of the batteries that Medford could afford and extend the duration that the building could be powered during an off-grid scenario.

The investigation performed for this proof of concept report indicates that investors appear to have limited interest in pursuing an energy storage project in locations where demand charges are less than $15/kW. This is due to the poor economic return of peak shaving avoided costs that could be claimed through a PPA or as shared savings under a performance contract. Therefore, the demand charges in the customer's rate structure has a notable impact for investor/developer interest and site selection. Additionally, anecdotal information indicates that investors and developers are hesitant to consider elective demand response programs in their ROI. Automating participation in demand response programs may increase confidence and participation.

The current net metering cap allocations are full for some areas, including Medford. Therefore, solar systems are sized to match building energy consumption, limiting the size in situations where the site could support increased solar PV and where added solar PV would provide additional resiliency and off-grid power capabilities. Additionally, the indication is that SMART and net metering are incompatible because of the potential for double counting benefits and incentives. However, a system with a supervisory controller similar proposed at both sites in Medford would be capable of providing granular system monitoring data for example of the output of solar PV systems and battery charge/discharge to confirm that benefits were not double counted.

Demand Response Economic Considerations

Electricity supply contract structure is important in order to maximize energy storage DR benefits. Demand capacity charges, for example, can be reduced through automatic participation only if the annual supply capacity charge is passed through to the customer in the electricity supply contract. At both Medford sites, the supply capacity charge is not passed through to the city under their existing supply contract, although Medford is actively working to modify the contract for these sites to take advantage of the supply demand cost-savings from their load curtailment efforts. Similarly, the value of energy arbitrage (charging the batteries during off-peak and discharging them during on-peak) is heavily dependent upon on-peak vs off-peak rates and has no value for a smaller customer that is not on a time-of-use rate structure. While the Andrews school is on a time-of-use rate structure for their electric delivery from National Grid, the difference between on peak and off-peak delivery rates is small and results in limited value from energy arbitrage. The DPW does not have a time-of-use electric delivery rate structure and therefore has no advantage from energy arbitrage; even if the rate structure were changed, the value of energy arbitrage would be significantly limited.

Administrative Considerations

Developing key project team is critical for successful resiliency review and application. This should include the owner's project manager, owner's facility staff, emergency manager, and knowledgeable technical staff. Throughout this project we worked with more than ten members of Medford's staff, all of whom were instrumental and provided key information and thoughtful input.

State and municipal contracting can be a long process, and although necessary for the project to proceed this phase can have unexpected impacts to proposed schedules. Contracting with the DOER and the City for this project took approximately six months when estimated to last two months in our grant proposal, shifting projections for phasing and estimated completion dates. The contracting phase should not be underestimated when considering project schedule estimates, particularly on projects with multiple funding sources and stakeholders.

Replicability and Scalability

Replicability of ADR Use Cases at Medford

The two types of buildings which are being considered for the City of Medford are a middle school and a department of public works facility. The Andrews Middle School is similar to other school/academic buildings since it has a variable occupancy throughout the day and although it is mechanically cooled during the summer, it is less occupied during this period than the winter months. Also, during periods of highest peak demand on the Massachusetts regional electrical grid (summer weekdays from 3 pm to 7 pm) summer activities in schools have usually ended for the day. Schools like Andrews, with electric cooling and summer programs, offer significant demand reduction potential.

The DPW facility is very different than the Andrews School. The peak load is approximately 75kW, and therefore has limited ability to be a significant contributor to a demand response program. Having stated this, it is important for many reasons that the energy industry figure out how to engage all sizes of buildings from all different market sector use types. Also, almost every municipality in the Commonwealth has a DPW facility, and DPW facilities have important contributions to community safety, especially during emergencies. Therefore, including the DPW facility in both the automated demand response and resiliency pilot projects is worthwhile. Additionally, the building was recently constructed in 2015 with new control systems that reduce the cost of integration and lower the first cost of automating load shedding. When equipped with batteries for resiliency, both the DPW and the Andrews school will have the capability to generate significant demand response revenue as the batteries can contribute to significantly load offset building loads.

Therefore, when the combined effect of site selection and leveraging resilient technologies, both Medford sites are good candidates for ADR and resiliency in this pilot project. The indication is that the ADR use case combining newer municipal schools and DPW facilities which also are pursuing battery energy storage for resiliency is practical and scalable to other municipal facilities within the Commonwealth.

Scalability of this Pilot Project

B2Q will continue to develop replicability and expand scalability metrics and analysis over the course of project implementation and year one of system operation. However, at this time the following scalability aspects of the project have been confirmed:

- The ADR signal receiver controller from EnergyIQ is universal and can be compatible with many control communication protocols. Therefore, it can be used in many different applications with a variety of technologies.
- Buildings with Building Automation systems can be readily integrated for peak demand response.
- Buildings with lighting control systems can be readily integrated for peak demand response.
- Facilities which have resiliency systems using energy storage can be leveraged for peak demand response activities to create additional revenue streams and peak demand reduction on the grid.

Potential Obstacles

Implementation of energy storage for both resiliency and peak demand response within Massachusetts municipalities involves numerous potential obstacles. Many of the obstacles are specific to the type of facility and resilient operations use case, and considerations for those are described in earlier sections. However, there are a few significant obstacles listed below that have been identified by Medford and B2Q which are likely to be relevant to most municipalities when considering future projects involving energy storage, renewables, resiliency, and peak demand response.

Municipal Procurement and Market Change

The municipal procurement process and rapid evolution of battery energy storage and solar markets create a challenge to implement this type of project successfully. Municipal procurement very structured and regulated and is therefore a slow-moving process, which works well for technologies and projects that municipal staff is familiar with. New and evolving markets are rapidly developing, with non-standardized equipment pricing, changing incentive and rebate programs, and short periods between new generations of technologies which are available from vendors result in a constantly-shifting project cost and economic environment coupled with new technical details and information that a municipality must navigate during procurement. Additionally, the goals of municipal staff and vendors are not always aligned, therefore municipal staff must perform their due diligence on behalf of the public entity they represent. In order to do this, municipal staff must invest significant time to stay on top of the technical details and market factors. Part of the solution to addressing this challenge is making sure there is a 3rd party consultant to help the municipality through the design development and procurement process.

Renewables and Energy Storage for Resiliency is a Customized Application

No two municipal buildings are alike in terms of electrical infrastructure and resiliency use cases. Therefore, there is no “off the shelf” resiliency package that can be used for several applications – each project must be designed and customized to meet the specific facility’s needs. This adds to the complexity described above for project development and procurement and underscores the need for a 3rd party consultant to be involved throughout the process.

The Value of Resiliency

It remains true that installing batteries only for resiliency is not clearly cost effective to municipalities, therefore additional value streams are important to develop for each project. For private companies, the value of adding resiliency can be easier to demonstrate due to the relationship of critical operations with revenue centers such as data centers, for example. However, until a dollar value can be applied to the ability of a municipal facility to function during an extended outage and serve its constituents, alternative value streams must be developed to demonstrate the return on investment. As with this project, peak demand response programs can be leveraged to create added value from resiliency investments in battery energy storage. Peak demand response may be applicable to create value for other use-cases, however the development of metrics for the value of resiliency and creation of alternative value streams is paramount to advance the market for energy storage and resiliency at municipal facilities.

ANDREWS MIDDLE SCHOOL PROOF OF CONCEPT

PEAK DEMAND RESPONSE SUMMARY

The Andrews Middle School's peak demand is approximately 375kW, however for 97% of the year the building demand is below 200kW and the annual load factor is 22%. These metrics indicate the facility is a great candidate for peak demand reduction and participating in demand response programs. We have identified changes to the building lighting and HVAC control systems which are expected to enable 99 kW of demand reduction, with 50 kW being permanent from the technology upgrade and 49 kW being dispatchable on demand (196 kWh dispatchable over four hours). The addition of battery storage at the anticipated energy storage capacity of 250 kWh increases the dispatchable demand reduction by 50 kW for an additional 200 kWh dispatchable over four hours. The total anticipated dispatchable load curtailment is 99kW for total of 396 kWh over a four-hour time period, as shown in the Table 5 on the following page.

The Andrews school can currently participate in ISO-NE forward capacity market and National Grid's Connected Solutions demand response program through CPower, a Curtailment Service Provider (CSP). CPower also offers a "Cap Tag Management" program which Andrews could take advantage of if the electric supply contract is changed to pass the annual capacity charge through to the customer. Automated Demand Response (ADR) can be provided by CPower using a controller set up for this purpose by EnergyIQ, which can be integrated with all technologies. Automated demand response is technically feasible for the following technologies:

- The HVAC demand management strategies involving changing the sequences of operation would enable 37.8 kW for a 4-hour demand response event.
- Lighting demand management through the new lighting control system could save 11.3 kW for a 4-hour demand response event.
- Battery system sized at 100 kW/400 kWh could deliver 80kW for a 4-hour demand response event, leaving 20% for reserve. This is approximately the size considered by the CCERI grant. The demand response capacity available and the revenue stream from the battery system is directly tied to the energy storage capacity. Therefore, the demand response capacity that will be available from the batteries at the Andrews school is a function of the energy storage capacity the CCERI resiliency grant can fund. Based on the resiliency technical and financial analysis of the batteries presented later in this report, a conservative estimate of 50kW for a 4-hour demand response event is used in the following Table 5, based on an energy storage capacity of 250kWh.

The table below summarizes the electrical demand savings, DR revenues, and technology-specific economics. This is based on the incremental cost of adding ADR to systems. The Incremental Project Cost assumes that the technology is already in place or planned by the facility or customer for reasons other than demand response and represents the added cost difference to enable automated demand response. For example, the total cost of the LED and lighting controls installation at the Andrews school is not implemented solely for demand response, and the incremental cost represents the added cost to leverage this system for automated demand response and provide additional revenue streams.

Andrews Demand Response Technologies Economic Summary							
Demand Response Technology	Summer Demand Savings	Winter Demand Savings	DR Average Annual Program Revenues	Technology Implementation Cost/kW	Incremental Project Cost	Payback on DR Revenues	ROI
	kW	kW	$	$/kW	$	yrs	%
HVAC Upgrades	37.8	8.5	$5,539	$864	$40,000	7.2	14%
Lighting Upgrades	11.3	11.3	$1,858	$443	$10,000	5.4	19%
Battery Energy Storage System (BESS)	50.0	50.0	$8,235	$200	$20,000	2.4	41%
TOTAL	**99.1**	**69.7**	**$15,631**	**$1,507**	**$70,000**	**4.5**	**22%**

Table 5 Andrews Middle School – Automated Demand Response Technologies Economic Summary. The ROI based on incremental project costs to add DR capabilities to the base technology installation.

RESILIENCY SUMMARY

The Andrews Middle School resiliency use-case is a community shelter. Discussions with Medford's Emergency Manager indicated that during an emergency event this building would be used as a temporary shelter for the public. Medford's current plan is to use the 1st floor cafeteria and gym spaces as the places of refuge and the administration area of the building as a support area.

The existing emergency generator at Andrews Middle School is rated for 250kW in standby operation, and 200kW in continuous operation. The current load on the generator is approximately 39kW. Since the generator doesn't have enough capacity to serve the entire building, and since it is currently wired to serve only a small number of loads and does not necessarily serve the spaces which will be used as places of refuge, the wiring of the electrical system needs to be rerouted to add resiliency loads to the standby generator.

The generator can support the existing emergency loads for 50 hours with a full tank of fuel. If the recommended electrical modifications to support an emergency shelter are implemented, the standby generator, if started with a full fuel tank, could operate at 200kW for 15 hours. This capacity of 200 kW is capable of providing power to the lighting and heating/ventilation systems in the areas of refuge with approximately 1.0 kW to be available for miscellaneous plug loads, with greater plug load capacity available when the building load is less than 200 kW. It should be noted that there is insufficient capacity to provide full cooling to these areas and the existing cooling equipment that can be served must be modified such that the equipment stages when starting up so that it does not trip the generator off-line. The Table 6 below exhibits the loads which are able and recommended to be connected to the standby generator.

Resiliency Loads and Corresponding Panels Proposed for Optional Standby Off-Grid Power			
Panel	Equipment Served	Sub Panel	Optional Standby Resiliency Loads to be added
PH1	Mechanical Equipment	PL1C, PL2C	Fan Powered Boxes and Unit Ventilators
PHK1	Kitchen Equipment	PLK1	Critical Kitchen Equipment including Convection Oven, Ice maker and Exhaust hood
LH1	1st Floor Lighting	PL1C, PL1A, PL1B	All First Floor Lighting
LH2	2nd Floor Lighting	PL2A	Cafeteria and Gym Lighting
PH3	Mechanical Equipment	PL3B	AHUs & AC units associated with gym and cafeteria, Fans & Unit Ventilators

Table 6 Proposed resiliency Loads and corresponding electric panels for optional standby off-grid power

The recommended battery type for this application is Lithium Ion (LI-ion). The original CCERI evaluation for this project was estimated using Sealed Lead-Acid (SLA) batteries. Although LI-ion battery systems cost about twice that of a similarly sized SLA system, B2Q recommends LI-ion over SLA for the following reasons:

- SLA batteries have a slow rate of charge compared to LI-ion batteries. This impacts how quickly a solar system could charge the batteries during an off-grid emergency event.
- LI-ion batteries have a longer life of SLA batteries. Cycle life (one cycle is comprised of one charge and one discharge) for SLA batteries the life is typically estimated to range from 500 to 1,500 cycles, while new LI-ion batteries are guaranteed by manufacturers for at least 3,000 cycles.
- LI-ion round-trip efficiency (discharge/charge efficiency) is approximately 95%, while SLA round-trip efficiency is closer to 80% or less.
- LI-ion batteries have very stable discharge voltage while the SLA battery voltage drops consistently during discharge. If discharge voltage drops or “sags” too far, lights could dim and equipment may not be able to operate.
- LI-ion is cleaner and safer for the environment than SLA because LI-ion does not contain lead.
- LI-ion batteries are more flexible in how they are used and can be discharged below 50% capacity without significant adverse impacts to battery life. Contrasted to SLA batteries, where, because of the nature of the SLA electro-chemical reaction, current draw from large equipment (such as AC compressors for cooling) can reduce the available energy storage capacity. Additionally, SLA batteries cannot be discharged below 50% of rated capacity without potentially significant impacts on cycle life.

The battery size that is recommended to maximize resiliency and also DR impact is 100kW/ 400kWh. This will allow the facility to support peak resiliency loads of 200kW for two hours off grid, and 50% load of 100kW for four hours. The battery energy storage capacity that is required to meet all CCERI goals is approximately 650kWh.

Off-grid power duration with the emergency generator and battery systems can be extended by automated load management, using modified peak demand response sequences.

The CCERI grant did not capture one of the key aspects related to increasing resiliency at the facility, namely, the electrical upgrades to add standby loads to the emergency power systems which are necessary to support emergency shelter activities. The estimate for maximizing the electrical loads for resiliency is approximately $120,000.
Including the electrical resiliency upgrades in the CCERI grant funding, the grant can support a battery size of approximately 100kW/250kWh if funding is shared with the DPW as described in the Executive Summary Project Budget section earlier in this report.

Facility Description And Exiting Conditions

General

Andrews Middle School was built in 2001 and is one of nine schools operated by City of Medford. Andrews Middle School is a three-story steel-frame building with a masonry exterior, totaling approximately 104,000 ft^2. The facility is 100% heated and air conditioned. In 2016 the enrollment was 479 students, and the facility has a maximum capacity of 600 students.

Building Use

Typical building use schedules are as follows:

- The school is most heavily occupied between 7:00 am – 4:00 pm. Custodial staff arrive at 5:00am and often stay until 10:00pm.
- Vacations include winter break, spring break, summer break and holidays.
- Summer activities at Andrews Middle School vary year to year, for musicals, orchestra, school plays etc. Summer activities and events typically use the Cafeteria, Auditorium and the Music room.
- The Gymnasium is used during the school day, as well as for non-school community sports and activities. The gymnasium is typically occupied between 7:00 am – 8:00 pm.
- The Cafeteria is regularly used for after school activities, typically until 4:00pm.

Electrical Systems

The main switch board receives a 480 V feed from National Grid's transformer. The main switch supplies electricity to various panel boards, condensing units, the chiller and two automatic transfer switches (ATS 1 and 2). ATS 1 and 2 carry emergency loads which are currently powered by the 250 kW Caterpillar diesel emergency generator during a loss of utility power.

Andrews Middle School - List of Electrical Panels			
Panel	**Floor**	**Voltage**	**Equipment Served**
MSB	1st floor	480	Main switch board supplying all panels in the building
PH1	1st floor	480	Pumps, Unit ventilators and unit heaters on 1st floor
PHK1	1st floor	480	Kitchen Equipment, eg. dish washer, booster heater
LH1	1st floor	277	Lighting equipment on 1st floor
LH2	2nd floor	277	Lighting equipment for cafeteria, gym and 2nd floor
LH3	3rd floor	277	Lighting equipment on 3rd floor
PH3	3rd floor	480/277	Air Handling units, unit ventilators, fans and fan powered boxes
PL1C	1st floor	120	Cabinet unit heaters, fans, domestic water heater on 1st floor
PL2C	1st floor	120	Unit heaters and Diffuser fans for 2nd floor
PLK1	1st floor	120/208	Lighting, kitchen equipment and plug loads in Kitchen area
PL1C	1st floor	120	floor
PL1A	1st floor	120	Lighting equipment serving 1st floor room spaces
PL1B	1st floor	120	Lighting equipment serving 1st floor room spaces
PL2C	2nd floor	120	Unit heaters and Diffuser fans in Gym
PL2A	2nd floor	120	Cafeteria lighting
PL2B	2nd floor	120	Lighting equipment serving 2nd floor room spaces
PL3	3rd floor	120	Lighting equipment serving 3rd floor room spaces
PL3A	3rd floor	120	Lighting equipment serving 3rd floor room spaces
PL3B	3rd floor	120/208	Rooftop fan units, heat pump and diffuser fans
ATS1	1st floor	480	Power though back Generator. Serves emergency equipment like Boiler, pumps, kitchen coolers and kitchen freezers.
ATS2	1st floor	480	Power though back Generator. Serves emergency lighting for spaces like corridors, restrooms, mechanical rooms and fire pump.

Table 7 Electrical panels serving Andrews Middle school

Utilities

Electricity and Natural Gas are supplied and delivered by National Grid. For the Fiscal year 2016 the energy consumption was 735,800 kWh and total annual natural gas consumption of 35,908 therms. The average "all-in" energy cost $0.17/kWh and $1.09/therm. The City of Medford is currently negotiating a new electric supply contract structured to take advantage of DR value streams.

HVAC

There are four AHUs serving the administrative areas, the gym, and the cafeteria. The AHUs are all equipped with hot water coils and Direct Expansion (DX) refrigerant coils and each is served by a dedicated air-cooled condensing unit. The four air-cooled condensing units (ACCU's) each have four compressors for four stages of cooling. There are approximately (45) unit ventilators (UVs) serving the classrooms and perimeter spaces. The UVs are equipped with dual temperature coils for hot water heating and chilled water cooling. Variable air volume (VAV) boxes equipped with hot water reheat coils are installed in the music room, admin areas, and all of the interior classrooms. Refer to Appendix D – Equipment List for a detailed equipment list.

Andrews Middle School - Mechanical Equipment					
Unit no	Location	(Yes/No)	Fan hp	Total CFM	kW
AHU-1	Area B and Adminstarion	Yes	20	13,600	12.3
AHU-2	Area A	Yes	20	13,000	11.5
AHU-3	Cafeteria	No	15	9,200	8.9
AHU-4	Gymnasium	No	10	10,000	6.2

Table 3 Andrews Middle School Air Handlers

Heating Systems

Andrews Middle School has two Burnham gas hot water boilers, each with a gross output of 3,580 MBH, a three hp blower motor. There is one 10 hp hot water pump equipped with a premium efficiency motor which provides 25% glycol hot water circulation for heating to AHUs, hot water reheat to VAVs, and fin tube radiation (FTR) in the gym, library and interior classrooms. During the winter, this system operates as a standard hot water system. During the summer, the boilers are valved off, and the hot water system is used to provide chilled water to the UVs only.

Two Domestic hot water heaters, each 399 kBtu/hr, with 250 gal storage serve the DHW loads.

Cooling

Andrews School is served by a 160-ton Trane air-cooled chiller which supplies 25% glycol chilled water to the classroom UVs, via the dual temperature loop. During cooling season, chilled water is circulated to the UVs by a 7.5hp pump, equipped with a premium efficiency motor.

There are four Direct Expansion condensing units on the roof one serving each air handler. DX capacity is listed below.

- Admin area A: 60 tons
- Admin area B: 40 tons
- Gym: 30 tons
- Cafeteria: 25 tons

There is also a small air-cooled DX split system which provides cooling for the IT systems in the data closet.

Lighting

Andrews Middle School has a total of lighting load of 102 kW. Table 8 describes the section of the building and lighting inventory associated with it. It is to be noted that Andrews Middle School does not have an existing lighting control system.

Andrews Middle School Existing Lighting Summary	
Building Area	Type of Exisitng Lighting Fixtures
Classrooms	Direct/indirect lighting fixtures with cable pendants and pendant mounted induction lighting fixtures
Cafeteria	165 watt pendant mounted induction lighting fixtures
Gymnasium	High bay fluorescent fixture each with six T8 32 watt lamps with an integral occupancy sensor
Hallways	Combination of 4 ft, 8 ft indirect cove lighting fixtures
Restrooms	Combination of 8' and 6' industrial fluorescent wall mounted indirect light fixtures
Administartion Offices	2x4 32 Watt T8 lamp recessed fixtures with either flat prismatic lenses or parabolic lenses
Lobby hallway	Large architectural fixtures with five - 175 MH lamps in individual ribbed glass globes
Miscellanous Utility, Storage, etc.	Two lamp, 32watt T8 industrial strip fixtures

Table 8 : Andrews Middle School Existing Lighting inventory summary

Building Automation System

The BAS at Andrews is comprised of several generations of controllers. The field equipment controllers for UVs, FTR and VAVs are older LON controllers dating to original construction. In 2010, a recommissioning upgrade was performed, which added newer LON supervisory controllers for the air handlers and global controls. The BAS controls all HVAC equipment with the exception of vestibule and unit heaters, which have self-contained thermostatic controls.

Other Equipment

The school also has a full-service kitchen which includes two Kitchen hoods, dishwasher, walk-in freezer and cooler, electric service coolers and warmers, gas ovens and deep fryer. There are two data server racks in the main IT closet. There are approximately 100 computers in the school.

UTILITY RATE ANALYSIS

Table 9 below represents Andrews Middle Schools utility rate analysis. Andrews Middle School falls under National Grid's G-3[2] (Time-of-Use) tariff rate, which is primarily for large commercial and industrial customers with demand greater than 200 kW.

The peak and off-peak hours described under this service are:

Peak Hours: Peak hours will be from 8:00 a.m. to 9:00 p.m. daily on Monday through Friday, excluding holidays.

Off-Peak Hours: Off-Peak hours will be from 9:00 p.m. to 8:00 a.m. daily Monday through Friday, and all day on Saturdays, Sundays, and holidays

It is to be noted that the distribution charge is different for on-peak and off-peak hours. The peak and off-Peak supply rates are assumed to be same. Any change in the peak supply costs vs off-peak supply costs would significantly impact the utility costs for the Andrews Middle School.

Andrews Middle School : Utility Rate Analysis			
	Cost per unit	On Peak	Off Peak
Distribution Demand Charge	$/kW	$5.76	-
Distribution Charge - On peak	$/kWh	$0.0162	-
Distribution Charge - Off Peak	$/kWh	-	$0.0086
Transmission Charge	$/kWh	$0.0206	$0.0206
Transition Charge	$/kWh	$0.0006	$0.0006
Energy Efficiency Charge	$/kWh	$0.0096	$0.0096
Renewables Charge	$/kWh	$0.0005	$0.0005
Energy Supply Costs	$/kWh	$0.1000	$0.1000
Total		$0.1474	$0.1399

Table 9 Andrews Middle School G3 tariff utility rate structure for the year FY 2016

ENERGY COST ANALYSIS

Table 10 below is the summary of the Annual energy spend at Andrews Middle School. It is to be observed that the supply costs account for 42% of the annual energy spend and the demand charges account for 15% of the annual energy spend. Any reduction of the above charges would result in significant savings in the energy spend. The demand charge of $5.76 per kW is accounted based on the highest peak demand. The peak demand for the year FY 2016 was 375 kW. If the peak demand is reduced to 200 kW the savings on demand charge would account for 5% of the overall energy spend.

[2] Time-of-Use (G-3) - National Grid Customers

Andrews Middle School- FY 2016 Energy Spend				
Utility Cost	***Units***	***Rate***	***Annual Spend***	***% of Total Annual Energy Spend***
Distribution - On Peak electric	$/kWh	$0.016	$6,694	4%
Distribution - Off Peak electric	$/kWh	$0.009	$2,746	2%
Supply on Peak Electric	$/kWh	$0.100	$41,400	24%
Supply Off Peak Electric*	$/kWh	$0.100	$31,780	18%
Electric Demand	$/kW	$5.760	$25,829	15%
Transmission Charge	$/kWh	$0.021	$15,068	9%
Transition Charge	$/kWh	$0.001	$424	0%
Energy Efficiency Charge	$/kWh	$0.010	$7,003	4%
Renewables Charge	$/kWh	$0.001	$366	0%
Customer Charge	$/ Month	$223.000	$2,676	2%
Delivery - Natural Gas	$/Therms	$0.646	$23,088	13%
Supply – Natural Gas	$/Therms	$0.446	$15,951	9%
Total			***$173,025***	***100%***

Table 10 Andrews Middle School FY 2016 Energy Spend Summary.

ENERGY USE AND BENCHMARKING

Annual Energy Spend of Andrews Middle School is shown in Table 11 and provides a summary snapshot of the various major contributing factor of the energy spending for FY 2016. It can be seen that the building EUI is approximately 59 kBtu/ft^2, which indicates the building is fairly efficient, however a target EUI for this building would be 50 kBtu/ft^2 to maximize efficiency. It can also be seen that the facility annual electric use metric is approximately 7.1 kWh/ft^2, while a target for this metric for a middle school should be around 6.0 – 6.5 kWh/ft^2.

Andrews Middle School - Annual Energy Summary		
Square Footage	104,000	Sq./ft
	Qty	*Units*
Annual Electricity Usage	735,800	*kWh*
Annual Electricity Usage - On Peak	414,000	*kWh*
Annual Electricity Usage - Off Peak	321,800	*kWh*
Annual Electrical Distribution Cost	$9,440	*$*
Annual Electrical Supply Cost	$73,180	*$*
Total Annual Electrical Cost (Combined)	$133,986	*$*
Average On peak demand	279.5	*kW*
Average Off peak demand	234.5	*kW*
Peak Energy Intensity	2.688	*W/Sq. Ft*
Annual Usage per Square Footage	7.08	*kWh/Sq. Ft*
EUI (Electrical)	*24.14*	*kBtu/SF*
Annual Gas Usage	35,908	*Therms*
Annual Gas Supply Cost	$15,951	*$*
Annual Gas Distribution Cost	$23,088	*$*
Total Annual Gas Cost	$39,039	*$*
EUI (Gas)	*34.53*	*kBtu/SF*
EUI (Total)	***58.67***	***kBtu/SF***

Table 11 Andrews Middle School Annual Energy Spend for FY 2016

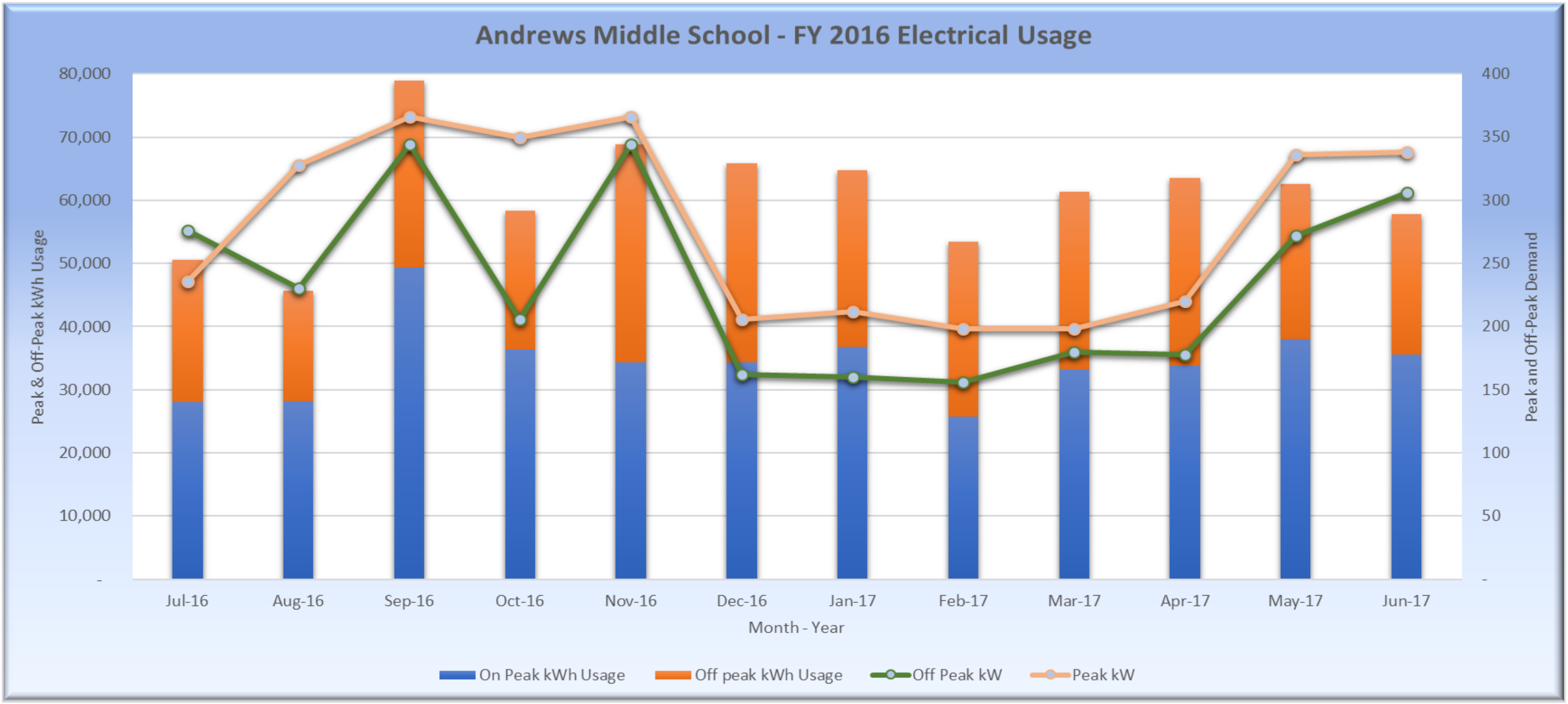

Figure 1 Andrews Middle School – FY 2016 Energy Usage

The graph in Figure 1, as well as Figure 7, Table 12 & Table 13, present various historical consumption statistics for a one-year period (FY 2016). The table presents energy usage data that is helpful in understanding if there is diversity in the demand and if there is off peak capacity available, indicating the potential to shift loads from peak periods.

The highest on peak occurred on 06/13/2017 1:15 PM (Tuesday) when the outside temperature was 95^{o}F, indicating the air conditioning units and the chiller significantly contributed to this peak. The off-peak demand occurred on 9/3/2016 1:30 PM on a weekend (Saturday), when the outside temperature was 70^{o}F. This may be an indication that the building was occupied for a program or event during the weekend, or it could indicate a problem with equipment operating sequences.

Andrews Middle School - FY 2016 - Electricity Usage and Demand		
	Qty	Units
Annual Electricity Usage	735,800	kWh
Annual Electricity Usage - On Peak	414,000	kWh
Annual Electricity Usage - Off Peak	321,800	kWh
% On Peak	56%	%
On-Peak - Maximum Demand	375	kW
On-Peak - Maximum Demand Date	6/13/17 1:15 PM	time
Off-Peak Maximum Demand	305	kW
Off-Peak - Maximum Demand Date	9/3/16 1:30 PM	time
Load Factor	22%	%

Table 12 Electric usage and demand for FY 2016

Andrews Middle School - Summer June - Sep - Electricity Usage and Demand		
	Qty	Units
Annual Electricity Usage	233,000	kWh
Annual Electricity Usage - On Peak	141,200	kWh
Annual Electricity Usage - Off Peak	91,800	kWh
% On Peak	61%	%
On-Peak - Maximum Demand	375	kW
On-Peak - Maximum Demand Date	6/13/17 1:15 PM	time
Off-Peak Maximum Demand	305	kW
Off-Peak - Maximum Demand Date	9/3/16 1:30 PM	time
Load Factor	7%	%

Table 13 Electric usage and demand for the summer months (June- Sep)

Load Factor[3]: Electrical Load factor is a measure of the utilization rate, or efficiency of electrical energy usage. It is the ratio of total energy (KWh) used in the billing period divided by the possible total energy used within the period, if used at the peak demand (KW) during the entire period. A load factor below 50%, suggests that the building experiences periods of very high usage (demand) and a low utilization rate. This, in conjunction with other energy data at Andrews indicates that the facility has some high-power equipment, primarily the chiller and DX units, which come on for only a small number of hours per year. The load-duration curve presented later in this section provides a graphical representation of the fraction of time that the facility is at or above various electric demand levels.

[3] Power Planet Energy Management Systems. Available at http://www.demandcharge.com/Web_Pages/Articles/Electrical_Load_Factor.html

PEAK VS. OFF PEAK USE

On-peak electric demand (kW) during the summer is approximately 61 % of total electric energy consumption compared to 57% overall for FY 2016. Figure 2 below provides a graphical representation of the on-peak peak electric demand. It can be observed that demand spikes notably during the summer months of June and September, while demand during July and August is notably lower when there are no classes in session. This appears to be a result of limited cooling systems use during summer break, and full cooling system use during warm periods of the school year.

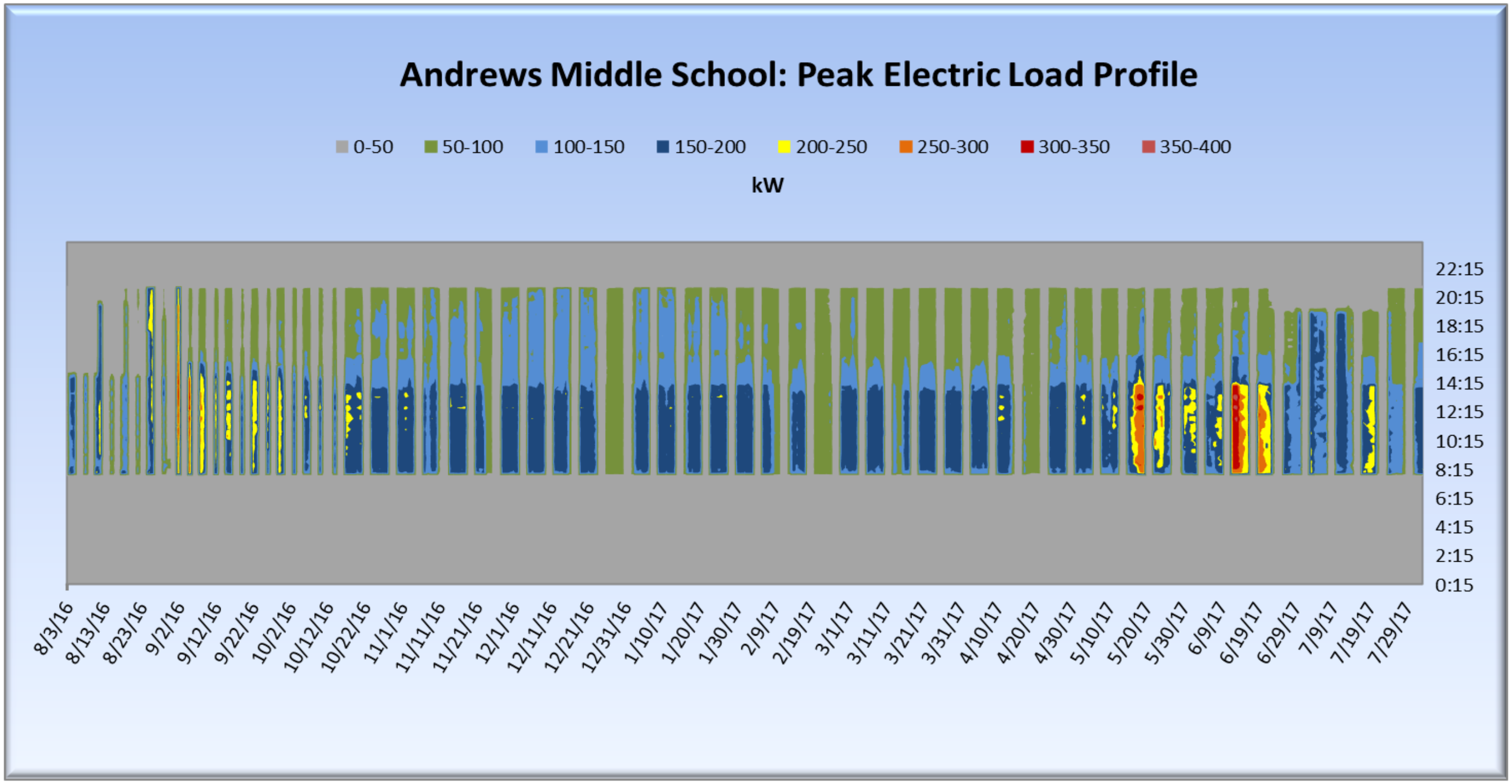

Figure 2 Andrews Middle School Peak Electric Load profile for FY 2016.

Off-peak electric demand (kW) during the summer is approximately 39% of total electric energy consumption compared to 43% overall for FY 2016. This amount of consumption during off-peak is high for a facility which is mostly unoccupied during this time. Such a level of energy consumption may indicate that some equipment or lighting is operating continuously (overnight and on weekends). Figure 3 below provides a graphical representation of the off peak electric demand. It can be observed lot of demand spikes during the month of September 2016 weekends.

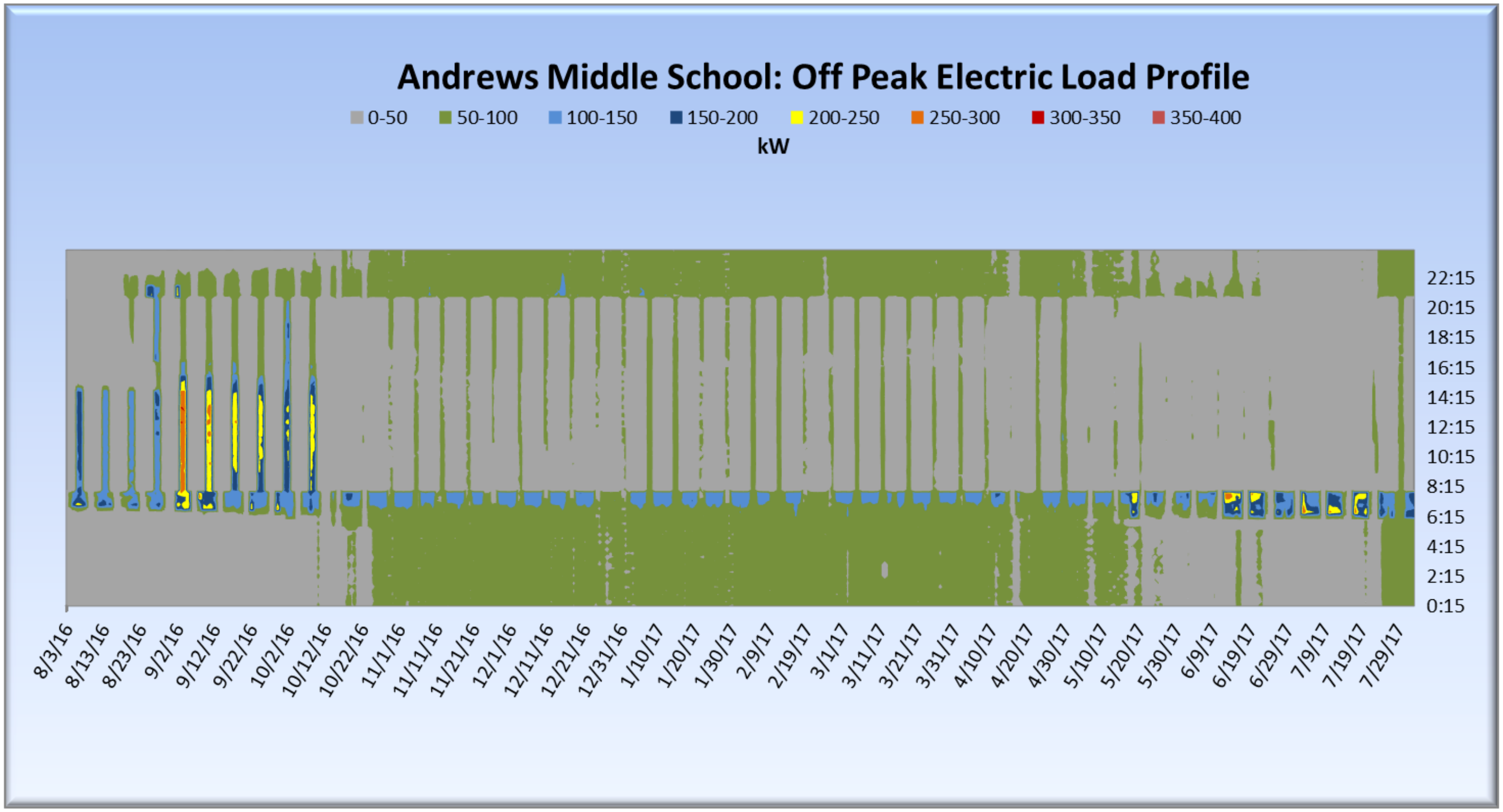

Figure 3 Andrews Middle School – Off Peak Electric Load profile for FY 2016

Electric Load Analysis

Load Duration Curve

The load duration curve is a plot of the percentage of time that the facility load is at or above various demand levels. For example, on a downward sloping curve, the demand at a 10% level would indicate that the demand is at or above that level for 10% of the time. A curve with a steep section at the beginning, such as the one below in Figure 4, would be indicative of a load profile that spends very little time at high or full load, and a flat curve would indicate that there is very little variation in load over time. This plot is useful in identifying the potential for load reduction, which is shown on Figure 5.

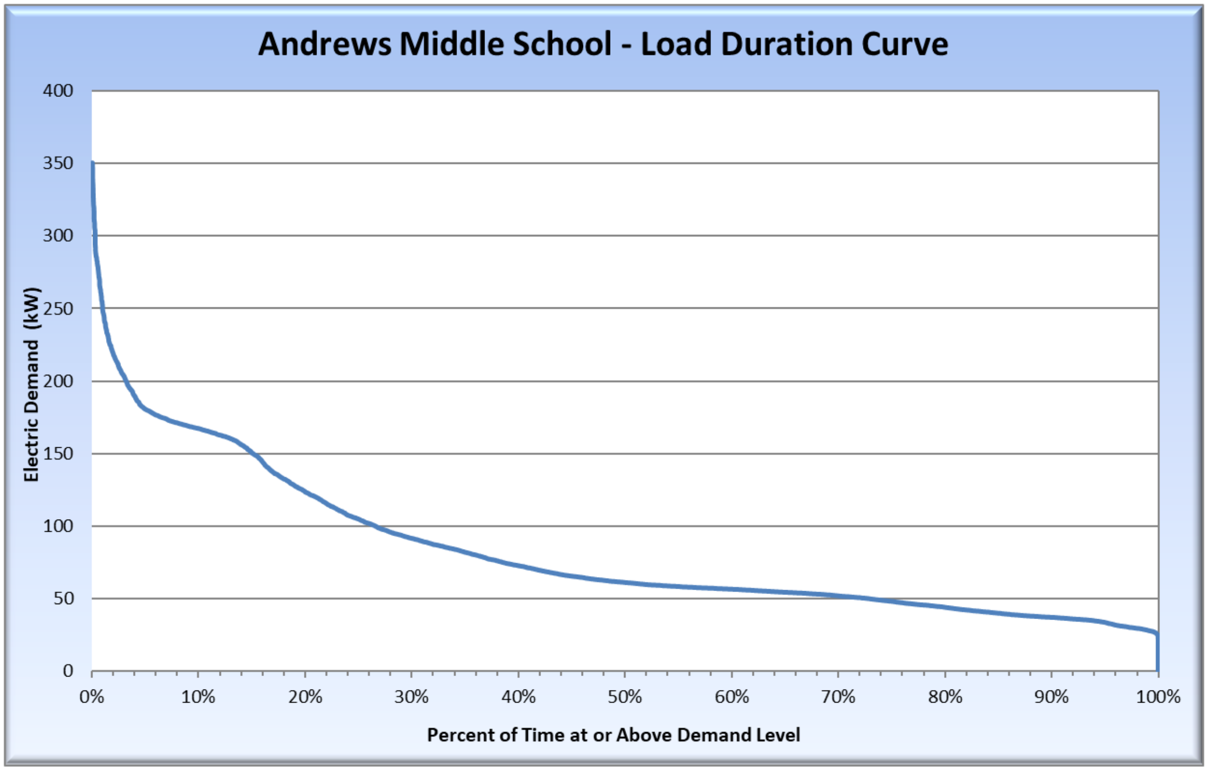

Figure 4 Andrews Middle School – Load duration curve for FY 2016

Below is the load duration curve in Figure 4 for the most recent year (FY 2016) of data available. The data from this curve shows that the load is above approximately 200 kW less than 3% of the time. This is an extremely steep load duration curve, as the 5% annual load of 178 kW is only 51% of the annual peak load of 350 kW. This indicates that most of the time the facility needs less than 175 kW, however for 5% of the year, the facility needs close to twice that. This is a very sharp increase and various demand reduction strategies addressed in later section of the report can be used to limit demand can be used to reduce the slope of this curve and create demand savings.

ZOOMED LOAD DURATION CURVE

The load duration curve above is zoomed-in on the figure on the following page. This figure illustrates the demand reduction opportunity. The 3% value represents 263 hours (3% x 8760hours/yr) of demand at or above that value. The 1% value represents 88 hours of demand at or above that value.

- During 1% of the year, demand is at or above 230 kW
- During 3% of the year, demand is at or above 200 kW

The limited number of hours during which peak demand occurs indicates that peak demands are being caused by infrequent events in the facility's operation. Typical events which cause peak demand include simultaneous operation of chiller and RTU air conditioning equipment and large kitchen equipment while baseload equipment such as lighting is also operating.

Demand management sequences can be utilized in the BAS and lighting systems to avoid these demand spikes by prioritizing the equipment which is limited or turned off when peak demand is approached.

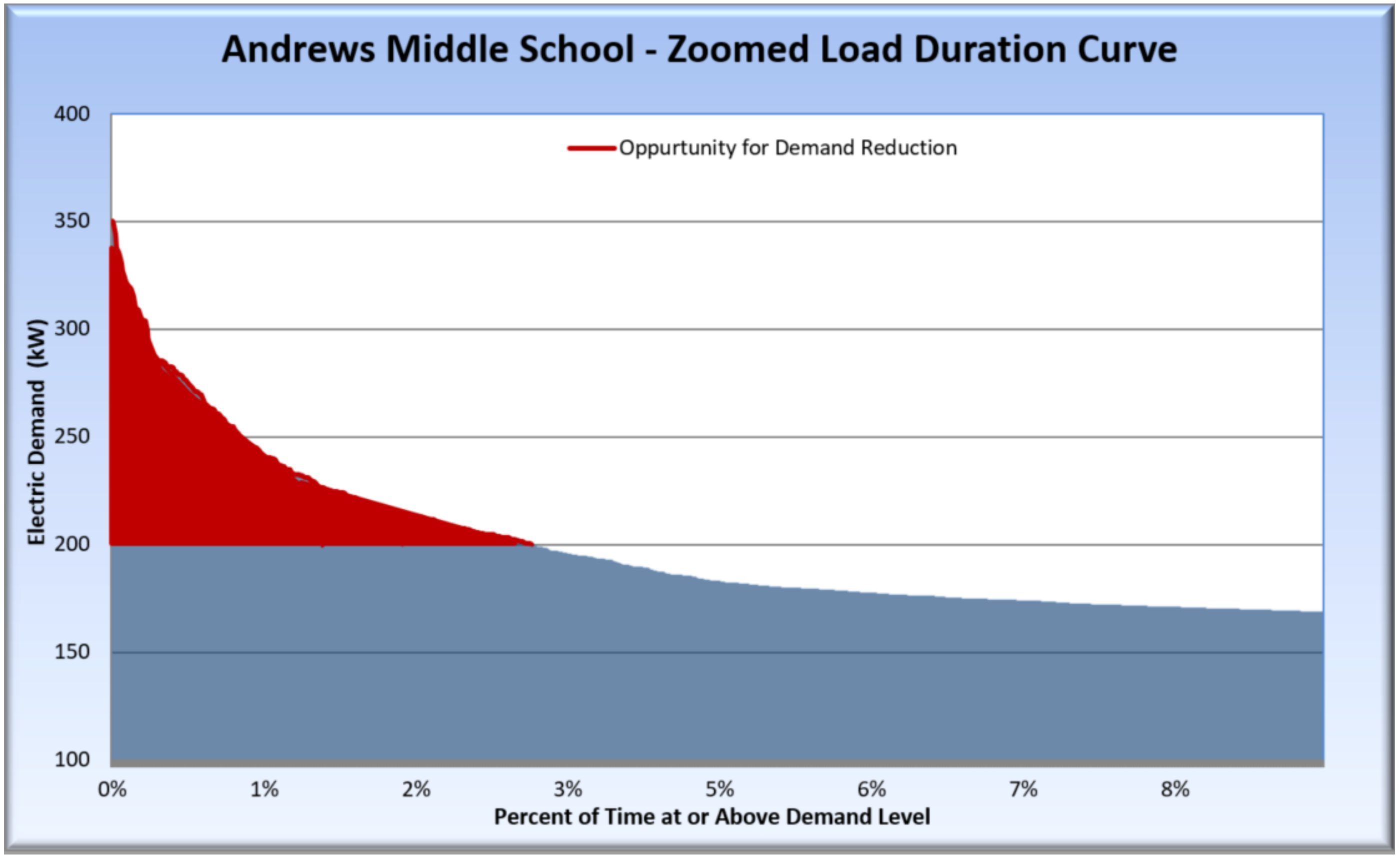

Figure 5 Andrews Middle School – Zoomed load Duration Curve showing the opportunity for demand reduction.

Note that there is a difference of 120 kW between the peak load and the 1% load. This indicates that there is a 120 kW spike in demand for less than 1% of the year (less than 88 hours). Since the peak load occurred on June 13th, 2017 when the temperature outside was 95°F, this demand spike was most likely caused by compressors on the chiller and DX units cycling on to provide cooling. The peak demand each month is used to determine the billing demand. If this 120-kW demand spike could be reduced or eliminated during these few hours of the year, the Andrews Middle School could reduce close to 33% of the demand charges on monthly electric bills.

LOAD PROFILES

The 2D demand graph that follows in Figure 6 is a graphical representation of when peak periods are occurring at the facility. The horizontal axis shows the day of the year, and the vertical axis shows the hours of the day. The colors of the graph indicate the range of electricity demand (kW), with each corresponding range identified by the legend at the top of the graph. Similar to a topographical map, each band can be thought of as a "contour line" of electricity demand.

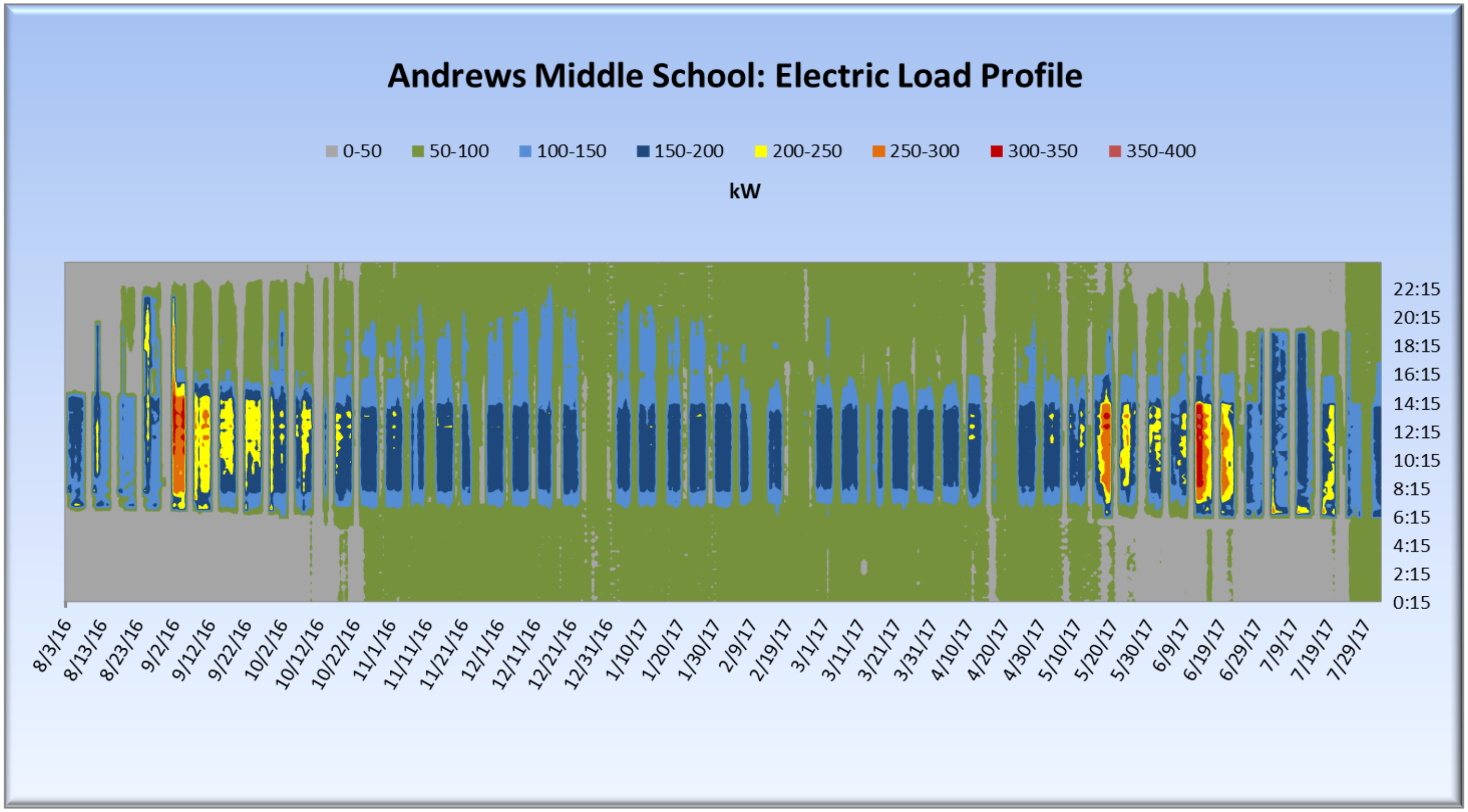

Figure 6 Andrews Middle School Electric load profile for FY 2016

The grey, green and blue bands in the graph depict times when the demand is equal to or less than the lower end of the kW scale, below 150kW. The red, orange and maroon bands depict times when the highest electric demands for the facility are reached. If the highest demands occur seasonally, then the demand is most likely cooling- or heating-related.

It appears from the graph above that some equipment or lighting may be operating during times when the facility is completely unoccupied resulting in a base load of 50 – 100 kW. While major mechanical equipment has a regular daily schedule, smaller equipment (such as exhaust fans or unit ventilators) can easily be overlooked. Monitoring-Based Commissioning (MBCx) can be used to identify the equipment which is running overnight and inform facility staff if equipment needs to be turned off.

The Figure 7 below introduces the concept of a “demand cap”, displaying values within 3% of the peak demand for the year. If a goal of reducing peak demand by 3% were set at this facility, regardless of whether there are demand response events or not, electric bill savings could be captured. Reducing peak demand can be accomplished by implementing energy efficiency measures, through demand-limiting programming and MBCx on the Building Automation System. A future Battery Energy Storage system could also be used to reduce the maximum peaks which are shown in Figure 7.

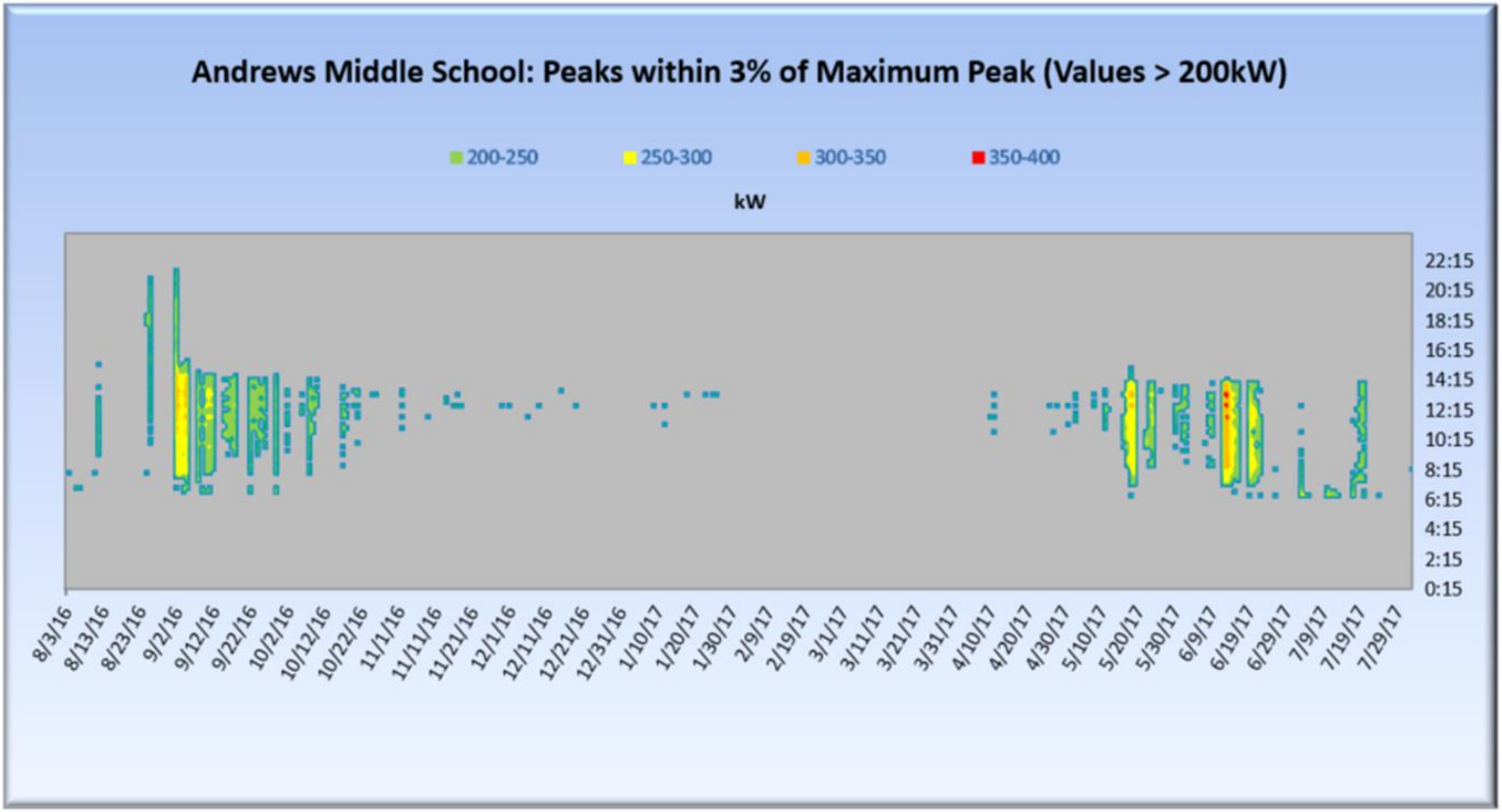

Figure 7 Andrews Middle School: graph showing peaks with 3% of maximum peak value

Load Shape

Peak demand during the summer months in New England is primarily driven by air conditioning loads, and as result the wholesale energy and demand response are usually most valuable during the hottest summer weekdays. The following graph in Figure 8 shows Andrews Middle School demand profiles for the average weekday, average weekend and annual peak day.

This section compares selected "daily" load shapes, using hourly load data:

- Customer Peak Day – The customer's demand profile for the peak day of 6/13/17 when the customer's actual peak demand occurred.
- Average Weekday – This curve adds all the weekdays annually and produces an average load shape.
- Average Weekend – This curve adds all weekends annually to produce an average load shape. Used as baseline reference

The average day is shown so that the time period near the peak can be examined to see whether the peak is accompanied by similar patterns, or to see if the peak appears to be an anomaly. These graphs are easiest to read if each series is read independently first, and then compared to the other series on the graph.

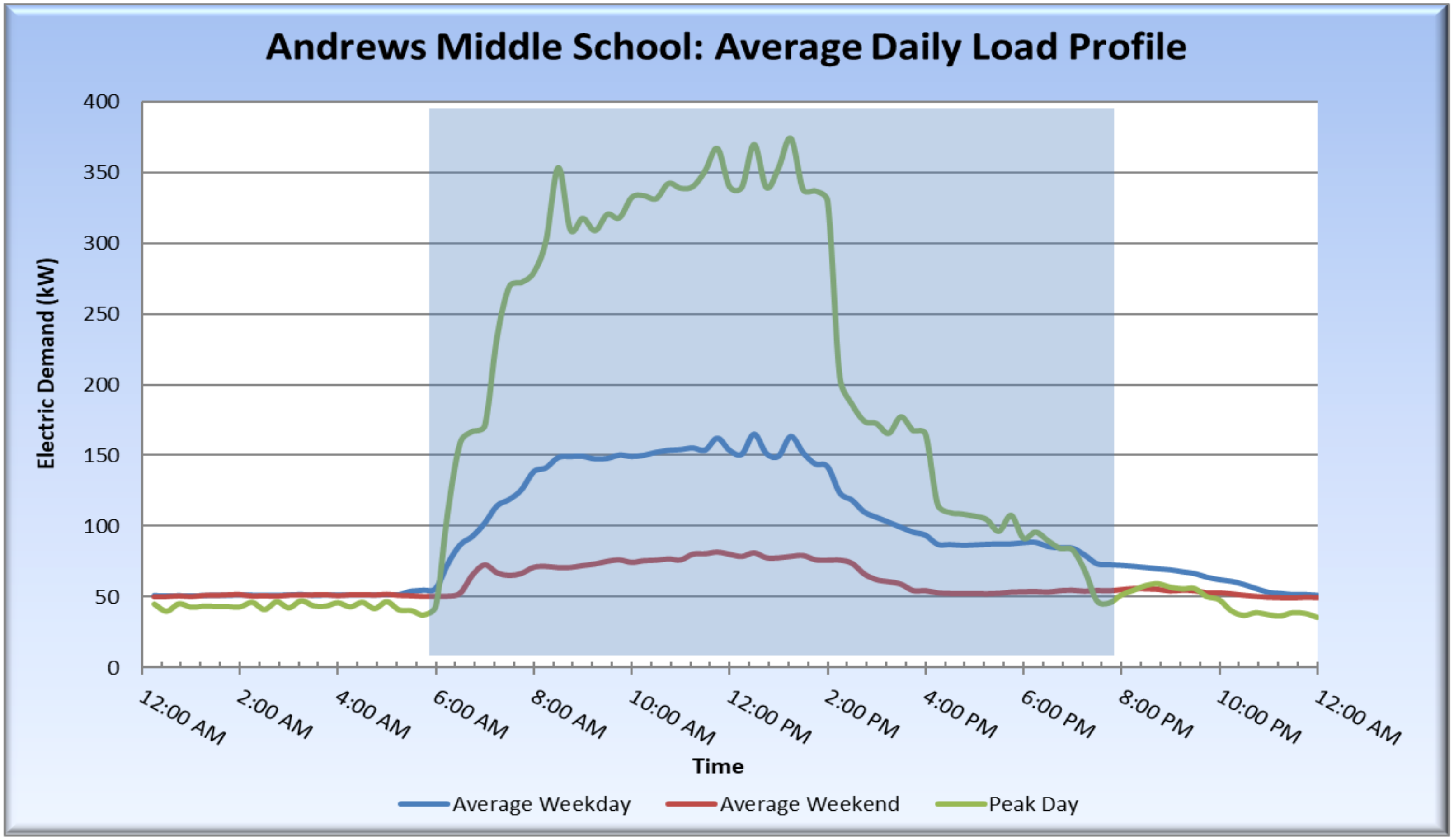

Figure 8 Graph showing Andrews Middle School Average Daily load profiles for Weekday, Weekend and a Peak Day.

The peak demand difference between an average weekday and the peak weekday is approximately 200 kW. Sharp peaks can be seen around noon each day on both the peak demand graph and the average graphs. These high, short duration peaks could be somewhat reduced through the strategies listed later in this report.

EQUIPMENT LOAD ANALYSIS

The Table 14 and pie chart in Figure 9 below show the estimated connected loads in kW of the major end-use categories at Andrews Middle School. The total connected kW is higher than the peak kW demand shown earlier in the report because not all equipment will be running at any one time.

Andrews Middle School Major End-use breakdown		
Major End Uses	*Connected kW*	*kWh*
Chiller unit and CHW pump	148	44,380
AC units	186	55,676
Air Handling units	44	131,631
Fans, Fan Powered Boxes, Unit Ventilators	20	61,279
Boiler and Heating Equipment, HW Pump	29	57,941
Miscellaneous and plugloads	31	78,000
Kitchen Equipment	90	36,003
Lighting	103	288,400
Total	**651**	**753,310**
Actual from Bills		735,800
% Diff		2%

Table 14 Andrews Middle School Major End use breakdown

The pie charts below and table above indicate the major end uses – air handling units, air conditioning equipment, lighting, chiller, heating equipment, fan equipment, kitchen equipment loads and miscellaneous items (includes plug loads, computers etc.)

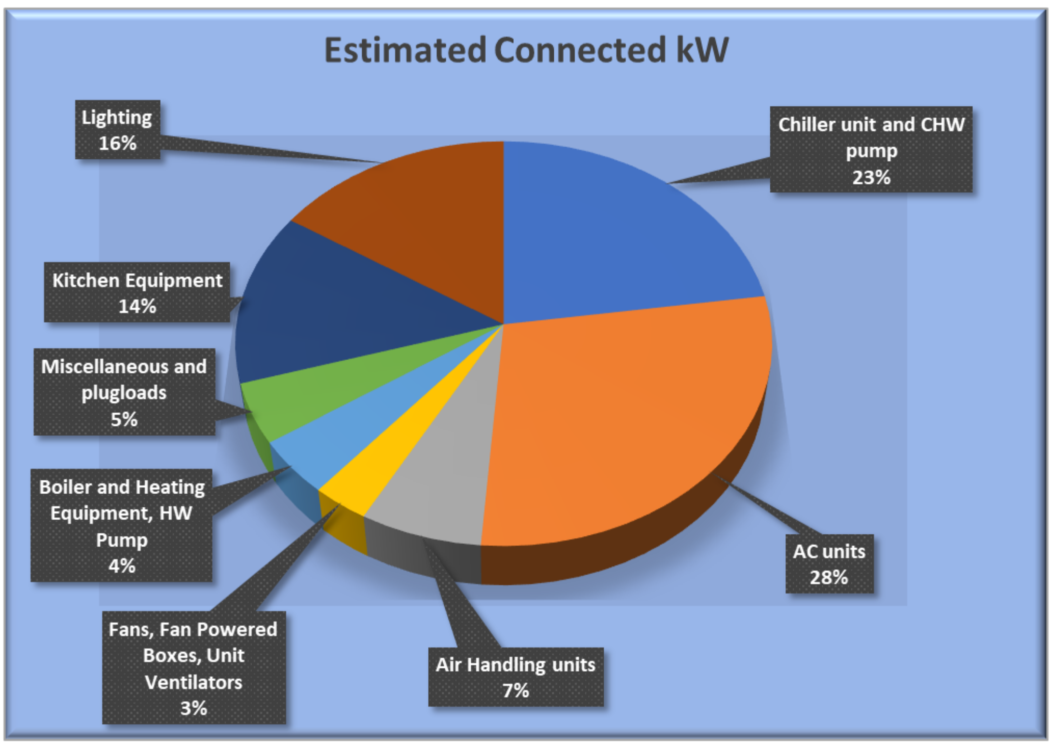

Figure 9 Andrews Middle School estimated Connected kW pie chart for FY 2016

The pie chart below in Figure 10 displays the electricity end-use reconciliation. This is created by estimating run hours based on building and equipment schedules for the major energy user shown above. This chart corresponds to the kWh values in the previous Table 14.

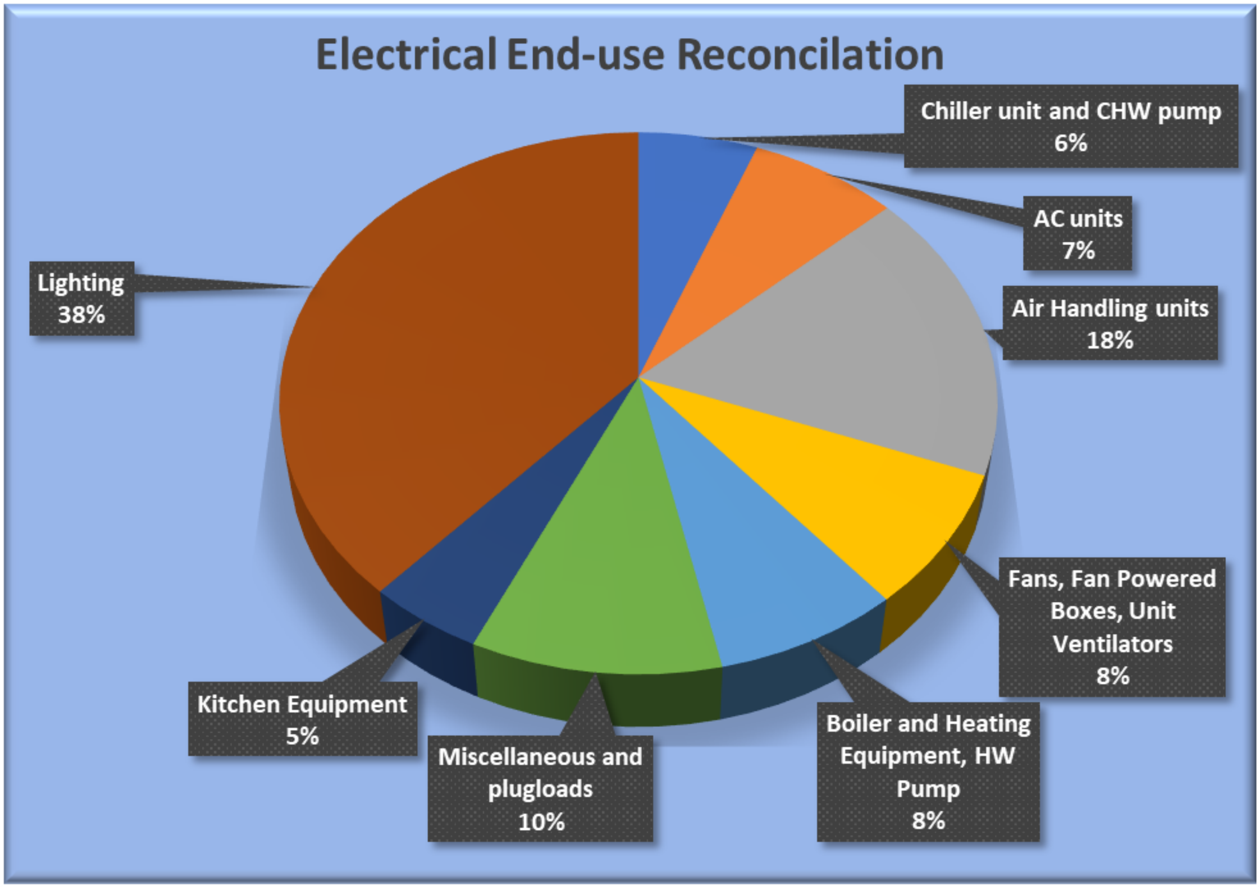

Figure 10 Andrews Middle School electric energy end-use reconciliation for the year FY 2016

Resiliency Analysis

Andrews School as an Emergency Shelter

Medford's emergency requirements and desired resiliency goals were developed through discussions with Alicia Hunt and MaryAnn O'Connor, Medford's Emergency Manager. Key details are listed below:

- The Andrews school can be used as an emergency shelter in a resiliency event.
- MaryAnn indicated that the most likely scenario expected would utilize the facility for 24 to 48 hours under a resiliency scenario.
- During a resiliency event, MaryAnn and Alicia identified that the anticipated highest use population is likely to be senior citizens living nearby in senior housing.
- The gym and cafeteria are the primary areas to be used during a resiliency event where the school becomes a shelter, therefore supplying power, ventilation, and heat to these areas is a critical requirement. The auxiliary areas are admin and the kitchen. It is unlikely that the classrooms or 2nd and 3rd floors would be used. Cots would be deployed in the primary areas to support community members sheltering.
- HVAC in these areas are important to support shelter operations although cooling could be sacrificed if necessary. This is addressed in the Basis of Design presented below in the Increasing Resiliency at Andrews School section.
- Lighting in these areas are critical to support shelter operations. Emergency lighting is limited to code requirements and the ideal scenario would be to have a fully-lit 1st floor during a resiliency event. This is addressed in the Basis of Design presented below in the Increasing Resiliency at Andrews School section.
- Kitchen equipment is useful but a lower priority because meals can be brought in from outside locations and served. This is addressed in the Basis of Design presented below in the Increasing Resiliency at Andrews School section.

Existing Emergency Systems

The Andrews school is equipped with backup emergency systems designed for code life safety and legally required duty. Key details are listed below

- Existing backup generator:
  - Diesel engine located in 1st floor generator room next to main electrical room.
  - Rated for 250kW standby. De-rated to 200kW for continuous operation.
  - Presently, approximately 39 kW of emergency loads are connected to the ATS powered by the backup generator.
  - The capacity of the existing backup generator's fuel tank (275 gal), with the current emergency load of approximately 39kW, can support 50 hours of emergency backup power before running out of fuel, assuming a full tank.
- Presently only circuits on ATS powered by backup generator can receive backup power on a loss of grid power. Below is a summary of circuits currently powered by the backup generator:

Andrews Middle School panels and loads served by generator		
ATS panel info	ATS Sub-panel info	Load served
ATS-1	ESH1	Boilers, pumps and elevator
ATS-1	ESL1	Kitchen equipment- freezers and coolers
ATS-2	ELH1	Lighting in walking spaces, corridors, restrooms and mechaincal
ATS-2	EPL1	rooms

Table 15 Andrews Middle School current emergency loads served by generator

Limitations of Existing Systems in a Resiliency Event

The facility is within the 1% probability of 100-year, 0.1% probability 100-year flood plain and 1% probability of sea level rise and storm surge vulnerability assessment. Refer to Appendix E - Flood Plain Maps for the detailed maps. The facility is at flooding risk in the event of a failure of the Emelia Erhardt Dam or upriver storm surge.

The facility's main electrical room is located on the first floor at grade, within the flood plain. This space contains the utility electric feed and main switchgear. In the event of flooding, the building is at risk of losing all electrical systems.

- Emergency backup generator systems are designed to power emergency lighting and other legally required and life safety circuits for 90 minutes. This is driven by code and the intent is for operation to allow occupants sufficient time to exit the building in the event of an emergency.
- Although the emergency systems are designed for 90-minute operation, they could be used in an extended outage scenario. Under this scenario, if completely full at the time of an emergency event, the diesel fuel tank has enough capacity for 50 hours of continuous operation before refueling. The duration between refueling is directly proportional to how full the tank is at the start of the event. Additionally, in the event that fuel deliveries were delayed, the facility would have no emergency backup systems, including heat and power, until fuel could be delivered.
- The existing emergency backup systems do not power building systems that are critical to the building operating as a shelter, namely full HVAC and lighting in gym and cafeteria, plug loads and kitchen loads.

The existing electrical emergency backup system does not provide emergency power to many of the systems that are required to support resilient operations at the school. This is a key limitation as existing systems are only designed to power enough systems to support evacuation of the school.

Increasing Resiliency at Andrews School

Maximize Capabilities of Existing Electric Emergency Generator and Off-Grid Power Systems

The following modifications should be implemented to increase the resiliency of the emergency systems at Andrews:

1) Maximize load on electric generator to power a greater number of building systems to support resiliency shelter activities:
   a) Re-circuit building electric wiring to add loads based on priorities for an Emergency Shelter. We recommend adding entire panels where many loads are desired during an off-grid event, while

intercepting individual circuits is most practical for panels which have only one or a few loads that are desired for an off-grid scenario.

b) The present emergency load on the generator is approximately 39 kW and the maximum continuous rated capacity is 200 kW, leaving approximately 161 kW of load that could be added as optional standby load. The following approach is recommended to maximize the generator capacity and support the needs of the facility when operating off-grid as a resilient emergency shelter:

i) Add air-side heating and ventilation to optional standby circuits – all air handlers and most exhaust fans, VAV boxes, and unit ventilators

ii) Add air conditioning in cafeteria and gym to optional standby circuits – air conditioning is one of the biggest loads and must be strategically selected for maximum impact to manage electrical load during an off-grid scenario.

iii) Add selected lighting systems to optional standby circuits – all lighting on the first floor, cafeteria, gym, and emergency circuits on the second floor, and emergency circuits only on the third floor.

iv) Add selected kitchen equipment to optional standby circuits – select only minimum kitchen equipment to support meal warming and preparation such as ovens, warming tables, refrigerator and freezer. Exclude large loads such as the dishwasher and electric booster heater.

v) Table 16 below presents the circuits recommended by B2Q to be added as optional standby to support resiliency activities:

Resiliency Loads and Corresponding Panels Proposed for Optional Standby Off-Grid Power			
Panel	Equipment Served	Sub Panel	Optional Standby Resiliency Loads to be added
PH1	Mechanical Equipment	PL1C, PL2C	Fan Powered Boxes and Unit Ventilators
PHK1	Kitchen Equipment	PLK1	Critical Kitchen Equipment including Convection Oven, Ice maker and Exhaust hood
LH1	1st Floor Lighting	PL1C, PL1A, PL1B	All First Floor Lighting
LH2	2nd Floor Lighting	PL2A	Cafeteria and Gym Lighting
PH3	Mechanical Equipment	PL3B	AHUs & AC units associated with gym and cafeteria, Fans & Unit Ventilators

Table 16 Andrews Middle School Proposed resiliency loads and corresponding panels for optional standby

2) With the addition of 161 kW of new optional standby loads to the generator, the total load on the generator during a utility outage is 200kW. The existing 275-gallon fuel tank can support the 200kW

load for 12 hours before refueling. Increasing the size of the diesel fuel storage so that the system can operate longer off-grid before refueling is necessary to continue operating. A second tank of the same size as the existing could extend off-grid generator operation to 24 hours when continuously loaded at 200kW.

3) Consider replacing the backup generator with a larger capacity in the range of 300kW – 450kW. This would allow all equipment with the exception of the chiller to be powered during a grid outage scenario and would simplify the project because the need for recircuiting would be eliminated.
4) Backup all HVAC controllers on emergency circuits. This will extend capabilities to manage building HVAC loads while keeping the building conditioned during a resiliency event.
5) Backup critical IT infrastructure on emergency circuits. This will extend communications and network capabilities during a resiliency event.

Install Energy Storage System and Renewable Energy Generation Assets

A Battery Energy Storage System (BESS) can be applied here successfully. Based on analysis of building loads and project goals, the recommended battery energy storage capacity is 250 – 650 kWh (described further in the following section "Proposed PDR and Resiliency Upgrades"). This BESS capacity range will provide 1 – 3 hours of backup power, as well as the "grid-forming" capability that is necessary for typical solar PV systems to operate and provide power to the building when utility grid power is unavailable and the capabilities of charging batteries with solar output, although the ability to use solar is weather dependent.

Solar PV does not currently exist at the site; however, it is a component of Medford's energy plan and is anticipated to be added in the future or together with the BESS. The BESS coupled with solar PV could significantly extend off-grid energy between generator diesel fuel deliveries.

Based on the analysis by Medford's Energy and Environment office, solar PV is the best candidate for this site, and wind energy generation is not presently a goal at this location.

Implement Off-Grid Electric Load Management

Effectiveness and discharge duration of battery energy storage system, as well as duration of emergency generator backup power before refueling, during a resiliency event is directly impacted by building electric load management. Electric load management for HVAC loads can be implemented through the BAS and lighting control systems, using sequences which are similar to those implemented for demand response. This would include turning off the chiller, the highest power piece of equipment, limiting the load on other HVAC systems, utilizing LED dimming capability and shutting off lights in non-essential areas. In addition to maximizing the generation and storage assets, load management is also critical to ensure that building loads do not exceed the rating of the BESS or the emergency generator capabilities. If loads are not properly managed, these assets could trip offline during an off-grid resiliency event and disrupt shelter activities.

Develop and Implement Flood Mitigation Strategies

Medford needs to create a water barrier deployment strategy in the event of high-flood waters to minimize impact on building systems both when grid power is available and during a grid outage. Water barriers such as sand bags or deployable temporary walls could be kept at a local facility and deployed to the site in the anticipation of a resiliency event. A permanent flood wall should be considered to maximize the facility resiliency against floordin. Flood mitigation strategies are recommended because, although this site is located in the 1% flood range, a unpredictable weather event triggering a resiliency response could exceed these ratings.

PROPOSED PDR AND RESILIENCY UPGRADES

BATTERY ENERGY STORAGE SYSTEM BASIS OF DESIGN

BATTERY ENERGY STORAGE SYSTEM SELECTION

The BESS must be selected based on several key financial to technical criteria, depending on the operating scenario and the building existing conditions. The BESS in this scenario has the following key selection criteria:

Criteria	Basis of Criteria
Optimize cost, discharge kW, discharge duration	Maximize value of resiliency grant to City of Medford and Commonwealth of Massachusetts while staying within the budget.
Discharge duration must be a minimum of 2 hours at full resiliency load and 4 hours at 50% load.	Extend off-grid power to support shelter activities during peak resiliency event and capacity for demand response to participate in DR revenue streams.
Battery energy capacity must be sufficient after discharge cycle to form grid for solar PV when available.	If battery is discharged after sun set, solar PV can begin generation again and provide building power/recharge battery when solar energy becomes available.
BESS inverter must be compatible with building electrical systems (480V/3phase/60cycle).	Avoid added cost of transformer and other associated electrical components to convert BESS electrical output to building voltage.
BESS must be in secure outdoor weatherproof enclosure	Increased building fire risk and limited indoor space. Outdoor enclosure must be protected from elements and secured for safety.
BESS must have on-board fire protection system.	Fire emergency suppression system is a necessity for safety precautions.
BESS must be capable of avoiding overload and absorbing current spikes due to equipment cycling.	Overload results in systems trip offline.
Battery Management System (BMS) compatible with common communication protocols, such as BACnet, Modbus, or DNP 3.0.	BMS must be compatible to send and receive communications with System Supervisory Controller for building energy systems management during demand response and resiliency events.

BATTERY ENERGY STORAGE SYSTEM CAPACITY ANALYSIS

The graph below in Figure 11 Andrews Middle School – Battery Energy Capacity vs battery backup for 72 hours shows the relationship between three BESS inverter output power levels and the energy storage capacity required to maintain that output for up to three days (72 hours).

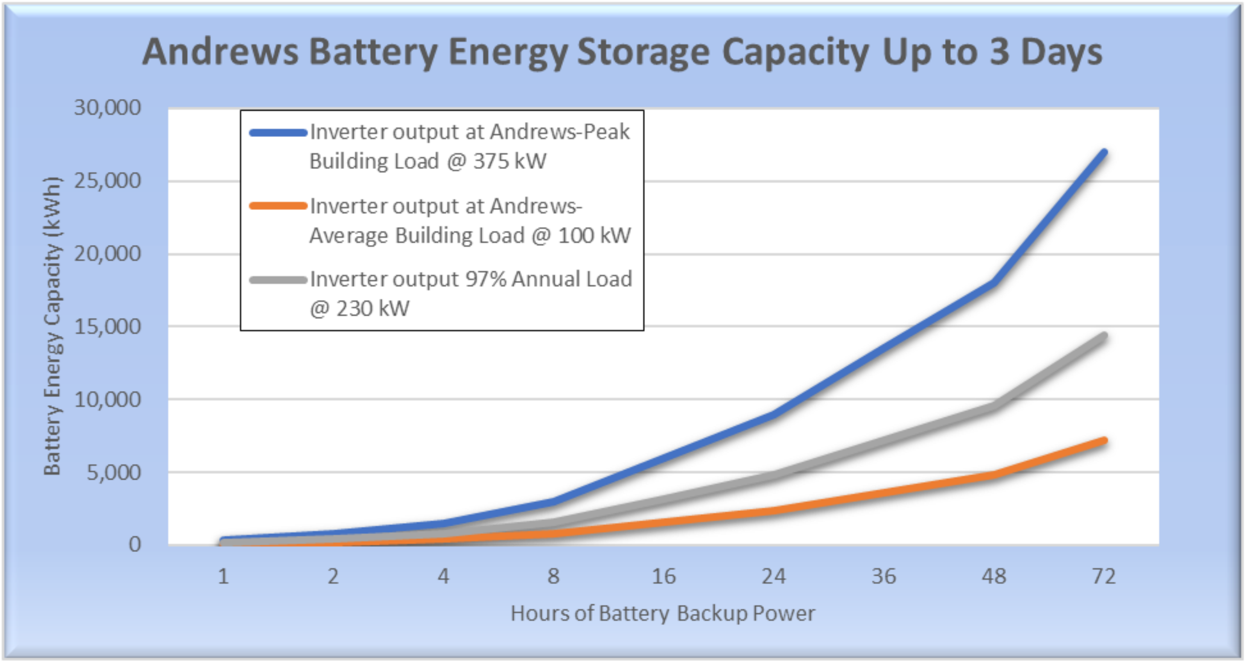

Figure 11 Andrews Middle School – Battery Energy Capacity vs battery backup for 72 hours

The graph in Figure 12 below displays energy storage capacity up to 8 hours for inverter output power, a magnified view of the lower left side of the graph shown in Figure 11. Referring back to the Electric Load Analysis section on page 43, Andrews peak load is 375kW, however the load is only greater than 200kW for 3% of the year and the average load is 100kW. According to the graph, a 400kWh battery could operate at 100kW for 4 hours, and at 200kW for 2 hours. This implies that if the BESS energy storage capacity as a function of continuous inverter output (kW) and energy storage capacity (kWh) can be selected at less than peak load to accommodate building loads for 2-4 hours for the majority of the year. A 200 kWh battery could accommodate resiliency loads for 2 hours at 100kW. The discharge duration is variable depending on the day of the year that the outage occurs, as seasonal weather effects on HVAC loads and resulting electric demand from HVAC Equipment. For instance, electric demand from HVAC equipment can vary from a high demand in the peak summer and winter months to reduced demand during the shoulder seasons when cooling and heating systems are more lightly loaded.

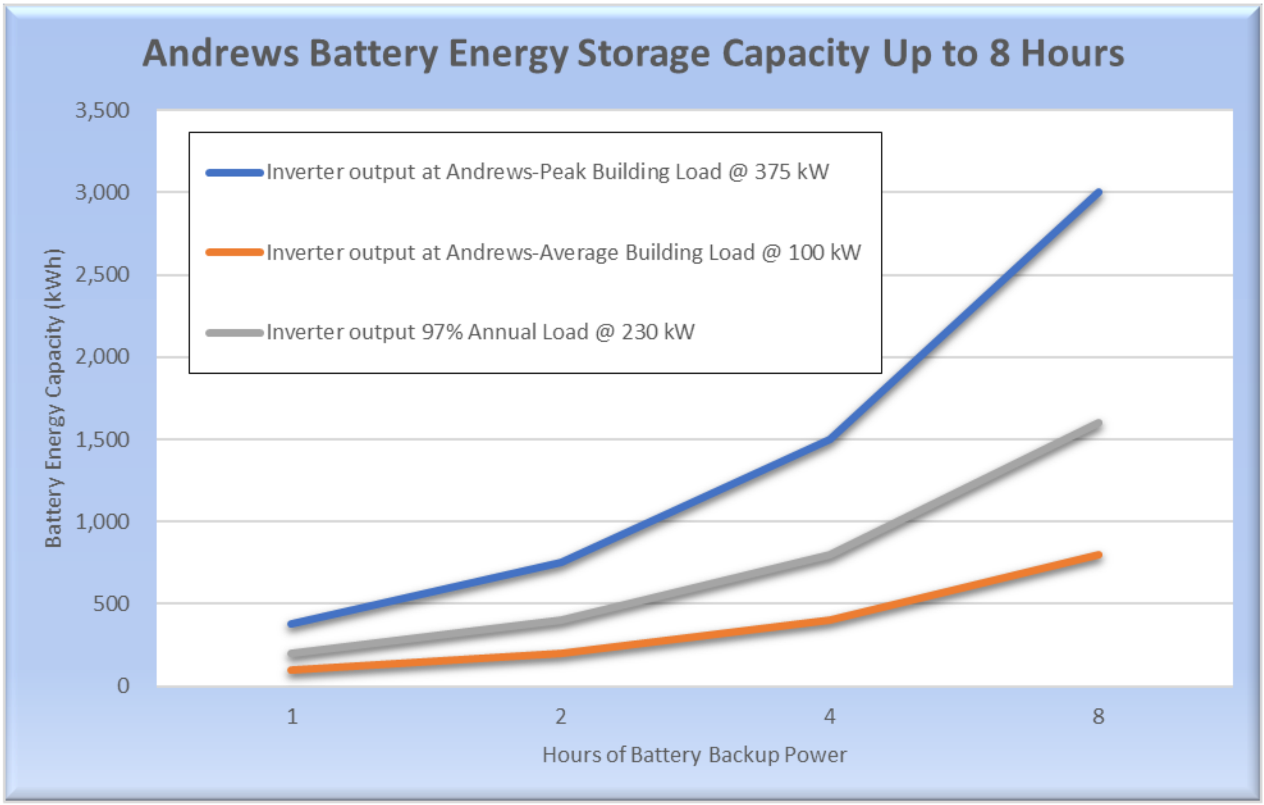

Figure 12 Andrews Middle School – Battery Energy Capacity vs Battery backup for 8 hours

A parametric comparison was developed to analyze the battery size selection compared to industry trends for installed costs. This can be seen in Figure 13 below. Industry estimates have been provided by Northern Reliability, NEC, and Solect, and are based on total cost of implementation. These vendors estimated the average project total implementation cost for energy storage in general to range from \$800/kWh to \$1,600/kWh. The total cost of implementation includes the BESS (enclosure(s), inverter(s), energy storage cells, battery management system, environmental controls, and fire suppression system), System Supervisory Controller (including associated programming and interfaces with subsystem controllers), soft costs (design, commissioning, construction administration and oversight, project management), and electrical modifications or upgrades.

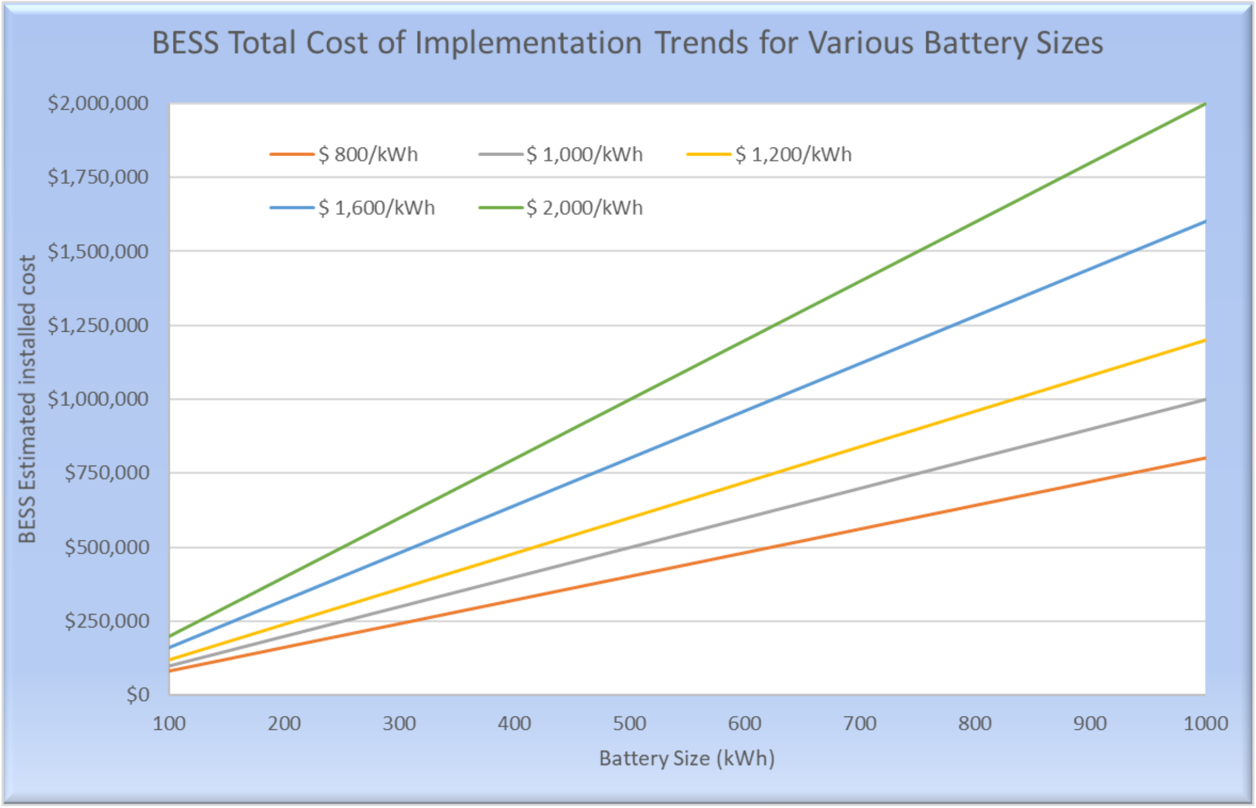

Figure 13 Graph showing BESS total implementation costs for various battery sizes

Battery System Selection and Discussion

The optimum battery system energy storage capacity is 400kWh based on the load analysis and sizing capacity analysis. To summarize, the selection criteria is as follows:

- The 400kWh battery could provide a minimum of 2 hours of power during a grid outage, under the assumption that the building was re-circuited to support 200kW of load when grid power is not available.
- Since the value of the DOER Resiliency grant for the Andrews school is approximately $450,000, and considering other costs associated with increasing resiliency at this site, the battery size is limited to 250 kWh or less.
- Battery must deliver load reduction for a minimum 4 hours for demand response, currently based on load duration curve - 75% of the time the facility uses less than 100kW.
- Inverter should be rated for a minimum of 200kW instantaneous power and 100kW for continuous use.
- The actual duration of a single charge of the battery energy system is heavily dependent on managing facility loads during this period, for example if building loads could be maintained at or less than 100kW, the battery would have a discharge duration of 4+hours.
- A 650kWh battery would be guaranteed to meet all project goals. The increased capacity is necessary to meet the criteria of 3 hours of dedicated off-grid backup power.

However, there is currently not enough funding to support a 400kWh or a 650kWh battery. Current funding is estimated to support approximately a 250kWh battery if funding is shared from the DPW as described in the Executive Summary Project Budget section earlier in this report.

Building Electric Load Management for Demand Response

HVAC Load Management for Peak Demand Response

HVAC load management for Demand Response (DR) can be implemented with BAS programming only. The demand response sequences will shed load upon the automatic signal from the ADR signal receiver/controller. Andrews Middle School has four levels of Peak Demand Response. These levels are given below, and the estimated electric load reduction possible from each DR level is shown in Table 17:

- *Peak DR level*:
  - During this level the AHU-1 & 2 supply fans are controlled to not to exceed a maximum fan speed of 60 % (adj),
  - CHW supply temperature setpoint shall be reset to 50 °F (adj.),
  - AHU cooling DAT setpoints raised to 62°F (adj.), ACCUs limited to 50 % capacity and
  - Reset all terminal device space temperature cooling setpoints to 80 °F (adj.).
- *High DR level*:
  - During this level the AHU-1 & 2 supply fans are controlled to not to exceed a maximum fan speed of 70 % (adj),
  - CHW supply temperature setpoint shall be reset to 48 °F (adj.),
  - AHU cooling DAT setpoints raised to 60°F (adj.), ACCUs limited to 50 % capacity and
  - Reset all terminal device space temperature cooling setpoints to 76 °F (adj.).
- *Medium DR level:*
  - During this level the AHU-1 & 2 supply fans are controlled to not to exceed a maximum fan speed of 80 % (adj),
  - CHW supply temperature setpoint shall be reset to 46 °F (adj.),
  - AHU cooling DAT setpoints raised to 58°F (adj.), ACCUs limited to 50 % capacity and
  - Reset all terminal device space temperature cooling setpoints to 78 °F (adj.).
- *Low DR level:*
  - During this level the AHU-1 & 2 static pressure setpoints shall be reset to their minimums,
  - CHW supply temperature setpoint shall be reset to 45 °F (adj.),
  - AHU cooling DAT setpoints raised to 56°F (adj.), ACCUs limited to 50 % capacity and
  - Reset all terminal device space temperature cooling setpoints to 74 °F (adj.).

Andrews Middle School - HVAC DR Savings				
Equipment/DR level	Low	Medium	High	Peak
Name	*kW*	*kW*	*kW*	*kW*
AHU - 1	0.66	0.66	3.17	4.56
AHU - 2	1.88	2.93	5.28	6.57
ACCUs	8.63	17.27	25.90	34.53
Chiller	0.87	1.75	3.49	5.24
Total	**12.04**	**22.61**	**37.84**	**50.90**

Table 17 The available load reduction kW of various HVAC Demand Response Levels at Andrews Middle School

LIGHTING LOAD MANAGEMENT FOR PEAK DEMAND RESPONSE

A comprehensive LED lighting fixtures retrofit project including a networked controlled system and various local controls is being implemented as a part of this project. The construction is expected to be completed in August 2018. The energy conservation and demand reduction capabilities of the new LEDs and lighting control system will be utilized in automated demand response events. The lighting control system will initiate the load reduction sequences upon receiving a signal from the ADR signal receiver/controller. As with the HVAC DR sequences, the Andrews Middle School lighting control system has four levels of Peak Demand Response. These levels are given below, and the estimated electric load reduction possible from each DR level is shown in Table 18:

- Peak Demand Response level: Dim LEDs to ***60%*** (adj.)
- High Demand Response level: Dim LEDs to ***70%*** (adj.)
- Medium Demand Response level: Dim LEDs to ***80%*** (adj.)
- Low Demand Response level: Dim LEDs to ***90%*** (adj.)

Andrews Middle School - Lighting DR Savings				
	Low	Medium	High	Peak
Equipment/DR level	*kW*	*kW*	*kW*	*kW*
Lighting - LED Dimming	3.76	7.52	11.28	15.04

Table 18 Table showing various Demand Response Level savings for lighting equipment at Andrews Middle School

BUILDING ELECTRIC LOAD MANAGEMENT FOR RESILIENCY MODE

The resiliency load management plan is very similar to peak demand response, however some systems which are under automatic control during normal operation are disabled. Controls can be used to turn off non-essential systems including the chiller and the two large admin DX cooling units. The critical aspects of load management during resiliency mode:

- Meet HVAC and Lighting needs for sheltering occupants and staff.
- Manage load below 200kW so backup systems are not tripped offline from overload.
- Maximize the duration of off-grid power available from both the emergency generator and the battery energy storage system.

When the BAS receives the resiliency mode signal from the System Supervisory Controller (described in the System Controls and Asset Management section below), the following shall occur:

- The chiller and chilled water pump shall be disabled.
- The admin area A and area B DX cooling units shall be disabled.
- Initiate demand response sequences for all systems not disabled during resiliency mode.

When the lighting control system receives the resiliency mode signal from the System Supervisory Controller, the following shall occur:

- All non-emergency 2nd and 3rd floor lighting shall be turned off. These zones shall only be able to be controlled manually from the front-end computer or through the SSC.
- All 1st floor lighting shall be turned on to 80% (adj.) LED output, with the exception of fixtures which are not controlled or are controlled by occupancy sensors.

Solar Photovoltaic Systems

Medford is evaluating options for solar PV installations, and preliminary estimates indicate that approximately 150kW of solar PV could be installed on the roof of the school, and another 150kW could be installed as canopy solar in the school's parking lots, for a preliminary estimate of 300kW total of solar PV that could be installed at the site. Traditional ground mounted solar is not viable at the site due to how areas adjacent to the school are used. Both the roof-mount and canopy options present challenges. The roof-mounted array is only feasible after the roof is replaced. The existing roof is on year 17 of a 20-year warranty, solar providers will not place equipment on a roof that is not under warranty, or under an expiring warranty. Replacement estimates provided to Medford are in the $600,000 range. The installation of solar canopies in the parking lot has the potential to unearth contaminated soil for pouring the footings for support steel. The potential risk was identified by Medford based on contamination found in nearby areas. Medford has identified and is evaluating potential risk-mitigation strategies for excavating these footings. During a resiliency event, 300kW of solar could power all resiliency loads at approximately 67% output.

System Controls and Asset Management

System Supervisory Controller

The System Supervisory Controller (SSC), acting as a microgrid controller, provides system control and monitoring and performs the duties of a master controller with logic programmed to direct all modes of operation. The SSC is a critical component for building-level resiliency systems and larger microgrids, in order to manage multiple energy generation and/or storage assets operating together during each operating mode. The operating modes of the SSC at the Andrews School include but are not limited to:

- Normal Operation (NO) when the utility Electric Service Provider (ESP) power is available;
- Standby Operation (SO) when the utility (National Grid) ESP power is not available (islanding mode);
- Automated Demand Reduction (ADR) during Normal Operation based on an external signal;
- Peak Shaving during Normal Operation for the purpose of lowering monthly demand costs;
- Power Management during all modes of operation including management of power to and from the Battery Energy Storage System (BESS) during NO and SO; and the BESS and Standby Generator (SG) and Solar PV Inverter System (PVIS) during SO.

The SSC is a Programmable Logic Controller (PLC), capable of multiple communication protocols for interfacing with each generation and storage asset, external communications, and other building systems. At the Andrews School, the SSC will interface with the solar PV control system, BESS control system, standby generator controls, utility main disconnect and automatic transfer switches, the BAS and lighting control system for load management, the automated demand response system, and the Monitoring-Based Commissioning (MBCx) system for data acquisition.

Automated Demand Response

The building SSC shall receive the automated demand response (ADR) signal from CPower, the Curtailment Service Provider, via the Energy IQ's CPower Link ADR signal receiver/controller. The ADR signal will be initiated by CPower for a Real-Time Demand Response event from ISO-NE, a National Grid Connected Solutions event, and for a Cap Tag management event (a CPower program). The impact and details of these programs are described later in the Demand Response Revenue Streams section of this report.

The SSC will interface with both the Energy IQ ADR signal receiver/controller, the BAS which controls the

HVAC systems, and the lighting control system. When the ADR signal is received, the SSC will initiate demand response sequences in the battery management system (BMS), BAS, and the lighting control system. Due to the project phasing, the ADR signal will be directly sent to the Andrews BAS and lighting controls in phase 1. These connections may remain in place or may be transferred to the SSC when it is installed in phase 2.

MONITORING-BASED COMMISSIONING (MBCX)

MBCx will be used at the Andrews School to monitor the HVAC equipment through the BAS to optimize the energy performance of the building HVAC system. Analytics will be deployed to identify problems that could cause wasted energy and operational issues. In addition to the energy use (kWh or therms) costs associated with HVAC problems, MBCx is indirectly valuable for demand management and demand response as a broken fan VFD or damper or other problem could significantly reduce potential DR revenues. It is also valuable for resilient buildings, as a similar problem undetected could cause excessive energy use and deplete energy storage and fuel reserves. Resilient buildings and microgrids should use MBCx to continuously optimize energy performance to maximize the impact of their resilient systems and infrastructure.

FacilityConneX will be used at the Andrews school as the MBCx system. FacilityConneX is a communications integrator, and the software can capture data from the BAS, SSC, ADR, lighting controls and other systems . In addition to the energy analytics deployed on the HVAC system FacilityConneX will capture data from the SSC for aggregation and visualization.

DEMAND RESPONSE REVENUE STREAMS AND SAVINGS IMPACT

DEMAND RESPONSE LOAD REDUCTION

The demand response savings shown below in Table 19 are developed based on the existing schedule of operations and modified schedules of operation for summer classes/programs. The batteries are scheduled to be installed in 2019 and both HVAC upgrades are scheduled to be completed by mid-2018.

The demand response savings for existing school schedules are calculated based on the assumption that school has high occupancy and usage in June and low occupancy and usage in the months of August and July as shown in Table 20. Note: the savings calculations assume the "high" demand response level described in the previous section Building Electric Load Management for Demand Response (page 61) .

Demand Response Summary: Existing School Schedule - High use in June, Low use Aug/July							
Facility - Season	H&V Units	ACCUs	Chiller	Pumps	Lighting	Batteries	**Total**
	kW	*kW*	*kW*	*kW*	*kW*	*kW*	***kW***
Andrews - June	8.4	13.5	5.2	0.0	13.2	50.0	**90.4**
Andrews - July/Aug	2.5	4.1	1.6	0.0	4.0	50.0	**62.1**
Andrews - Winter	8.4	0.0	0.0	0.0	13.2	50.0	**71.7**

Table 19: Total peak demand load reduction at Andrews Middle School for both Summer (High use in June, low use in Aug/Jul) and Winter Peak periods

The demand response savings for a modified school schedule in the event the school is used for more summer classes/programs are shown in Table 20. This alternative is presented because Medford was interested in understanding the potential demand response value of increasing summer use at the school. This modified school schedule scenario load shedding capacity assumes higher occupancy and usage in July and August. It can be seen by comparing Table 19 and Table 20 that the impact is a 30kW increase on potential demand response load reduction during July and August if summer programs are moved to this facility.

Demand Response Summary: Modified School Schedule - High use all summer from more summer classes / programs.							
Facility - Season	H&V Units	AC Units	Chiller	Pumps	Lighting	Batteries	**Total**
	kW	*kW*	*kW*	*kW*	*kW*	*kW*	***kW***
Andrews - Summer	8.4	13.5	5.2	0.0	13.2	50.0	**90.4**
Andrews - Winter	8.4	0.0	0.0	0.0	13.2	50.0	**71.7**

Table 20 : Total peak demand load reduction at Andrews Middle School for both Summer and Winter Peak periods for modified Summer Schedule

DEMAND RESPONSE PROGRAM REVENUES

City of Medford has enrolled Andrews Middle School in the demand response programs presented below through a Curtailment Service Provider (CSP). The CSP is a company authorized to act as interface party between the Independent service operator (in this case ISO-NE and National Grid) and end-use customer (in this case City of Medford) to deliver demand response capacity. The CSP provides advance notice of when curtailment request is likely to be made. Following the curtailment, the CSP works with the grid operator to identify how much power was reduced by the customer, what the prevailing rates for electricity were during that time and how much revenues are generated. The CSP charges 35% of the overall revenue generated as service charge and the remaining 65% of the overall revenue goes to the customer as the revenue generated. The demand response programs considered are:

- Real Time-Demand Response (RTDR) program
- Connected Solutions – a National Grid demand response program
- Peak Demand Management (Cap-Tag) program – Cpower Supply Capacity Charge Management

The Andrews school cannot participate in the Cap-Tag program unless the electric supply contract is changed to pass through the annual capacity charge to Medford.

REAL-TIME DEMAND RESPONSE REVENUES

The Real-Time Demand Response (RTDR) program revenue is based on demand savings each month when an event is called. Real time demand response program offsets rising energy costs with revenue earned from using less energy when the grid is stressed. ISO-NE's Real Time Demand Response program pays customers to curtail energy on short notice when the ISO-NE grid is due to unforeseen circumstances. The participant receives payment based on a winter and a summer test, adjusted based on the facility's actual demand reduction during a demand response event. The participation events can be called Summer Season (Jun-Nov, Apr-May) and Winter Season (Dec-Mar) during each Program Year (Jun-May). The program guidelines include a minimum load reduction of 100 kW (which can be aggregated for a customer over multiple accounts), and load curtailment events can last for several hours. The scenario presented below in Table 21 represents the potential value for participating in RTDR with the existing school schedule.

RTDR - Existing School Schedule - High use in June, Low use Aug/July								
Program Revenues for Real-Time Demand Response								
Forward Capacity Market Year	Description	Summer kW (6 months)	Summer kW (2 months)	Winter kW (4 months)	FCM Price $/kW-mth	Program Gross Revenue	Customer Share %	Annual Revenue to Customer $
06/1/2018 - 05/31/2019	BAS and Lighting DR	49.1	14.7	19.7	$9.55	$3,850	65%	$2,502
06/1/2019 - 05/31/2020	Batteries, BAS and Lighting DR	99.1	64.7	69.7	$7.03	$7,052	65%	$4,584
06/1/2019 - 05/31/2021	Batteries, BAS and Lighting DR	99.1	64.7	69.7	$5.30	$5,317	65%	$3,456
3 Year Total						**$16,218**		**$10,542**

Table 21: Andrews Middle School – revenues form RTDR program with existing schedule

A second scenario is presented in Table 22 below, representing the potential RTDR savings from a modified school schedule that assumes the school is used for summer activities. It can be seen that if the school schedule modified to accommodate more summer classes, there is potential to generate approximately $1,000 additional 3-year total revenue when compared to the existing school schedule.

RTDR -School schedule is modified for more summer classes / programs							
Program Revenues for Real-Time Demand Response							
Forward Capacity Market Year	Description	Summer kW (8 months)	Winter kW (4 months)	FCM Price $/kW-mth	Program Gross Revenue	Customer Share %	Annual Revenue to Customer $
06/1/2018 - 05/31/2019	BAS and Lighting DR	49.1	19.7	$9.55	$4,506	65%	$2,929
06/1/2019 - 05/31/2020	Batteries, BAS and Lighting DR	99.1	69.7	$7.03	$7,535	65%	$4,898
06/1/2019 - 05/31/2021	Batteries, BAS and Lighting DR	99.1	69.7	$5.30	$5,681	65%	$3,693
3 Year Total					**$17,723**		**$11,520**

Table 22: Andrews Middle School – revenues form Realtime demand response program with more summer classes

Connected Solutions Revenues

Connected Solutions is National Grid's demand response program, where participating customers are working to lower the amount of total energy used during the summer months when demand for electricity on the grid is at its highest (peak demand). The program is anticipated to call 20 hours of events per year with the longest duration of a single DR event being 4 hours. The connected solutions demand response program has revenues based on the highest peak period and curtailed load for each event. The Table 23 below presents potential annual revenues assuming five events, each for a four-hour duration.

Connected Solutions		
Program Revenues for National Grid Demand Reponse Program		
Capacity payment	$20	per kW per year
Performance Payment	$0.75	per kWh during DR
Total DR Event Hours	20.0	hours
Curtailed Load	90.4	kW
Customer Share	65%	%
Total Incentive/Year	$2,057	$

Table 23 : Andrews Middle School- Revenues from National Grid demand response program (Connected Solutions)

CAP-TAG REVENUES

The Cap-Tag demand response program is offered by CPower to manage the supply capacity charge on the day it is set (day of highest peak load on regional utility grid). Cap-Tag revenue is not available to Medford based on their existing supply contract. However, the kW savings value shown in Table 24 assumes the BESS and associated demand response load-offset capacity is not online or available until 2019. CPower anticipates the day and time that the annual demand capacity charge is set and dispatches a Cap-Tag event to curtail load during this period. The Andrews school cannot take advantage of the Cap-Tag program unless the electric supply contract is renegotiated to pass through the annual demand capacity charge to Medford.

Cap Tag					
Program Revenues for Peak Demand Management (Cap-Tag) Program					
Cap-Tag is set for Summer of this Year	ISO-NE Zone	Cap Tag Power Year	Cap-Tag Value $/kW	kW Savings	Annual Savings $
2018	NEMA	2019-2020	$81.00	49.1	$3,979
2019	NEMA	2020-2021	$63.60	99.1	$6,304
2020	NEMA	2021-2022	$55.57	99.1	$5,508
Total for 3 years					$15,791

Table 24: Andrews Middle School- Revenues from peak demand management program (Cap - Tag)

PEAK SHAVING

Peak shaving is a strategy that is used to reduce electrical power consumption consistently during on-peak periods when delivery demand charges are set. Earlier in the Electric Load Analysis section, Figure 5on page 45 shows the demand reduction opportunity from peak shaving at Andrews Middle school. The peak demand at Andrews middle school is currently 375 kW, for 1% of the year demand is at or above 230 kW, and for 3% of the year demand is at or above 200 kW. By reducing the annual peak load of 375 kW to 230 kW (1% of the year) Andrews Middle School could save about 2.8% of its annual electricity costs as shown in Table 25. Similarly, reducing the annual peak load of 375 kW to 200 kW (3% of the year), and 6.5% of the annual electricity costs (Table 26). It should be noted that in both of these tables, the majority of the energy cost savings is not from savings on demand charges, rather energy (kWh) cost savings that are a result of the demand management strategies. Medford's low delivery demand charge of $5.67/kW-month results in limited avoided demand charges from peak shaving. Peak shaving is also not compatible with batteries that are used for resiliency purposes due to the high cycling frequency.

Andrews Middle School - Peak Shaving Opportunity by reducing 1% peak		
	Qty	Units
Annual Electricity Usage	735,800	kWh
On-Peak - Maximum Demand	374	kW
Off-Peak Maximum Demand	305	kW
Percentage time peak demand is above 230 kW	1	%
Percentage time peak demand is above 200 kW	3	%
Total Hours - peak demand is above 230 kW	88	Hrs
On-peak - Maximum Demand after reducing peak below 1%	230	kW
Off-Peak Maximum Demand after reducing peak below 1%	230	kW
Annual Electricity usage after 1% peak reduction	715,652	kWh
Annual Electric demand cost savings by 1% peak reduction	$828	$
Annual Electricity usage savings	$2,970	$
Total Annual Savings	$3,798	$
Total Annual Cost Savings	2.8%	%

Table 25: Andrews Middle School – Peak Shaving opportunity by reducing to current 1% peak load

Andrews Middle School - Peak Shaving Opportunity by reducing 3% peak		
	Qty	Units
Annual Electricity Usage	735,800	kWh
On-Peak - Maximum Demand	374	kW
Off-Peak Maximum Demand	305	kW
Percentage time peak demand is above 230 kW	1	%
Percentage time peak demand is above 200 kW	3	%
Total Hours - peak demand is above 200 kW	263	Hrs
On-peak - Maximum Demand after reducing peak below 3%	200	kW
Off-Peak Maximum Demand after reducing peak below 3%	200	kW
Annual Electricity usage after 1% peak reduction	683,240	kWh
Annual Electric demand cost savings by 1% peak reduction	$1,000	$
Annual Electricity usage savings	$7,748	$
Total Savings	$8,748	$
Total Annual Cost Savings	6.5%	%

Table 26 : Andrews Middle School – Peak Shaving opportunity by reducing to current 3% peak load

Energy Arbitrage

Andrews Middle School has the same on-peak and off-peak energy supply costs. Figure 14 shows how Energy Arbitrage cost savings vary based on change in off-peak electric supply cost. The arbitrage savings increases as the off-peak supply cost decreases. The energy arbitrage cost savings shown below is based on the assumption that batteries are not charged by solar PPA and are directly charged from grid power during off-peak periods. Energy arbitrage is also not compatible with batteries that are used for resiliency purposes due to the high cycling frequency.

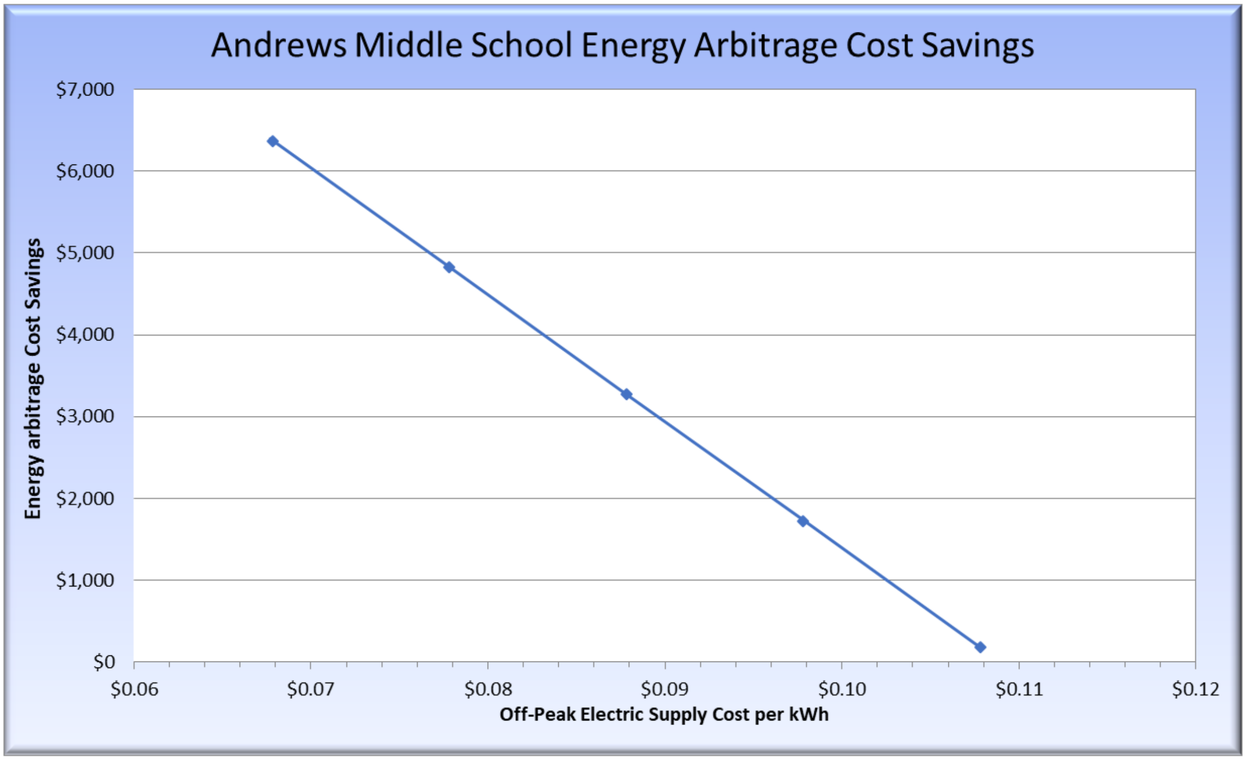

Figure 14 Energy arbitrage cost savings vs off-peak supply cost per kWh at Andrews Middle School

Peak Demand Economic Summary

The results of the investigation show that for this facility, participating in peak demand response programs through a CSP generates more net value flow for the city than peak shaving. Demand response programs provide a positive revenue stream to the city for participating, while peak shaving results in avoided electric demand and energy costs. Peak shaving is also incompatible with a resiliency application due to the number of cycles (daily discharge). Presently, there is no advantage to energy arbitrage, and energy arbitrage is also incompatible with resiliency applications. Arbitrage would only become lucrative if the city obtained a new supply contract with a very low off-peak rate. The Table 27 below summarizes the value of the peak demand opportunities examined over a three-year value stream.

Value of DR Options at Andrews				
Demand Response Path	Year 1 Value	Year 2 Value	Year 3 Value	**Total 3-year Value**
Real-Time Demand Response[1]	$2,502	$4,584	$3,456	**$10,542**
National Grid Connected Solutions	$2,057	$2,057	$2,057	**$6,170**
Cpower Cap-Tag Management[2]	$3,979	$6,304	$5,508	**$15,791**
Peak Shaving to 1% Annual Load[1]	$3,798	$3,798	$3,798	**$11,393**
Energy Arbitrage	$206	$206	$206	**$618**

Notes:

1 RTDR and Peak Shaving are mutually exclusive.

2 In order to take advantage of the Cap-Tag program, Medford must negotiate a new supply contract that passes supply capacity charges through to the city.

Table 27 Economic value of demand response options at Andrews Middle School

Two primary strategies emerge for demand response at this site. The recommended option is to participate in as many DR programs provided by the CSP as possible. B2Q also recommends that Medford renegotiate the Andrews School electric supply contract to pass through demand capacity charges to the city so that they can manage that cost and create additional revenue through the Cap-Tag management program provided by CPower. The alternative is to implement strategies to manage demand charges actively through peak shaving and energy arbitrage. The Table 28 below shows that even if Medford was able to obtain a new electric supply contract with a $0.08/kWh off-peak rate, the value of the avoided cost savings opportunity from peak shaving and arbitrage is still less than the revenue opportunity of Medford participating in all three demand response programs through CPower.

Value of Comprehensive DR Strategies				
DR Strategy	Year 1 Value	Year 2 Value	Year 3 Value	**Total 3-year Value**
All Curtailment Programs Together: RTDR + NGRID CS + Cap-Tag	$8,965	$13,259	$11,257	**$33,481**
Peak Shaving + Energy Arbitrage + Negotiate $0.08/kWh off Peak Rate	$8,642	$8,642	$8,642	**$25,927**

Table 28 Economic value of comprehensive DR strategies at Andrews Middle School

Additionally, if Medford is unable to make any favorable changes to their electric supply contract, participating in only the RTDR and Connected Solutions programs would generate $17,690 of net revenue to the city over the first 3 years, compared to $12,011 in avoided energy costs from peak shaving and arbitrage over the same period.

Table 29 below shows the economic payback summary of the demand response technologies revenues for Andrews Middle school. The overall demand revenues make ADR attractive when used with demand response programs. The return on investment is calculated using the incremental project cost and a 3-year average of DR revenues. The incremental project costs assume the base technology is already installed and represents the cost of the changes needed to add and automate the demand response capacity. These incremental costs are estimates, developed from vendor estimates and proposals.

Andrews Demand Response Technologies Economic Summary							
Demand Response Technology	Summer Demand Savings	Winter Demand Savings	DR Average Annual Program Revenues	Technology Implementation Cost/kW	Incremental Project Cost	Payback on DR Revenues	ROI
	kW	kW	$	$/kW	$	yrs	%
HVAC Upgrades	37.8	8.5	$5,539	$864	$40,000	7.2	14%
Lighting Upgrades	11.3	11.3	$1,858	$443	$10,000	5.4	19%
Battery Energy Storage System (BESS)	50.0	50.0	$8,235	$200	$20,000	2.4	41%
TOTAL	**99.1**	**69.7**	**$15,631**	**$1,507**	**$70,000**	**4.5**	**22%**

Table 29 : Andrews Middle School Demand Response Technologies Revenues Economic Summary. Note: The project costs represent incremental costs for Lighting and BESS to implement demand response program

Project Costs

Resiliency Project Costs and Funding

The resiliency project costs at Andrews School are greater than the funding allocated for a battery system of a capacity that can make an impact in off-grid operations at the facility. This is primarily due to two factors, the first of which being the low cost/kWh ($400/kWh) for the energy storage system that was assumed to develop funding structure, as shown earlier in this report. The second significant cost add is the electrical recircuiting required to support resilient building operations at this facility, which is estimated to add approximately $100,000 to $120,000 to the project cost. Therefore, in order to meet all of the project goals, additional funding is required. The estimated project costs for various energy storage capacities can be seen in the Table 30 below.

Andrews Energy Storage Capacity and Resiliency Project Costs

	Energy Storage Capacity	Battery-Only Off Grid Duration[2]	Opinion of Project Cost	All-In Cost per kWh Installed	Estimated Funding Increase Required[3]
Description	**kWh**	**hours**	**$**	**$/kWh**	**$**
Base Project[1]	250	1	$573,558	$2,294	$115,205
CCERI Documents Allocation	389	1-2	$656,528	$1,688	$198,175
Increased Off-Grid Backup	425	2	$676,109	$1,591	$217,757
Meets All Project Goals	650	3	$834,521	$1,284	$376,169

Notes

1 Base Project does not account for any costs shifted between sites.

2 Battery-Only Off Grid Duration assumes that the battery is fully charged and under peak resiliency loads for each project site.

3 Estimated Funding Increase Required does not include any contingency.

Table 30 Andrews Middle School Energy Storage and Resiliency Project costs

The graph below in Figure 15 presents the opinion of probable cost for each option compared to the industry trends. One important take-away is that the electrical modifications required at Andrews to support resiliency operations push the energy storage system cost into a higher cost/kWh range. BESS costs have been developed by obtaining estimates from Northern Reliability, NEC, and Solect. It is noteworthy that as the BESS energy storage capacity increases, the cost per kWh of energy storage is reduced. This is in part because the costs associated with all electrical work to integrate the BESS with the building and to recircuit the building loads are fairly fixed, while economies of scale apply to the BESS.

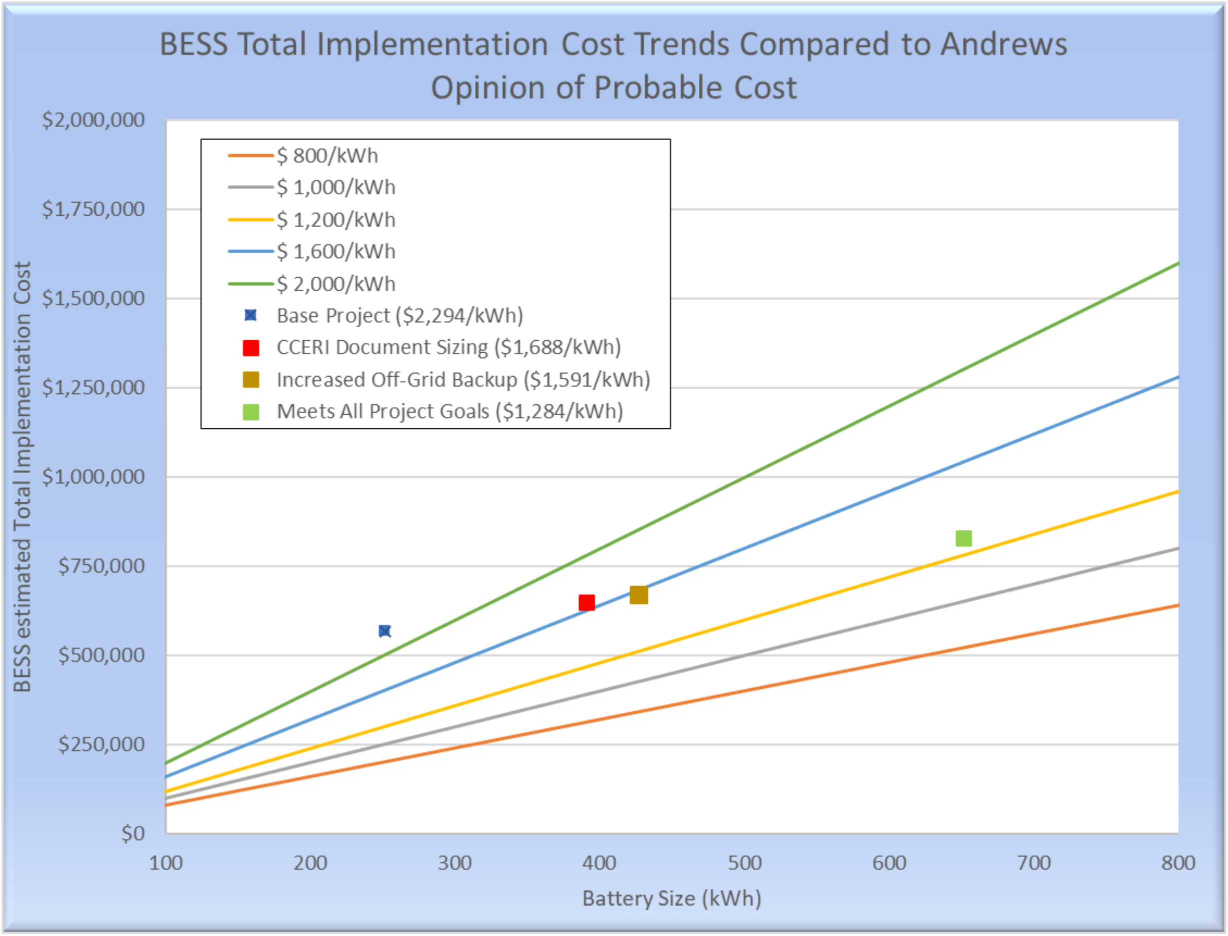

Figure 15 BESS cost trends vs Andrews BESS opinion of probable cost for various energy storage system capacities.

INTEGRATED PROJECT COST

Figure 16 on the following page shows the Opinion of Probable Cost for the integrated Base Project with a 250kWh energy storage capacity. Cost data was provided by various sources, as noted in the table. Vendors who provided cost information or firm quotes included: Northern Reliability, NEC, Solect, EnergyIQ, ENE Systems, CPower, and Energy Source. The Funding column in the estimate indicates the budget allocated for each line item with "R" for CCERI Grant, "PD" for the Peak Demand Grant, and "M" for Medford. The integrated project opinion of probable cost is a comprehensive view of all costs associated with this pilot project. Opinions of Probable cost for other energy storage capacities presented in Table 30 above can be found in Appendix A. The DOER's State of the Charge Report references maintenance costs of $10/kW-year, while NREL's 2015 Economic Analysis Case Studies of Battery Energy Storage assumes[4] $20/kW-year. Using these estimates, the projected annual maintenance costs are expected to be in the range of $1,000 - $2,000 for a project of this size. Based on discussions with vendors, it is assumed that 10 years of annual maintenance is included in the cost of the BESS.

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[4]National Renewable Energy Laboratory. DiOrior, Nicholas; Dobos, Aron; Janzou, Steven: "Economic Analysis Case Studies of Battery Energy Storage with SAM". Available at https://www.nrel.gov/docs/fy16osti/64987.pdf

Opinion of Probable Construction Cost							
ANDREWS SCHOOL RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT							
B2Q Associates, Inc. 100 Burtt Rd. Ste. 212 Andover, MA 01810 (978) 208 - 0609			Customer: City Of Medford Address: 3000 Mystic Valley Parkway Medford, MA 02155	Created by: JD Checked by:			
General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$21,942	$21,942
2	R	2	Installation Labor	ea	1	$26,330	$26,330
3	R	5	Pad and Site Work	ea	1	$11,947	$11,947
4	R	2	Galvanized Chain Link Fence	ea	1	$4,827	$4,827
5	R	2	Battery Package 100kW/255kWh	ea	1	$188,212	$188,212
6	R	2	Microgrid Controller	ea	1	$40,000	$40,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$330,280**
Building Resiliency Upgrades							
9	R	6	Electrical Demolition	ea	1	$5,000	$5,000
10	R	6	Install New ATS	ea	1	$25,000	$25,000
11	R	6	Recircuiting: Intercept Circuits and Route to New ATS	ea	22	$2,000	$44,000
12	R	6	Recircuiting: Intercept Panels and Route to New ATS	ea	3	$10,000	$30,000
						Subtotal	**$104,000**
Battery Energy Storage System - Engineering and Procurement							
13	R	1	Battery Procurement	ea	1	$4,000	$4,000
14	R	1	Feasibility Study	ea	1	$32,728	$32,728
15	R	1	Design and Bid	ea	1	$39,550	$39,550
16	R	1	Commissioning Agent	ea	1	$8,000	$8,000
17	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
18	R	6	BESS Package Provider Commissioning & Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
19	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
20	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
21	PD	1	Facility ConneX - MBCx	ea	1	$14,953	$14,953
22	PD	1	BAS Peak Demand Strategy Programming and Integration	ea	1	$60,000	$60,000
23	M	3	LED Lighting Upgrades	ea	1	$265,000	$265,000
24	PD	3	Lighting Controls and Integration	ea	1	$90,000	$90,000
25	PD	1	Lighting Bid, Cx, and PM	ea	1	$11,853	$11,853
26	PD	3	Recommissioning Fixes Budget	ea	1	$18,000	$18,000
						Subtotal	**$469,256**
Demand Response and Energy Systems Integration - Engineering and Procurement							
27	PD	1	Peak Demand Response Systems Engineering	ea	1	$12,450	$12,450
28	PD	1	Peak Demand Response PM/CA	ea	1	$18,900	$18,900
29	PD	1	Peak Demand Response Systems Commissioning	ea	1	$6,950	$6,950
						Subtotal	**$38,300**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Consultant Opinion of Cost	
6	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	
M	City of Medford	Grand Total Resiliency & Peak Demand Project **$1,081,114**

Figure 16 Andrews Middle School DR and Resiliency Opinion of probable cost

DEPARTMENT OF PUBLIC WORKS PROOF OF CONCEPT

PEAK DEMAND RESPONSE SUMMARY

The DPW's peak load is approximately 75kW, and therefore has limited ability to be a significant contributor to a demand response program. Having said this, it is important for many reasons that the energy industry figure out how to engage all sizes of buildings from all different market sector use types. Also, almost every municipality in the Commonwealth has a DPW facility, and DPW facilities have important contributions to community safety, especially during emergencies. Therefore, including the DPW facility in both the automated demand response and resiliency pilot projects is worthwhile. The Because the DPW facility's peak demand is so low, it is currently on National Grid's G-2 tariff and is not charged for demand in accordance with the time of day. This does not mean that the DPW facility is not a viable candidate to participate in demand response programs, it just means that it would have to be able to change to a different tariff to realize savings from peak shaving and energy arbitrage. Due to the limited savings associated with peak shaving and energy arbitrage in particular, it is not recommended to change DPW's rate structure to a time of use tariff. Also, there is no interval data available which makes understanding the daily load profile of the facility difficult. B2Q did install data loggers to meter load on the incoming service for a short period in order to obtain some measured feedback regarding the daily load profile and then extrapolated to create the typical annual load profiles.

We have identified changes to the building lighting and HVAC control systems which are expected to enable 10.3 kW (41 kWh over four hours) of demand reduction, all of which is dispatchable on demand. The addition of battery storage (at the anticipated size of 100 kW/ 85 kWh) adds 15kW of load sheading capability and increases the dispatchable demand reduction to 25.3 kW (101.2 kWh over a four-hour time period).

The DPW can participate in ISO-NE forward capacity market and National Grid's Connected Solutions demand response program through CPower. The DPW could take advantage of CPower's "Cap Tag Management" program if the electric supply contract is changed to pass the annual capacity charge through to the customer.

- The battery system size of 100kW/85kWh could conservatively deliver 15kW for a 4-hour demand response event. The demand response capacity available and the revenue stream from the battery system is directly tied to the energy storage capacity. Therefore, the demand response capacity that will be available from the batteries at the DPW is a function of the energy storage capacity the CCERI resiliency grant can fund. Based on the resiliency technical and financial analysis of the batteries presented later in this report, a conservative estimate of 15 kW for a 4-hour demand response event is used in the following Table 31.

- HVAC demand management through the BAS could save 6.1 kW for a 4-hour demand response event.

The Table 31 below summarizes the electrical demand savings, DR revenues, and technology-specific economics. This is based on the incremental cost of adding ADR to systems. The Incremental Project Cost assumes that the technology is already in place or planned by the facility or customer for reasons other than demand response and represents the added cost difference to enable automated demand response. For example, the total cost of the lighting controls system re-programming at the DPW is not implemented solely for demand response, and the incremental cost represents the added cost to leverage this system for automated demand response and provide additional revenue streams.

DPW Demand Response Technologies Economic Summary							
Demand Response Technology	Summer Demand Savings	Winter Demand Savings	DR Average Annual Program Revenues	Technology Implementation Cost/kW	Incremental Project Cost	Payback on DR Revenues	ROI
	kW	kW	$	$/kW	$	yrs	%
HVAC Upgrades	6.1	5.4	$984	$436	$5,000	5.1	20%
Lighting Upgrades	4.2	4.2	$690	$596	$5,000	7.2	14%
Battery Energy Storage System (BESS)	15.0	15.0	$2,470	$333	$10,000	4.0	25%
TOTAL	**25.3**	**24.6**	**$4,145**	**$1,366**	**$20,000**	**4.8**	**21%**

Table 31 DPW Demand Response technologies economic summary. Note: The project costs represent incremental costs for the BAS, Lighting controls, and BESS to implement automated demand response.

RESILIENCY SUMMARY

The Department of Public Works resiliency use-case is a critical operations support facility. During a resiliency event, all areas of the DPW are in use 24/7. The existing standby generator is rated for 300kW in standby operation, and 250kW in continuous operation. Unlike the Andrews School where the emergency generator was sized to serve only specific emergency loads, the DPW's standby generator was sized to support the entire building load, while emergency lighting systems are battery-powered. With a measured annual peak demand of 75 kW, the generator is significantly oversized. With a full fuel tank, the generator can support the existing building loads for 95 hours before needing to be refueled. The addition of solar PV coupled with battery energy storage will enable the solar PV to power the building during an off-grid scenario whenever the sun is shining, significantly extending the off-grid capabilities of the site and reducing the environmental impact of the fossil-fuel standby generator. Off-grid power duration can be extended by automated load management, using modified peak demand response sequences.

The battery size that is recommended to maximize DR and resiliency impact is 100kW/ 300kWh, which would carry the facility peak operational load for 4 hours during an event. However, CCERI grant funding is constrained and creates a limit of the capacity that can be procured. Since the existing generator is capable of supporting the entire facilities load for an extended period of time, and due to funding limitations, we recommend that the capacity of the batteries be limited to the 100kWh – 250kWh range. At 100kWh, the battery systems could support unoccupied loads of 45kW for approximately 2 hours and occupied/operational loads for little more than 1 hour. At 250 kWh, the BESS could support occupied operational loads for about 3 hours, meeting the project goals.

The recommended battery type for this application is lithium Ion (LI-ion). The original CCERI evaluation for this project was estimated using Sealed Lead-Acid (SLA) batteries. Although LI-ion battery systems cost about twice that of a similarly sized SLA system, B2Q recommends LI-ion over SLA for the following reasons:

- SLA batteries have a slow rate of charge compared to LI-ion batteries. This impacts how quickly a solar system could charge the batteries during an off-grid emergency event.

- LI-ion batteries have a longer life of SLA batteries. Cycle life (one cycle is comprised of one charge and one discharge) for SLA batteries the life is typically estimated to range from 500 to 1,500 cycles, while new LI-ion batteries are guaranteed by manufacturers for at least 3,000 cycles.
- LI-ion round-trip efficiency (discharge/charge efficiency) is approximately 95%, while SLA round-trip efficiency is closer to 80% or less.
- LI-ion batteries have very stable discharge voltage while the SLA battery voltage drops consistently during discharge. If discharge voltage drops or "sags" too far, lights could dim and equipment may not be able to operate.
- LI-ion is cleaner and safer for the environment than SLA because LI-ion does not contain lead.
- LI-ion batteries are more flexible in how they are used and can be discharged to less than 50% capacity without significant adverse impacts to battery life. Contrasted to SLA batteries, where, because of the nature of the SLA electro-chemical reaction, current draw from large equipment (such as AC compressors for cooling) can reduce the available energy storage capacity. Additionally, SLA batteries cannot be discharged below 50% of rated capacity without potentially significant impacts on cycle life.

Medford's PPA with Solect will install approximately 180kW of solar PV at the DPW. At 50% of system output, the solar array could charge the BESS at a rate of approximately 90kWh per hour of charging. During a resiliency event, if sufficient solar energy is available, the solar energy would be the first source of power for the facility and would charge the batteries with the excess power. In the event that there is insufficient solar available to pick up the entire building load, then the standby generator would operate to meet the load and to charge the batteries.

FACILITY DESCRIPTION AND EXITING CONDITIONS

GENERAL

Department of Public Works is a public works facility for the City of Medford which was built in 2015 and it serves over 57,000 citizens of City of Medford.

The DPW is spanned over 44,000 square foot in size and helps maintaining the safety and beauty of City of Medford. The key division covered under DPW are Highways, Forestry, Parks, Water & Sewer, Engineering and Cemetery division.

DPW provides critical services during an emergency such as clearing streets, removing snow & debris, repairing water infrastructure to the City of Medford.

BUILDING USE

Typical building use schedules are:

- Monday, Tuesday, Thursday: 8:30 AM – 4:30 PM
- Wednesday: 8:30 AM – 7:30 PM
- Friday: 8:30 AM – 12:30 PM
- During the emergencies, the facility is open 24/7

ELECTRICAL SYSTEMS

The main switch board receives a 208V feed from National Grid's transformer. The main switch supplies electricity to various panel boards, RTU, ERV and automatic transfer switch. The automatic transfer switch act as a bi directional automatic switch between utility feed and the emergency generator. The ATS and emergency electrical system is designed to carry the whole building load during power loss and is currently powered by the 300kW "SD 300 Genrac" diesel emergency generator. The backup generator currently is wired to serve the whole building load during emergency.

UTILITIES

Electricity and Natural Gas is supplied and delivered by National Grid. The average annual Electricity consumption of 321,680 kWh and thermal consumption of 15,852 therms.

HVAC

The air-conditioned spaces in the DPW are served by a Trane THC 067 Roof Top Unit (RTU), with 5-tons of DX cooling capacity and a 5hp supply fan motor, equipped with a VFD. This RTU serves the administration area and provides primary air for the 6 Fan powered VAV boxes each of 1/8 hp and 9 Exhaust fans serving on the air side system. There is also a 100% OA energy recovery ventilator serving the shop areas. The supply and exhaust fan motors are 7.5hp and equipped with VFDs. This unit uses an energy recovery wheel to preheat incoming air during the winter.

HEATING SYSTEMS

DPW has (2) hot water condensing boilers located in Mechanical room. There are (9) HW Unit Heaters, (2) HW Cabinet unit heaters, (10) natural gas-fired radiant heaters serve the high-ceiling vehicle bays, (3) stand-alone 3kW electric unit heaters of each serve vestibules. Airside heating is delivered via ERV, RTU, and VAV reheat coils.

COOLING

Cooling in DPW is only available for the office area via the Trane DX RTU. A Mitsubishi Split system serves the communications/data room.

LIGHTING

Lighting systems throughout building are LEDs and multiple zones having occupancy sensors. The lighting systems in the building are zoned and monitored by lighting controllers designed Acuity Controls. It is observed that currently these Lighting controls are not functionally operative in many zones. Refer to appendix for the table containing existing lighting fixtures and the corresponding zones associated with it.

BUILDING AUTOMATION SYSTEM

The existing building automation system (BAS) serving the Department of Public Works is a Niagara Triduum system with a JCI FX-60 controller. There are (3) network controllers that provide supervisory control functions to the individual equipment controllers. There is a front-end user interface work station that accesses and displays information from the network controllers. The BAS uses BACnet communication protocol for data exchange among devices.

OTHER EQUIPMENT

- Two vending machines
- Public works communication equipment
- Mechanical shop equipment
- Vehicle washing stations
- Fuel island pumps
- Shop air compressor with 15hp compressor motor

UTILITY RATE ANALYSIS

Table 32 below represents Department of Public Works utility rate analysis. DPW falls under G-2[5] (Time-of-Use) tariff rate, which is primarily for commercial and industrial customers with average use exceeding 10,000 kWh per month and demand not exceeding 200 kW.

The peak and off-peak hours described under this service are:

Peak Hours: Peak hours will be from 8:00 a.m. to 9:00 p.m. daily on Monday through Friday, excluding holidays.

Off-Peak Hours: Off-Peak hours will be from 9:00 p.m. to 8:00 a.m. daily Monday through Friday, and all day on Saturdays, Sundays, and holidays

It is to be noted that the distribution charge is same for on-peak and off-peak hours. The peak and off-Peak supply rates are assumed to be same. Any change in the peak supply costs vs off-peak supply costs would significantly impact the utility rate structure for the DPW.

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[5] Time-of-Use (G-2) - National Grid Customers

DPW : Utility Rate Analysis		
	Cost per unit	Cost
Distribution Demand Charge	$/kW	$8.50
Distribution Charge	$/kWh	$0.0172
Transmission Charge	$/kWh	$0.0233
Transition Charge	$/kWh	$0.0006
Energy Efficiency Charge	$/kWh	$0.0096
Renewables Charge	$/kWh	$0.0005
Energy Supply Costs	$/kWh	$0.0960
Total		$0.1472

Table 32 DPW G2 tariff utility rate structure for the year FY 2016

UTILITY COST ANALYSIS

Table 33 below is the summary of the Annual energy spend at the DPW. It is to be observed that the supply costs account for 40% of the annual energy spend and the demand charges account for 9% of the annual energy spend. Any reduction of the above charges would result in significant savings in the energy spend. The demand charge of $8.5 per kW is accounted based on the highest peak demand. The peak demand for the year FY 2016 was 68 kW.

DPW - FY 2016 Energy Spend				
Utility Cost	*Units*	*Rate*	*Annual Spend*	*% of Total Annual Energy Spend*
Distribution Charge	$/kWh	$0.017	$5,530	7%
Supply Charge	$/kWh	$0.096	$30,881	40%
Electric Demand	$/kW	$8.500	$6,936	9%
Transmission Charge	$/kWh	$0.023	$7,505	10%
Transition Charge	$/kWh	$0.001	$187	0%
Energy Efficiency Charge	$/kWh	$0.010	$3,078	4%
Renewables Charge	$/kWh	$0.001	$161	0%
Customer Charge	$/ Month	$25.000	$300	0%
Delivery - Natural Gas	$/Therms	$1.014	$16,071	21%
Supply – Natural Gas	$/Therms	$0.446	$7,074	9%
Total			***$77,722***	***100%***

Table 33 DPW FY 2016 Energy Spend Summary.

ENERGY BENCHMARKING

Annual Energy Spend of DPW as shown in the Table 34, provides a summary snapshot of the various major contributing factor of the energy spending for FY 2016. The peak usage per square foot and electric energy usage per square foot provides the performance of the building.

DPW - Annual Energy Summary		
Square Footage	44,000	Sq./ft
	Qty	*Units*
Annual Electricity Usage	321,680	*kWh*
Annual Electrical Distribution Cost	$5,530	*$*
Annual Electrical Supply Cost	$30,881	*$*
Total Annual Electrical Cost (Combined)	$54,578	*$*
Average On peak demand	68	*kW*
Peak Energy Intensity	1.545	*W/Sq. Ft*
Annual Usage per Square Footage	7.31	*kWh/Sq. Ft*
Load Factor	54%	*%*
EUI (Electrical)	*24.94*	*kBtu/SF*
Annual Gas Usage	15,852	*Therms*
Annual Gas Supply Cost	$7,074	*$*
Annual Gas Distribution Cost	$16,071	*$*
Total Annual Gas Cost	$23,144	*$*
EUI (Gas)	*36.03*	*kBtu/SF*
EUI (Total)	***60.97***	***kBtu/SF***

Table 34 DPW Annual Energy Spend for FY 2016

The graph in Figure 17 present various historical consumption statistics for a one-year period (FY 2016) to put the facility's consumption in perspective. It can be seen that consumption is much lower in the spring months when less lighting and mechanical cooling is required. It can also be seen that consumption in December 2016 is the highest of all months that year. This could be due to how the facility was used during that time or may be due to equipment not operating properly. The annual load factor for DPW is 54 %, which is low (anything lower than 75% is generally considered to be low). A low load factor indicates that peak loads at the facility are being seen for a small percentage of the hours in a year.

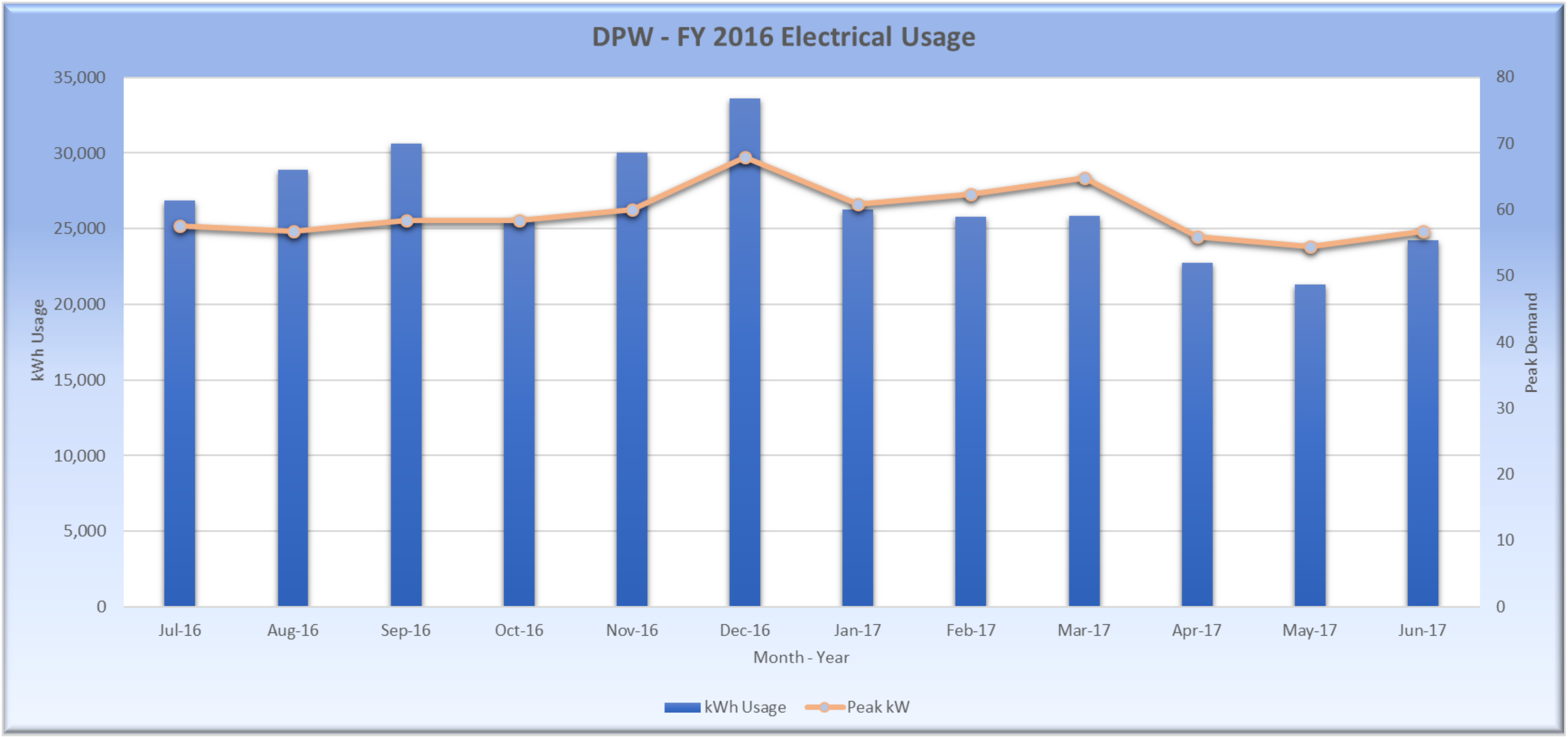

Figure 17 DPW – FY 2016 Energy Usage

Load Factor[6]: Electrical Load factor is a measure of the utilization rate, or efficiency of electrical energy usage. It is the ratio of total energy (KWh) used in the billing period divided by the possible total energy used within the period, if used at the peak demand (KW) during the entire period. The load factor ratio is above 75% suggests the electrical usage is reasonably efficient. The load factor below 60 %, suggests that the building experiences periods of very high usage (demand) and a low utilization rate.

[6] Power Planet Energy Management Systems. Available at http://www.demandcharge.com/Web_Pages/Articles/Electrical_Load_Factor.html

Electric Load Analysis

Load Duration Curve

The load duration curve is a plot of the percentage of time that the facility load is at or above various demand levels. For example, on a downward sloping curve, the demand at a 10% level would indicate that the demand is at or above that level for 10% of the time. A curve with a steep section at the beginning, such as the one below in Figure 4, would be indicative of a load profile that spends very little time at high or full load, and a flat curve would indicate that there is very little variation in load over time.

Below is the load duration curve in Figure 18 for the data available between dates 1/15/2018 – 3/15/2018. The data from this curve shows that the load is above approximately 60 kW less than 2 % of the time. This is a steep load duration curve, as the 10 % load of 50 kW is only 33 % of the annual peak load of 75 kW. This indicates that most of the time the facility needs less than 56 kW, however for 5 % of the year, the facility needs close to twice that. This is a very sharp increase and various demand reduction strategies addressed in later section of the report can be used to limit demand can be used to reduce the slope of this curve and create demand savings.

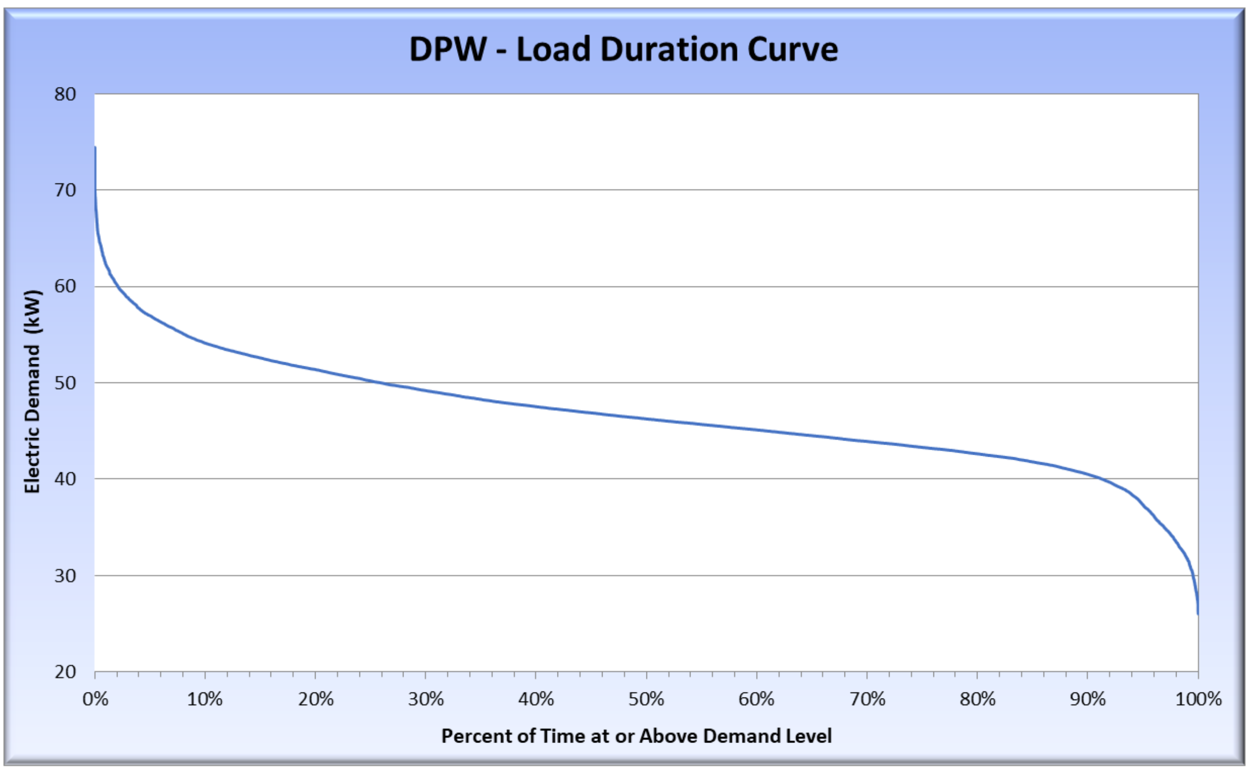

Figure 18 Department of Public Works – Load duration curve for FY 2016

Load Profile Analysis

The graph that follows in Figure 19 is a graphical representation of when demand peak periods are occurring at the facility between dates 1/15/2018 – 3/16/2018. Data loggers were used to log the demand data at DPW between 1/5/2018 – 3/16/2018 due to lack availability of 15 min EPO demand data for G-2 utility accounts like DPW. The horizontal axis shows the day of the year, and the vertical axis shows the hours of the day. The colors of the graph indicate the range of electricity demand (kW), with each corresponding range identified by the legend at the top of the graph. The data was logged using current transducers recording an amp reading at 1-minute intervals. Real power was calculated using the average annual power factor calculated from the facility's utility bills.

The graph shows that unoccupied demand typically ranges from 40-45kW, and that occupied demand typically ranges from 60-70kW. The load profile appears consistent, except for a dip in late February, which could be a result of how the building was used or equipment not operating properly.

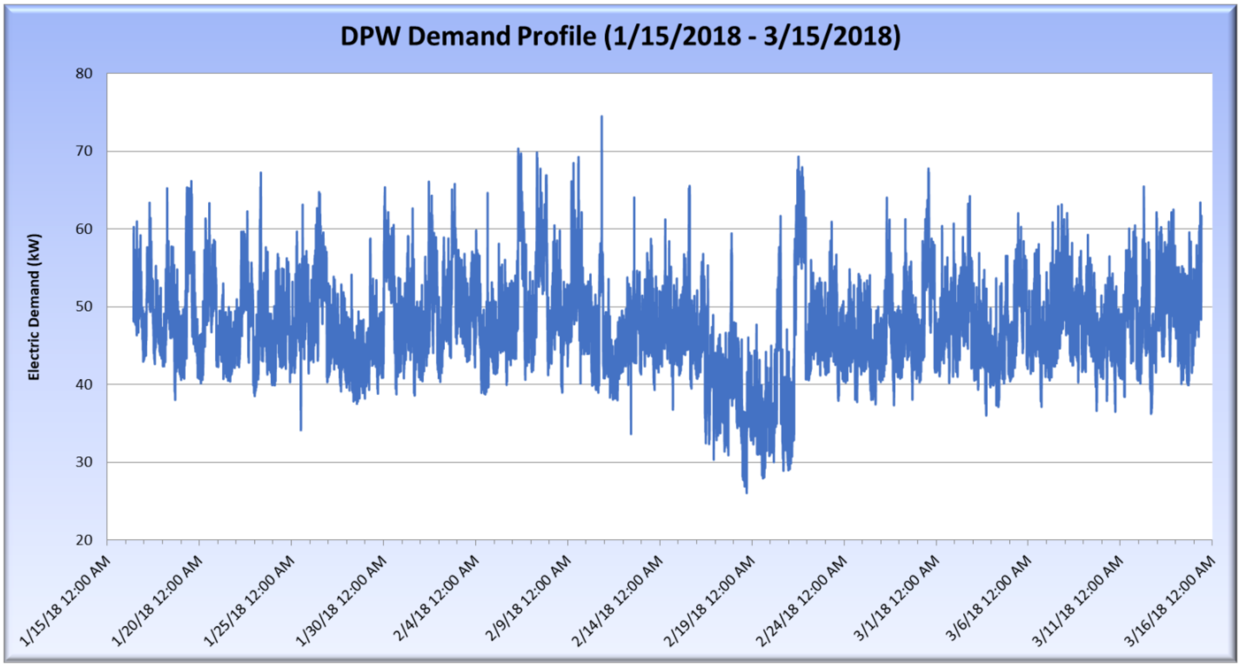

Figure 19 Department of Public Works Electric load profile for FY 2016

Equipment Load Analysis

The Table 35 below shows the estimated connected loads in kW and annual energy consumption of the major end-use categories at Department of Public Works. The total connected kW is higher than the peak kW demand shown earlier in the report because not all equipment will be running at any one time.

Department of Public Works Major End-use breakdown		
Major End Uses	*Connected kW*	*kWh*
AC units	5	41,172
Air Handling units	14	56,000
Fans, Fan Powered Boxes, Unit Ventilators	8	32,800
Electric Heaters and Unit Heaters	6	15,000
Miscellaneous and plugloads	25	100,000
Lighting	25	100,400
Total	**83**	**345,372**

Table 35 Department of Public Works Major End use breakdown

The pie chart below in Figure 20and Table 35above indicate the major end uses – air handling units, air conditioning equipment, lighting, heating equipment, fan equipment, miscellaneous equipment and plug loads (includes shop equipment loads, fuel island pumps, computers etc.). The connected kW data is primarily from building equipment schedules, however the shop equipment inventory estimated based on available information and electrical data.

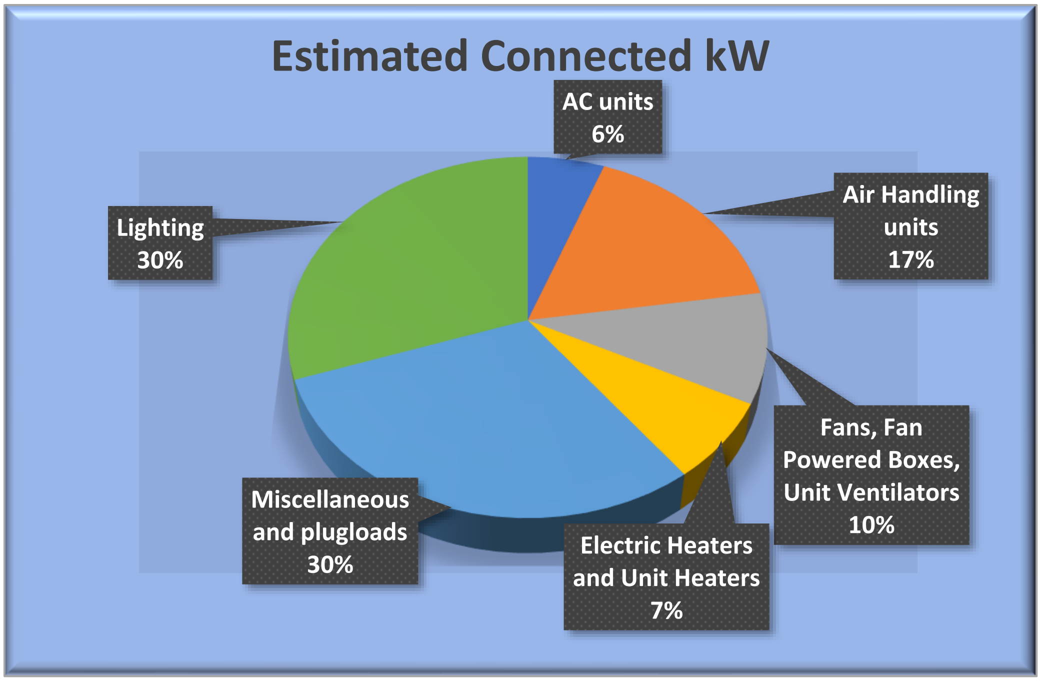

Figure 20 DPW estimated connected kW pie chart for FY 2016

The pie chart below in Figure 21 displays the electricity end-use reconciliation. This is created by estimating run hours based on building and equipment schedules for the major components of energy use shown above.

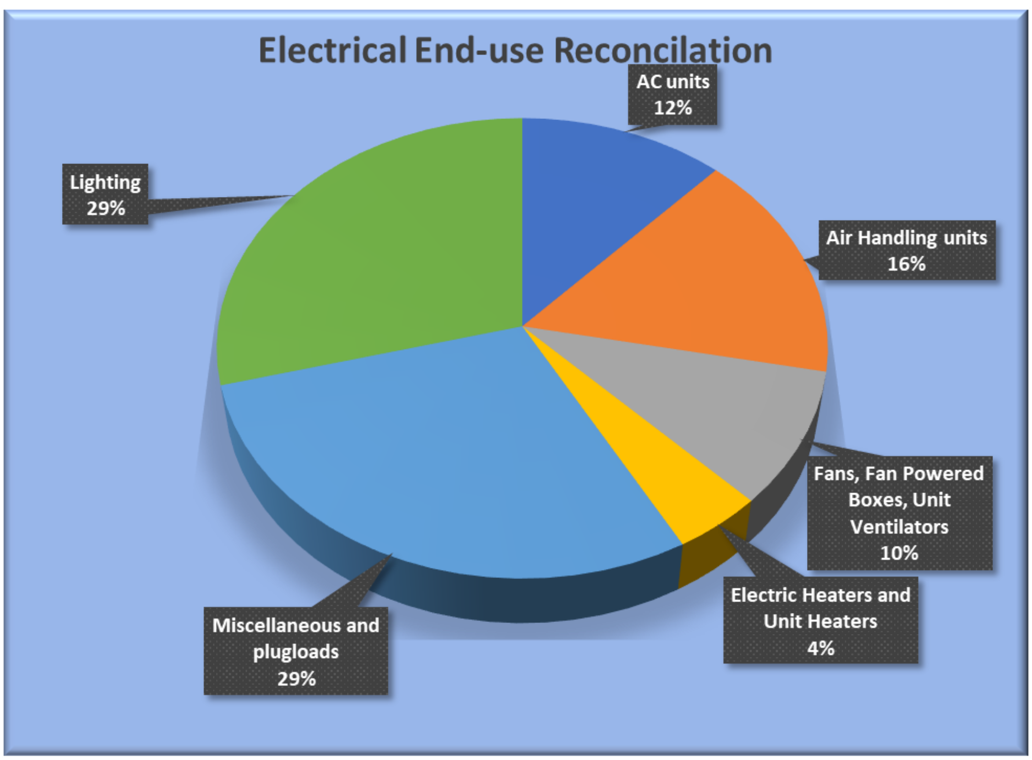

Figure 21 DPW- end use reconciliation for the year FY 2016

Resiliency Analysis

Department of Public Works as an Critical Operations Facility

Medford's emergency requirements and desired resiliency goals were developed through discussions with Alicia Hunt It is to be noted, during emergency DPW is open 24/7 and is key for critical services like clearing streets, removing snow & debris, repairing water infrastructure. In addition to these critical services, there is a civil dispatch and equipment maintenance and refueling operations.

Existing Emergency Systems

The DPW is equipped with backup systems designed to power the entire building. Key details are listed below:

- Existing standby generator:
  - The diesel generator is pad mounted, with exterior sound attenuated weatherproof enclosure and sub-base fuel tank and is located outside the building next to main electrical room.
  - The emergency generator is currently rated for 300kW standby continuous operation and presently, the building peak load is 75 kW.
  - All building electrical loads are connected to the ATS and powered by the standby generator.
  - The capacity of the existing backup generator fuel tank (700 gal) can support 95 hours of standby power before refueling, assuming the fuel tank is completely full at the beginning of an event.
  - For an extended outage / resiliency event of 3 days, the generator system fuel tank need not be refueled during the event if it is completely full at the beginning of an event.
- Building emergency lighting is battery-powered and is not supported by the ATS and emergency generator.

Limitations of Existing Systems in a Resiliency Event

The facility is within the 1% probability of 100-year, 0.1% probability 100-year flood plain and 1% probability of sea level rise and storm surge vulnerability assessment. Refer to Appendix E Flood Planes Maps for detailed maps. The facility is at flooding risk in the event of a failure of the Emelia Erhardt Dam or upriver storm surge. The facility's main electrical room is located on the first floor at grade, within the flood plain. This space contains the utility electric feed and main switchgear. In the event of flooding, the building is at risk of losing all electrical systems.

Standby generator systems are designed to power the entire facility. This provides continuous operation of all critical building functions in the event of a loss of grid power. Under an extended outage scenario, if completely full at the time of an emergency event, the diesel fuel tank has enough capacity for 95 hours of continuous operation before refueling. The duration between refueling is directly proportional to how full the tank is at the start of the event. Additionally, in the event that fuel deliveries were delayed, the facility would have no emergency backup systems, including heat and power, until fuel could be delivered.

Increasing Resiliency at Department of Public Works

Install Energy Storage System

A Battery Energy Storage System (BESS) can be applied here successfully. Based on analysis of building loads and project goals, the battery energy storage capacity that can be afforded with current grant funding is approximately 100 kWh (described further in the following section "Proposed PDR and Resiliency Upgrades"). This BESS capacity will provide approximately 1 hour of battery-only backup power as well as the "grid-forming" capability that is necessary for typical solar PV systems to operate when grid power is unavailable and charge batteries with solar output.

Solar PV does not currently exist at the site, Medford has committed to a solar PPA with Solect and construction is anticipated to begin in June 2018. The solar PV coupled with a BESS could significantly extend off-grid energy between generator diesel fuel deliveries.

Based on the analysis by Medford's Energy and Environment office, solar PV is the best candidate for this site, and wind energy generation is not presently a goal at this location.

Implement Off-Grid Electric Load Management

Effectiveness and discharge duration of battery energy storage system, as well as duration of standby generator backup power before refueling, during a resiliency event is directly impacted by building electric load management. Electric load management for HVAC loads can be implemented through the Building Automation System (BAS) and lighting control systems, using sequences which are similar to those implemented for demand response. This would include turning off the highest power piece of equipment, limiting the load on other HVAC systems and shutting off lights in non-essential areas. In addition to maximizing the generation and storage assets, load management is also critical to ensure that building loads do not exceed the rating of the BESS or the emergency generator capabilities. If loads are not properly managed, these assets could trip offline during an off-grid resiliency event and disrupt shelter activities.

Develop and Implement Flood Mitigation Strategies

Medford needs to create a water barrier deployment strategy in the event of high-flood waters to minimize impact on building systems both when grid power is available and during a grid outage. Water barriers such as sand bags or deployable temporary walls could be kept at a local facility and deployed to the site in the anticipation of a resiliency event. Flood mitigation strategies are recommended because, although this site is located in the 1% flood range, an unpredictable weather event triggering a resiliency response could exceed these ratings.

Proposed PDR and Resiliency Upgrades

Battery Energy Storage System Basis of Design

Battery Energy Storage System Selection

The BESS must be selected based on several key financial to technical criteria, depending on the operating scenario and the building existing conditions. The BESS in this scenario has the following key selection criteria:

Criteria	Basis of Criteria
Optimize cost, discharge kW, discharge duration	Maximize value of resiliency grant to City of Medford and Commonwealth of Mass.

Discharge duration must be a minimum of 2 hours at full resiliency load and 4 hours at 50% load.	Extend off-grid power to support shelter activities during peak resiliency event and capacity for demand response to participate in DR revenue streams.
Battery energy capacity must be sufficient after discharge cycle to form grid for solar PV when available.	If battery is discharged after sun set, solar PV can begin generation again and provide building power/recharge battery when solar energy becomes available.
BESS must be compatible with building electrical systems (208V/3phase/60cycle).	Electrical integration compatibility with existing building systems and infrastructure.
BESS must be in secure outdoor weatherproof enclosure	Increased building fire risk and limited indoor space. Outdoor enclosure must be protected from elements and secured for safety.
BESS must have on-board fire protection system.	Fire emergency suppression system is a necessity for safety precautions.
BESS must be capable of avoiding overload and absorbing current spikes due to equipment cycling.	Overload results in systems trip offline.
Battery Management System (BMS) compatible with common communication protocols, such as BACnet, Modbus, or DNP 3.0.	BMS must be compatible to send and receive communications with System Supervisory Controller for building energy systems management during demand response and resiliency events.

Table 36 BESS selection criteria

Battery Energy Storage System Capacity Analysis

The graph below in Figure 22 DPW Battery Energy Capacity for 3 days (72 hours) shows the relationship between two BESS inverter output power levels and the energy storage capacity required to maintain that output for up to three days (72 hours).

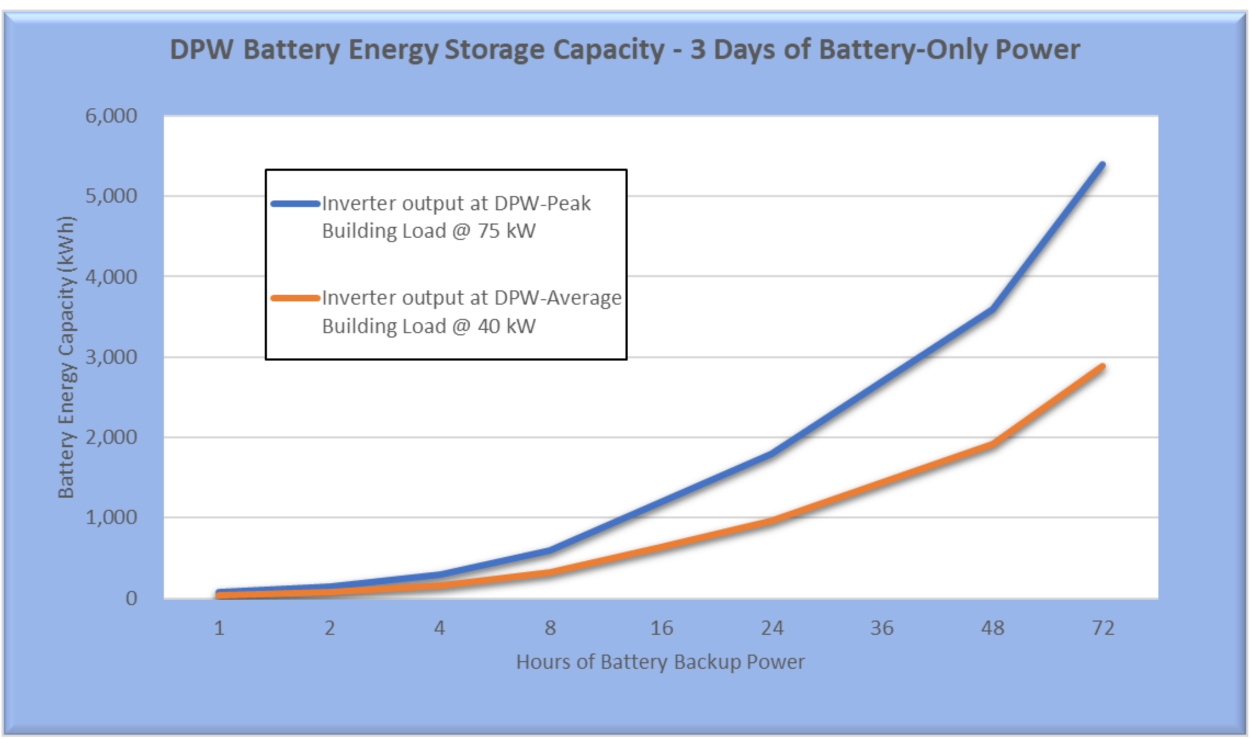

Figure 22 DPW Battery Energy Capacity for 3 days (72 hours) at peak building load and at reduced load of 40kW.

The graph in Figure 23 below displays energy storage capacity up to 8 hours for inverter output power, a magnified view of the lower left side of the graph shown above in Figure 22. Referring back to the Electric Load Analysis section on page 82, DPW's peak load is 75kW, while the average unoccupied load is 40kW. According to the graph, a 250kWh battery could operate at 75kW for approximately three hours, and notably longer at a reduced load of 40kW. A 170kWh battery could accommodate resiliency loads for 2 hours at 75kW and approximately 4 hours at 40kW. The discharge duration is variable depending on the day of the year that the outage occurs, as facility shop equipment operation needs and seasonal weather effects on HVAC loads and resulting electric demand from building equipment. For instance, electric demand from HVAC equipment can vary from a high demand in the peak summer and winter months to reduced demand during the shoulder seasons when cooling and heating systems are more lightly loaded.

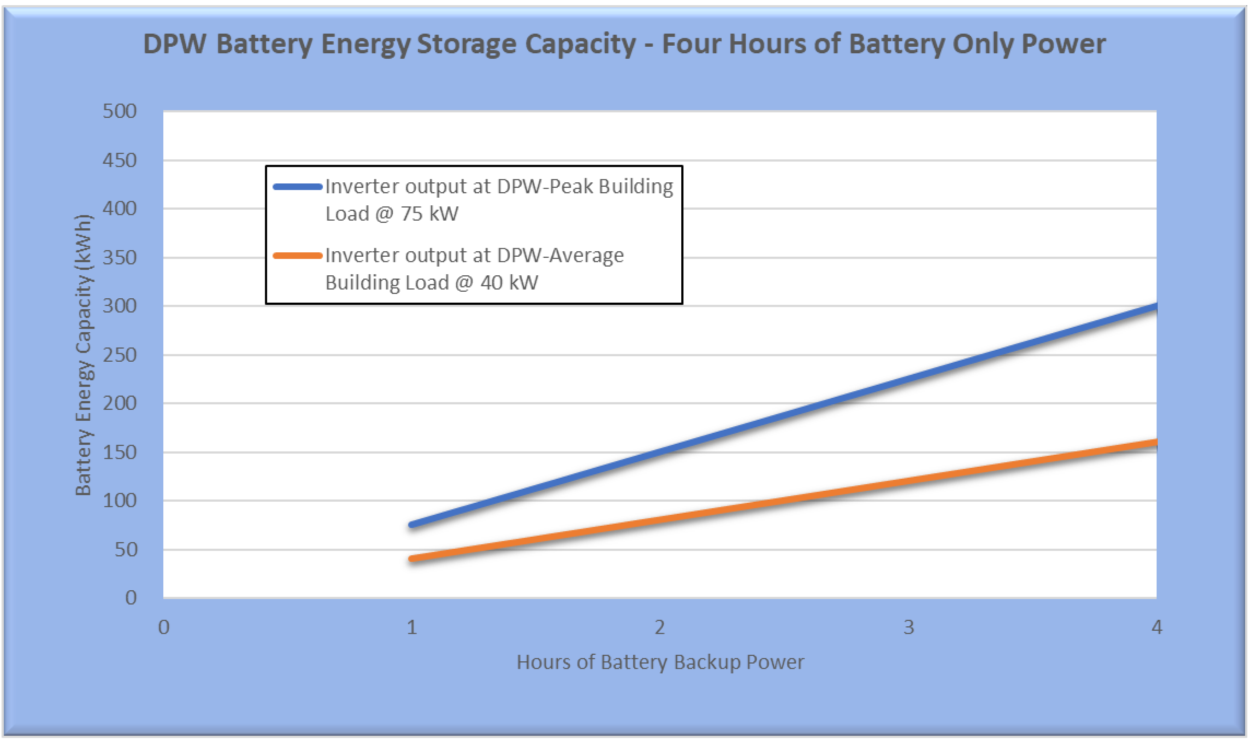

Figure 23 DPW Battery Energy Capacity for 8 hours at peak building load and at reduced load of 40kW.

A parametric comparison was developed to analyze the battery size selection compared to industry trends for installed costs. This can be seen in Figure 24 below. Industry estimates have been provided by Northern Reliability, NEC, and Solect, and are based on total cost of implementation. These vendors estimated the average project total implementation cost for energy storage in general to range from $800/kWh to $1,600/kWh. The total cost of implementation includes the BESS (enclosure(s), inverter(s), energy storage cells, battery management system, environmental controls, and fire suppression system), System Supervisory Controller (including associated programming and interfaces with subsystem controllers), soft costs (design, commissioning, construction administration and oversight, project management), and electrical modifications or upgrades.

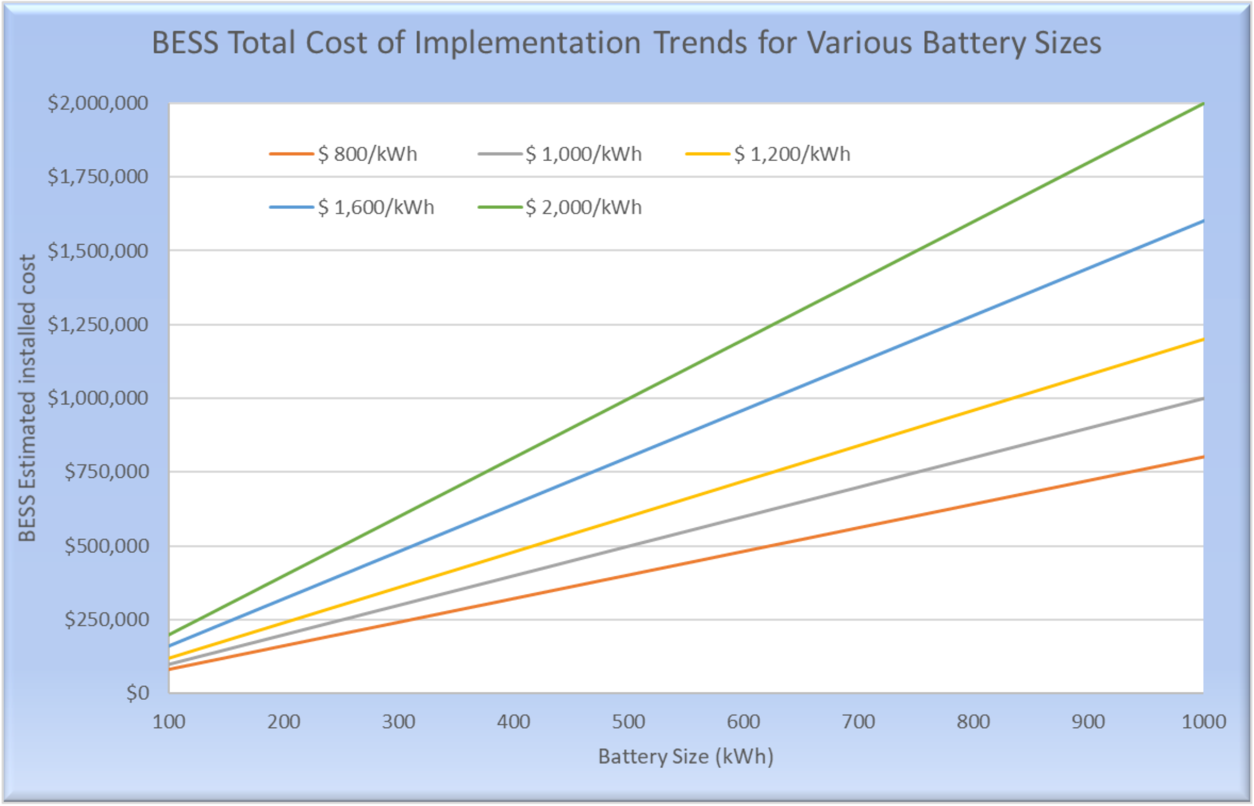

Figure 24 Battery Energy Storage System total implementation cost for various battery sizes

Battery System Selection and Discussion

The battery system energy storage capacity which meets all project goals is 250kWh, based on the electric load and resiliency analysis presented earlier. To summarize, the selection criteria is as follows:

- The 250kWh battery could provide a minimum of 3 hours of battery-only power during a grid outage. However, there is currently not enough funding to support a 250kWh battery. Current funding is estimated to support approximately a 85kWh battery if grant funding is shared with the Andrews school, or a 170kWh battery if the allocated grant funding for the DPW is used completely at this site.
- Inverter should be rated for a minimum of 100 kW instantaneous power and 75 kW for continuous use to meet building loads, and in particular the inrush current of electric motors starting on compressors and fans.
- During a resiliency event, the actual duration of a single charge of the battery energy system is heavily dependent on managing facility loads during this period, for example if building loads could be maintained at or less than 40 kW using energy management strategies, discharge duration of an 85kWh battery could increase from one hour to two hours. Under the same reduced load scenario, larger energy storage capacities of 170kWh or 250kWh could be extend off-grid battery-only power to 4 and 6 hours, respectively.
- In order to participate in demand response programs, the battery must deliver load reduction for a minimum 4 hours for demand response. Therefore, the BESS participating in demand response programs could offset 15kW for an 85kWh battery, 30kW for a 170kWh battery, and 50kW for a 250kWh battery. This assumes starting from a fully charged state, a four-hour discharge period, and that approximately 20% charge is maintained as reserve.

- The 389kWh originally proposed by the CCERI grant documents appears to be more than needed to accommodate this facility's loads and provide the grid-forming necessary to utilize solar PV in an off-grid scenario. This energy storage capacity is greater than required to meet the CCERI grant project goals.

Building Electric Load Management for Demand Response

HVAC Load Management for Peak Demand Response

HVAC load management for Demand Response (DR) can be implemented with BAS programming only. The demand response sequences will shed load upon the automatic signal from the ADR signal receiver/controller. DPW has three levels of Peak Demand Response. These levels are given below, and the estimated electric load reduction possible from each DR level is shown in Table 37.

- *High DR level*:
  - During this level the ERV unit supply fan shall be controlled not to exceed a maximum speed of 75% (adj.)
  - RTU DX Cooling Discharge Air Temperature (DAT) Setpoint raised to 54°F(adj.)
  - Reset all terminal device space temperature cooling setpoints to 78 °F (adj.).
- *Medium DR level:*
  - During this level the ERV unit supply fan shall be controlled not to exceed a maximum speed of 75% (adj.)
  - RTU DX Cooling Discharge Air Temperature (DAT) Setpoint raised to 52°F(adj.)
  - Reset all terminal device space temperature cooling setpoints to 76 °F (adj.).
- *Low DR level:*
  - During this level the ERV unit supply fan shall be controlled not to exceed a maximum speed of 75% (adj.)
  - RTU DX Cooling Discharge Air Temperature (DAT) Setpoint raised to 50°F(adj.)
  - Reset all terminal device space temperature cooling setpoints to 74 °F (adj.).

DPW - HVAC DR Savings			
Equipment/DR level	Low	Medium	High
Name	*kW*	*kW*	*kW*
ERV	5.40	5.40	5.40
RTU - DX	0.34	0.67	1.01
Total	**5.74**	**6.07**	**6.41**

Table 37 Demand Response Level savings for major equipment at DPW at various levels of load reduction

Facility Lighting Controls Programming Upgrade for Peak Demand Response

DPW facility currently has switchable (non-dimmable) LEDs and these LEDs are controlled through two Lighting Control panels. The scope of this project includes reprogramming the Lighting Control panels LCP1 and LCP2 and connection to the BAS for automatic control. These panels and their associated controlled areas are:

- LCP 1: Controls Exterior lighting like wall packs, flagpoles and light poles.
- LCP 2: Controls Interior Lighting in areas namely maintenance garage, vehicle storage and wash bay areas.

The energy conservation and demand reduction capabilities of the LEDs and reprogrammed lighting control system will be utilized in both automated demand response and resiliency events.

DPW Lighiting Zones - Demand Repsonse						
LCP Panel	PP Panel Circuit #	Fixture Type	Purpose	Fixture Quanity	Fixture Wattage	DR Mode (1 = On, 0 = Off)
LCP 1	PP1 106,108	F103A	DPW Flagpole Lighitng	1	42	1
LCP 1	PP1 62,64	F100	Exterior Wallpacks	13	74	1
LCP 1	PP1 70,72	P1-HS	North/West Site Light Poles	2	68	1
LCP 1	PP1 70,72	P2	North/West Site Light Poles	2	136	1
LCP 1	PP1 70,72	P3	North/West Site Light Poles	1	204	1
LCP 1	PP1 74,76	P1	North/West Site Light Poles	1	68	1
LCP 1	PP1 74,76	P1-HS	North/West Site Light Poles	4	68	1
LCP 2	PP5 1,3	F100	Exterior Wallpacks	9	74	1
LCP 2	PP5 10,12	F6	Vehicle Storage lighting	4	245	0
LCP 2	PP5 10,12	F6E	Vehicle Storage lighting	5	245	1
LCP 2	PP5 13,15	F101	Exterior Wallpacks	3	158	1
LCP 2	PP5 14,16	F6	Vehicle Storage lighting	8	245	0
LCP 2	PP5 18,20	F6	Vehicle Storage lighting	3	245	1
LCP 2	PP5 18,20	F6E	Vehicle Storage lighting	3	245	1
LCP 2	PP5 2,4	F6	Vehicle Storage lighting	8	245	1
LCP 2	PP5 22,24	F6	Vehicle Storage lighting	3	245	0
LCP2	PP5 22,24	F6E	Vehicle Storage lighting	3	245	1
LCP 2	PP5 30	F5	EM W&S bay Lighitng	4	80	1
LCP 2	PP5 30	F6	EM W&S bay Lighitng	2	245	0
LCP2	PP5 34	F3	Mezzanine Corridor Lighitng	14	41	1
LCP 2	PP5 41	F6	Lighitng Maintenance Garage	4	245	0
LCP 2	PP5 41	F6e	Lighitng Maintenance Garage	2	245	1
LCP 2	PP5 43	F6	Lighitng Maintenance Garage	2	245	0
LCP 2	PP5 43	F6e	Lighitng Maintenance Garage	3	245	1
LCP 2	PP5 45	F6	Lighitng Maintenance Garage	5	245	1
LCP 2	PP5 45	F6e	Lighitng Maintenance Garage	0	245	1
LCP 2	PP5 47	F5	Lighitng Maintenance Garage	3	80	0
LCP 2	PP5 47	F6	Lighitng Maintenance Garage	2	245	0
LCP 2	PP5 47	F6e	Lighitng Maintenance Garage	3	245	1
LCP 2	PP5 49	F7	Wash Bay Lighitng	4	160	0
LCP 2	PP5 49	F7E	Wash Bay Lighitng	2	160	1
LCP 2	PP5 5,7	F100	Exterior Wallpacks	3	74	1
LCP 2	PP5 55	F5	Ebu's vehicle Storage	5	80	0
LCP2	PP5 55	F5E	Ebu's vehicle Storage	10	80	1
LCP 2	PP5 6,8	F6	Vehicle Storage lighting	5	245	1
LCP 2	PP5 6,8	F6E	Vehicle Storage lighting	4	245	0
LCP 2	PP5 9,11	F101	Exterior Wallpacks	10	158	1

Table 38 Table showing various Lighting Zones and their operation during demand response mode at DPW

During a demand response event, every other row of lights is shutoff in Vehicle Storage, Lighting Maintenance Garage, Ebu's vehicle Storage and EM W&S bay Lighting as shown in Table 38. It is estimated that 4.2kW could be saved by shutting off these areas.

HVAC and Lighting Load Management for Resiliency Mode

When the lighting control system receives the resiliency mode signal from the BAS, all lighting loads shall be on to support critical facility operations and HVAC shall operate as normal to support critical operations. Depending on the anticipated length of outage, peak demand response sequences could be used to extend battery system backup power duration by approximately 10-20%.

Solar Photovoltaic Systems

Medford's PPA with Solect will install approximately 180kW of solar PV at the DPW. At 50% of system output, the solar array could charge the BESS at a rate of approximately 90kWh per hour of charging. During a resiliency event, if sufficient solar energy is available, the solar energy would be the first source of power for the facility. In the event that there is insufficient solar available to pick up the entire building load, then the standby generator would operate to meet the load and to charge the batteries.

System Controls and Asset Management

System Supervisory Controller

The System Supervisory Controller (SSC), acting as a microgrid controller, provides system control and monitoring and performs the duties of a master controller with logic programmed to direct all modes of operation. The SSC is a critical component for building-level resiliency systems and larger microgrids, in order to manage multiple energy generation and/or storage assets operating together during each operating mode. The operating modes of the SSC at the Department of Public Works include but are not limited to:

- Normal Operation (NO) when the utility Electric Service Provider (ESP) power is available;
- Standby Operation (SO) when the utility (National Grid) ESP power is not available (islanding mode);
- Automated Demand Reduction (ADR) during Normal Operation based on an external signal;
- Peak Shaving during Normal Operation for the purpose of lowering monthly demand costs ;
- Power Management during all modes of operation including management of power to and from the Battery Energy Storage System (BESS) during NO and SO; and the BESS and Standby Generator (SG) and Solar PV Inverter System (PVIS) during SO.

The SSC is a Programmable Logic Controller (PLC), capable of multiple communication protocols for interfacing with each generation and storage asset, external communications, and other building systems. At the DPW, the SSC will interface with the solar PV control system, BESS control system, standby generator controls, utility main disconnect and automatic transfer switches, the BAS and lighting control system for load management, the automated demand response system, and the Monitoring-Based Commissioning (MBCx) system for data acquisition.

Automated Demand Response

The building SSC shall receive the automated demand response (ADR) signal from CPower, the Curtailment Service Provider, via the Energy IQ's CPower Link ADR signal receiver/controller. The ADR signal will be initiated by CPower for a Real-Time Demand Response event from ISO-NE, a National Grid Connected Solutions event, and for a Cap Tag management event (a CPower program). The impact and details of these programs are described later in the Demand Response Revenue Streams section of this report.

The SSC will interface with both the Energy IQ ADR signal receiver/controller, the BAS which controls the HVAC systems, and the lighting control system. When the ADR signal is received, the SSC will initiate demand response sequences in the battery management system (BMS), BAS, and the lighting control system. Due to the project phasing, the ADR signal will be directly sent to the BAS and lighting controls in phase 1. These connections may remain in place or may be transferred to the SSC when it is installed in phase 2.

Monitoring-Based Commissioning (MBCx)

MBCx will be used at the DPW to monitor the HVAC equipment through the BAS to optimize the energy performance of the building HVAC system. Analytics will be deployed to identify problems that could cause wasted energy and operational issues. In addition to the energy use (kWh or therms) costs associated with HVAC problems, MBCx is indirectly valuable for demand management and demand response as a broken fan VFD or damper or other problem could significantly reduce potential DR revenues. It is also valuable for resilient buildings, as a similar problem undetected could cause excessive energy use and deplete energy storage and fuel reserves. Resilient buildings and microgrids should use MBCx to continuously optimize energy performance to maximize the impact of their resilient systems and infrastructure.

FacilityConneX will be used at the DPW as the MBCx system. FacilityConneX is a communications integrator, and the software can capture data from the BAS, SSC, ADR, lighting controls and other systems. In addition to the energy analytics deployed on the HVAC system FacilityConneX will capture data from the SSC for aggregation and visualization.

DEMAND RESPONSE REVENUE STREAMS AND SAVINGS IMPACT

DEMAND RESPONSE LOAD REDUCTION

The demand response savings shown below in Table 39 are developed based on the existing schedule of operations and are based on the “Medium” peak demand response level. The batteries are scheduled to be installed early 2019 and both HVAC upgrades are scheduled to be completed by mid-2018.

Demand Response Summary						
Facility - Season	H&V Units	ACCUs	Pumps	Lighting	Batteries	**Total**
	kW	*kW*	*kW*	*kW*	*kW*	***kW***
DPW - Summer	5.4	0.7	0.0	4.2	15.0	**25.3**
DPW - Winter	5.4	0.0	0.0	4.2	15.0	**24.6**

Table 39: Peak demand response load shedding capacity at DPW for both Summer and Winter Peak periods

DEMAND RESPONSE PROGRAM REVENUES

City of Medford has enrolled Department of Public Works to participate in the demand response programs mentioned below through Automated Demand Response (ADR) through curtailment service provider (CSP). Curtailment service provider is a company authorized to act as interface party between the Independent service operator (in this case ISO-NE) and end-use customer (in this case City of Medford) to deliver demand response capacity. The CSP provides advance notice of when curtailment request is likely to be made. Following the curtailment, the CSP works with the grid operator to identify how much power was reduced by the customer, what the prevailing rates for electricity were during that time and how much revenues are generated. The CSP charges 35% of the overall revenue generated as service charge and the remaining 65% of the overall revenue goes to the customer as the revenue generated. The demand response revenue streams considered below are:

- Real Time-Demand Response (RTDR) program
- Connected Solutions – a National Grid demand response program
- Peak Demand Management (Cap-Tag) program – Cpower Supply Capacity Charge Management

These programs explained in detail in the glossary section of the report. In order for the DPW to take advantage of the Cap-Tag program, the supply contract must be restructured to pass the annual supply capacity charges through to the customer. Please also note that the analysis is performed assuming the Base Project 85kWh battery is installed. Demand response value from the BESS could increase considerably is a larger capacity system is installed.

REAL-TIME DEMAND RESPONSE

The Real-Time Demand Response (RTDR) program revenue is based on demand savings each month when an event is called. Real time demand response program offsets rising energy costs with revenue earned from using less energy when the grid is stressed. ISO-NE's Real Time Demand Response program pays customers to curtail energy on short notice when the ISO-NE grid is due to unforeseen circumstances. The participant receives payment based on a winter and a summer test, adjusted based on the facility's actual demand reduction during a demand response event. The participation events can be called Summer Season (Jun-Nov, Apr-May) and Winter Season (Dec-Mar) during each Program Year (Jun-May). The program guidelines include a minimum load reduction of 100 kW (which can be aggregated for a customer over multiple accounts), and load curtailment events can last for several hours. The scenario presented below in Table 40 shows the revenues from RTDR program for demand response events. In 2018, only HVAC and lighting load shedding can be performed. Starting in 2019 and thereafter the battery systems will be available for peak demand response to offset building loads.

RTDR							
Program Revenues for Real-Time Demand Response							
Forward Capacity Market Year	Description	Summer kW (8 months)	Winter kW (4 months)	FCM Price $/kW-mth	Program Gross Revenue	Customer Share %	Annual $
06/1/2018 - 05/31/2019	BAS and Lighting DR	10.3	9.6	$9.55	$1,150	65%	$748
06/1/2019 - 05/31/2020	Batteries, BAS and Lighting DR	25.3	24.6	$7.03	$2,112	65%	$1,373
06/1/2019 - 05/31/2021	Batteries, BAS and Lighting DR	25.3	24.6	$5.30	$1,592	65%	$1,035
3- Year Total					**$4,855**		**$3,156**

Table 40: DPW – Real-Time Demand Response Program revenues

CONNECTED SOLUTIONS

Connected Solutions is National Grid's demand response program, where participating customers are working to lower the amount of total energy used during the summer months when demand for electricity on the grid is at its highest (peak demand). The program is anticipated to call 20 hours of events per year with the longest duration of a single DR event being 4 hours. The connected solutions demand response program has revenues based on the highest peak period and curtailed load for each event. **Error! Reference source not found.** below presents potential annual revenues assuming five events, each for a four-hour duration.

Connected Solutions		
Program Revenues for National Grid Demand Reponse Program		
Capacity payment	$20	per kw per year
Performance Payment	$0.75	per kWh during DR
Total DR Event Hours	20.0	hours
Curtailed Load	25.3	kW
Customer Share	65%	%
Total Incentive/Year	$575	$

Table 41: DPW- Revenues from National Grid's Connected Solutions demand response program

Cap-Tag

The Cap-Tag demand response program is offered by CPower to manage the supply capacity charge on the day it is set (day of highest peak load on regional utility grid). Cap-Tag revenue is not available to Medford based on their existing supply contract. However, the kW savings value shown in Table 42 assumes the BESS and associated demand response load-offset capacity is not online or available until 2019. CPower anticipates the day and time that the annual demand capacity charge is set and dispatches a Cap-Tag event to curtail load during this period. The Andrews school cannot take advantage of the Cap-Tag program unless the electric supply contract is renegotiated to pass through the annual demand capacity charge to Medford.

Cap Tag					
Program Revenues for Peak Demand Management (Cap-Tag) Program					
Cap-Tag is set for Summer of this Year	ISO-NE Zone	Cap Tag Power Year	Cap-Tag Value $/kW	kW Savings	Annual Savings $
2018	NEMA	2019-2020	$81.00	10.3	$831
2019	NEMA	2020-2021	$63.60	25.3	$1,607
2020	NEMA	2021-2022	$55.57	25.3	$1,404
3- Year Total					**$3,842**

Table 42: DPW- Revenues from peak demand management program (Cap - Tag)

Peak Shaving

Peak shaving is a technique that is used to reduce electrical power consumption during peak periods of to manage utility costs and create energy cost-savings. Assuming 15kW is reduced consistently each month for 12 months using battery energy storage, the DPW could save approximately $1,530 in avoided annual energy cost. Peak shaving could not utilize lighting and HVAC for load shedding due to the frequency of load shed (every day) for peak shaving. Peak shaving is also incompatible with demand response programs, as the consistent peak shave will reduce the baseline demand and limit the impact of demand response strategies when an event is called. Peak shaving is also not compatible with batteries that are used for resiliency purposes due to the high cycling frequency.

Energy Arbitrage

At DPW, in order to utilize energy arbitrage cost savings, DPW utility account rate needs to be modified to time-of-use account (G-3 utility tariff) account. Currently the DPW utility account is on G-2 tariff rate and in this account the distribution costs are same for both on-peak and off-peak periods. Based on the analysis, changing utility rate tariff structures is not recommended for the DPW because there is limited financial benefit for this facility. Energy arbitrage is also not compatible with batteries that are used for resiliency purposes due to the high cycling frequency.

Peak Demand Economic Summary

The results of the investigation show that for this facility, participating in peak demand response programs through a CSP generates revenue for the City. Demand response programs provides a positive revenue stream to the city for participating, while peak shaving results in avoided electric demand and energy costs. Presently, there is no advantage to energy arbitrage, as it is incompatible with batteries used for resiliency purposes. Arbitrage would only become lucrative if the city obtained a new supply contract with a very low off-peak rate. Peak shaving also has less value than participating in demand response programs and is incompatible with batteries used for resiliency purposes. The Table 43 below summarizes the value of the peak demand opportunities examined over a three-year value stream.

Value of Demand Response Programs at DPW				
Demand Response Path	Year 1 Value	Year 2 Value	Year 3 Value	**Total 3-year Value**
Real-Time Demand Response[1]	$748	$1,373	$1,035	**$3,156**
National Grid Connected Solutions	$575	$575	$575	**$1,724**
Cpower Cap-Tag Management[2]	$831	$1,607	$1,404	**$3,842**
Potential Combined Revenues				**$8,722**

Notes:

1 RTDR and Peak Shaving are mutually exclusive.

2 In order to take advantage of the Cap-Tag program, Medford must negotiate a new supply contract that passes supply capacity charges through to the city.

Table 43 Potential three-year Demand Response program revenue at DPW.

The recommended option is to participate in as many DR programs provided by the CSP as possible. B2Q also recommends that Medford renegotiate the DPW electric supply contract to pass through demand capacity charges to the city so that they can manage that cost and create additional revenue through the Cap-Tag management program provided by CPower. Medford should also determine if this can be accomplished with the electric supplier without changing the distribution rate structure with National Grid.

Table 44 shows the economic payback summary of the demand response technologies for the DPW. The overall demand revenues make the project attractive, particularly when considered with the other benefits of improving operator control of the lighting systems and the increased energy resiliency. The return on investment is calculated using the incremental project cost and a 3-year average of DR revenues. The incremental project costs assume the base technology is already installed and represents the cost of the changes needed to add and automate the demand response capacity. These incremental costs are estimates, developed from vendor estimates and proposals.

DPW Demand Response Technologies Economic Summary							
Demand Response Technology	**Summer Demand Savings**	**Winter Demand Savings**	**DR Average Annual Program Revenues**	**Technology Implementation Cost/kW**	**Incremental Project Cost**	**Payback on DR Revenues**	**ROI**
	kW	kW	$	$/kW	$	yrs	%
HVAC Upgrades	6.1	5.4	$984	$436	$5,000	5.1	20%
Lighting Upgrades	4.2	4.2	$690	$596	$5,000	7.2	14%
Battery Energy Storage System (BESS)	15.0	15.0	$2,470	$333	$10,000	4.0	25%
TOTAL	**25.3**	**24.6**	**$4,145**	**$1,366**	**$20,000**	**4.8**	**21%**

Table 44 : DPW Demand Response Technologies Revenues Economic Summary. Note: The project costs represent incremental costs for the BAS, Lighting controls, and BESS to implement automated demand response.

PROJECT COSTS

RESILIENCY PROJECT COSTS AND FUNDING

The resiliency project costs at DPW are within the funding allocated for a battery system of a capacity that can make an impact in off-grid operations at the facility. However, the funding is not sufficient to achieve all project goals. This is primarily due to the low cost/kWh ($400/kWh) for the energy storage system that was assumed to develop funding structure, as shown earlier in this report. Therefore, in order to meet all of the project goals, additional funding is required. The estimated project costs for various energy storage capacities can be seen in Table 45 below.

DPW Energy Storage Capacity and Resiliency Project Costs

	Energy Storage Capacity	Battery-Only Off Grid Duration[2]	Opinion of Project Cost	All-In Cost per kWh Installed	Estimated Funding Increase Required[3]
Description	**kWh**	**hours**	**$**	**$/kWh**	**$**
Base Project[1]	85	1	$343,084	$4,036	--
Increased Off-Grid Backup	170	2	$422,638	$2,486	--
Meets All Project Goals	250	3	$487,497	$1,950	$29,146
CCERI Documents Allocation	389	5	$555,809	$1,429	$97,459

Notes

1 Base Project does not account for any costs shifted between sites.

2 Battery-Only Off Grid Duration assumes that the battery is fully charged and under peak resiliency loads for each project site.

3 Estimated Funding Increase Required does not include any contingency.

Table 45 DPW Energy Storage and Resiliency Project costs for various energy storage capacities

The graph below in Figure 25 presents the opinion of probable cost for each option compared to the industry trends. One important take-away is that the electrical modifications required at Andrews to support resiliency operations push the energy storage system cost into a higher cost/kWh range. BESS costs have been developed by obtaining estimates from Northern Reliability, NEC, and Solect. It is noteworthy that as the BESS energy storage capacity increases, the cost per kWh of energy storage is reduced. This is in part because the costs associated with all electrical work to integrate the BESS with the building and to connect to DERs are fairly fixed.

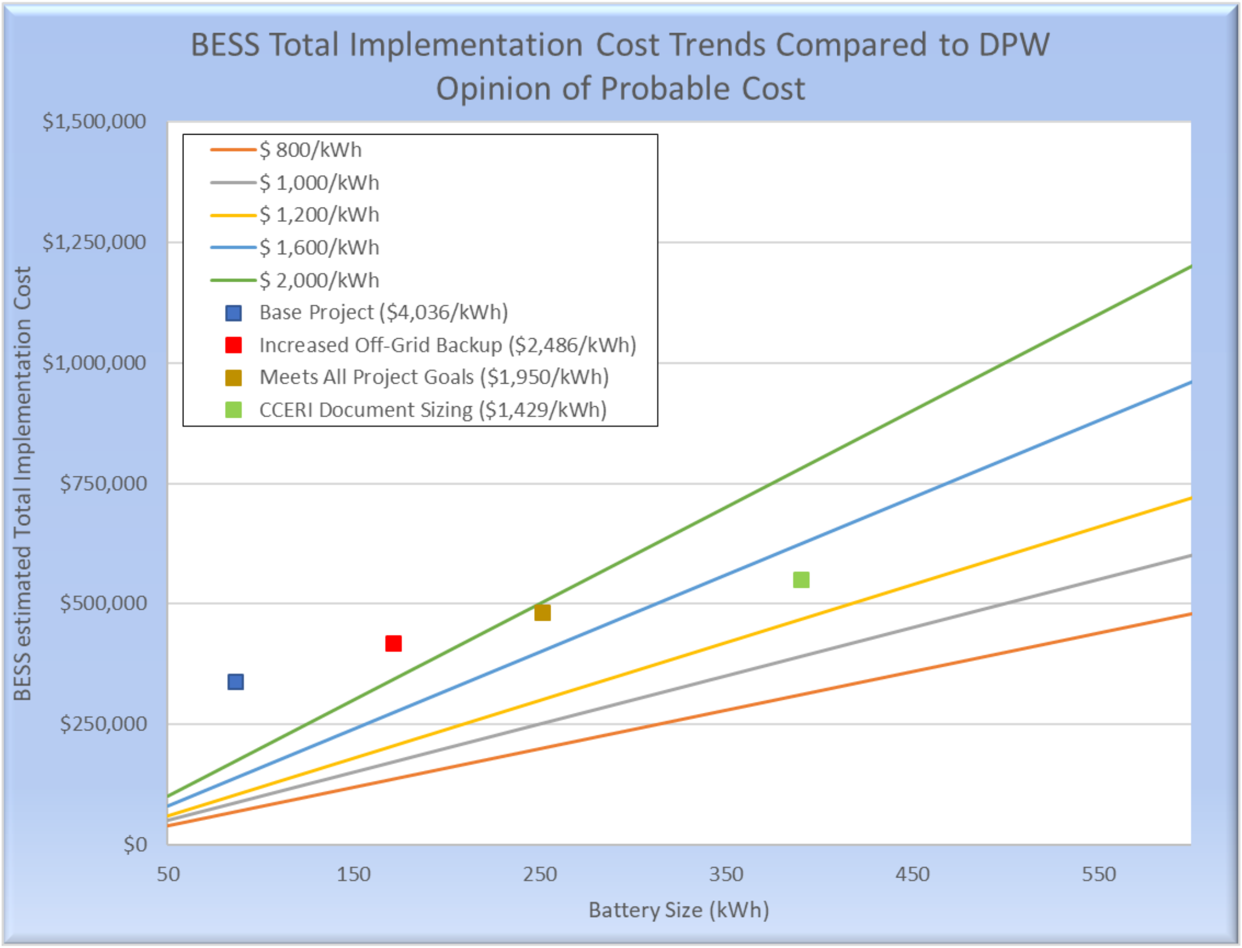

Figure 25 BESS cost trends vs DPW BESS opinion of probable cost for various energy storage capacities.

INTEGRATED PROJECT COST

Figure 26 on the following page shows the Opinion of Probable Cost for the integrated Base Project with a 85kWh energy storage capacity. Cost data was provided by various sources, as noted in the table. Vendors who provided cost information or firm quotes included: Northern Reliability, NEC, Solect, EnergyIQ, ENE Systems, CPower, and Energy Source. The Funding column in the estimate indicates the budget allocated for each line item with "R" for CCERI Grant and "PD" for the Peak Demand Grant. The integrated project opinion of probable cost is a comprehensive view of all costs associated with this pilot project. Opinions of Probable cost for other energy storage capacities presented in Table 45 above can be found in Appendix A. The DOER's State of the Charge Report references maintenance costs of $10/kW-year, while NREL's 2015 Economic Analysis Case Studies of Battery Energy Storage assumes[7] $20/kW-year. Using these estimates, the projected annual maintenance costs are expected to be in the range of $1,000 - $2,000 for a project of this size. Based on discussions with vendors, it is assumed that 10 years of annual maintenance is included in the cost of the BESS.

[7]National Renewable Energy Laboratory. DiOrior, Nicholas; Dobos, Aron; Janzou, Steven: "Economic Analysis Case Studies of Battery Energy Storage with SAM". Available at https://www.nrel.gov/docs/fy16osti/64987.pdf

Opinion of Probable Construction Cost

DPW RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT

B2Q Associates, Inc.	Customer:	City Of Medford		
100 Burtt Rd. Ste. 212	Address:	21 James St	Created by:	JD
Andover, MA 01810		Medford, MA 02155	Checked by:	
(978) 208 - 0609				

General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$14,628	$14,628
2	R	2	Installation Labor	ea	1	$17,553	$17,553
3	R	2	Pad and Site Work	ea	1	$10,824	$10,824
4	R	2	Galvanized Chain Link Fence	ea	1	$3,218	$3,218
5	R	2	Battery Package 100kW/85kWh	ea	1	$85,560	$85,560
6	R	2	Microgrid Controller	ea	1	$35,000	$35,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$203,806**
Battery Energy Storage System - Engineering and Procurement							
9	R	1	Battery Procurement	ea	1	$4,000	$4,000
10	R	1	Feasibility Study	ea	1	$32,728	$32,728
11	R	1	Design and Bid	ea	1	$39,550	$39,550
12	R	1	Commissioning Agent	ea	1	$8,000	$8,000
13	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
14	R	5	BESS Package Provider Commissioning and Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
15	PD	1	Automated DR Controller & Setup		1	$6,950	$6,950
16	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
17	PD	1	Facility ConneX - MBCx	ea	1	$3,738	$3,738
18	PD	3	BAS Peak Demand Strategy Programming and Integration	ea	1	$10,000	$10,000
19	PD	3	Lighting Systems Integration to BAS	ea	1	$10,000	$10,000
20	PD	3	Recommissioning Fixes Budget	ea	1	$5,000	$5,000
						Subtotal	**$38,188**
Demand Response and Energy Systems Integration - Engineering and Procurement							
21	PD	1	Peak Demand Response Systems Engineering	ea	1	$4,650	$4,650
22	PD	1	Peak Demand Response PM/CA	ea	1	$8,900	$8,900
23	PD	1	Peak Demand Response Systems Commissioning	ea	1	$3,250	$3,250
						Subtotal	**$16,800**

Sources	
1	Vendor Firm Quote
2	Vendor Budget Quote
3	B2Q Grant Budget
4	CCERI Grant Documents
5	Other
Funding	
R	DOER Resiliency Grant
PD	DOER Peak Demand Grant

Notes

1) Project Labor based on prevailing wage rates for trades.

Grand Total Resiliency & Peak Demand Project **$398,072**

Figure 26 Opinion of Probable Cost for integrated Resiliency and Peak Demand Response project at the DPW.

APPENDIX A – OPINION OF PROBABLE COSTS PROJECT WITH VARYING ENERGY STORAGE CAPACITY

ANDREWS SCHOOL – 250KWH ENERGY STORAGE CAPACITY

Opinion of Probable Construction Cost							
ANDREWS SCHOOL RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT							
B2Q Associates, Inc. 100 Burtt Rd. Ste. 212 Andover, MA 01810 (978) 208 - 0609			Customer: Address:	City Of Medford 3000 Mystic Valley Parkway Medford, MA 02155		Created by: Checked by:	JD
General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$21,942	$21,942
2	R	2	Installation Labor	ea	1	$26,330	$26,330
3	R	5	Pad and Site Work	ea	1	$11,947	$11,947
4	R	2	Galvanized Chain Link Fence	ea	1	$4,827	$4,827
5	R	2	Battery Package 100kW/255kWh	ea	1	$188,212	$188,212
6	R	2	Microgrid Controller	ea	1	$40,000	$40,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$330,280**
Building Resiliency Upgrades							
9	R	6	Electrical Demolition	ea	1	$5,000	$5,000
10	R	6	Install New ATS	ea	1	$25,000	$25,000
11	R	6	Recircuiting: Intercept Circuits and Route to New ATS	ea	22	$2,000	$44,000
12	R	6	Recircuiting: Intercept Panels and Route to New ATS	ea	3	$10,000	$30,000
						Subtotal	**$104,000**
Battery Energy Storage System - Engineering and Procurement							
13	R	1	Battery Procurement	ea	1	$4,000	$4,000
14	R	1	Feasibility Study	ea	1	$32,728	$32,728
15	R	1	Design and Bid	ea	1	$39,550	$39,550
16	R	1	Commissioning Agent	ea	1	$8,000	$8,000
17	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
18	R	6	BESS Package Provider Commissioning & Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
19	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
20	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
21	PD	1	Facility ConneX - MBCx	ea	1	$14,953	$14,953
22	PD	1	BAS Peak Demand Strategy Programming and Integration	ea	1	$60,000	$60,000
23	M	3	LED Lighting Upgrades	ea	1	$265,000	$265,000
24	PD	3	Lighting Controls and Integration	ea	1	$90,000	$90,000
25	PD	1	Lighting Bid, Cx, and PM	ea	1	$11,853	$11,853
26	PD	3	Recommissioning Fixes Budget	ea	1	$18,000	$18,000
						Subtotal	**$469,256**
Demand Response and Energy Systems Integration - Engineering and Procurement							
27	PD	1	Peak Demand Response Systems Engineering	ea	1	$12,450	$12,450
28	PD	1	Peak Demand Response PM/CA	ea	1	$18,900	$18,900
29	PD	1	Peak Demand Response Systems Commissioning	ea	1	$6,950	$6,950
						Subtotal	**$38,300**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Consultant Opinion of Cost	
6	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	
M	City of Medford	Grand Total Resiliency & Peak Demand Project **$1,081,114**

ANDREWS SCHOOL – 389KWH ENERGY STORAGE CAPACITY

Opinion of Probable Construction Cost

ANDREWS SCHOOL RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT

B2Q Associates, Inc.	Customer:	City Of Medford	
100 Burtt Rd. Ste. 212	Address:	3000 Mystic Valley Parkway	Created by: JD
Andover, MA 01810		Medford, MA 02155	Checked by:
(978) 208 - 0609			

General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$29,256	$29,256
2	R	2	Installation Labor	ea	1	$35,106	$35,106
3	R	5	Pad and Site Work	ea	1	$11,947	$11,947
4	R	2	Galvanized Chain Link Fence	ea	1	$6,436	$6,436
5	R	2	Battery Package 100kW/389kWh	ea	1	$253,482	$253,482
6	R	2	Microgrid Controller	ea	1	$40,000	$40,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$413,250**
Building Resiliency Upgrades							
9	R	6	Electrical Demolition	ea	1	$5,000	$5,000
10	R	6	Install New ATS	ea	1	$25,000	$25,000
11	R	6	Recircuiting: Intercept Circuits and Route to New ATS	ea	22	$2,000	$44,000
12	R	6	Recircuiting: Intercept Panels and Route to New ATS	ea	3	$10,000	$30,000
						Subtotal	**$104,000**
Battery Energy Storage System - Engineering and Procurement							
13	R	1	Battery Procurement	ea	1	$4,000	$4,000
14	R	1	Feasibility Study	ea	1	$32,728	$32,728
15	R	1	Design and Bid	ea	1	$39,550	$39,550
16	R	1	Commissioning Agent	ea	1	$8,000	$8,000
17	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
18	R	6	BESS Package Provider Commissioning & Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
19	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
20	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
21	PD	1	Facility ConneX - MBCx	ea	1	$14,953	$14,953
22	PD	1	BAS Peak Demand Strategy Programming and Integration	ea	1	$60,000	$60,000
23	M	3	LED Lighting Upgrades	ea	1	$265,000	$265,000
24	PD	3	Lighting Controls and Integration	ea	1	$90,000	$90,000
25	PD	1	Lighting Bid, Cx, and PM	ea	1	$11,853	$11,853
26	PD	3	Recommissioning Fixes Budget	ea	1	$18,000	$18,000
						Subtotal	**$469,256**
Demand Response and Energy Systems Integration - Engineering and Procurement							
27	PD	1	Peak Demand Response Systems Engineering	ea	1	$12,450	$12,450
28	PD	1	Peak Demand Response PM/CA	ea	1	$18,900	$18,900
29	PD	1	Peak Demand Response Systems Commissioning	ea	1	$6,950	$6,950
						Subtotal	**$38,300**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Consultant Opinion of Cost	
6	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	
M	City of Medford	Grand Total Resiliency & Peak Demand Project **$1,164,083**

ANDREWS SCHOOL – 425KWH ENERGY STORAGE CAPACITY

Opinion of Probable Construction Cost							
ANDREWS SCHOOL RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT							
B2Q Associates, Inc.		Customer:	City Of Medford				
100 Burtt Rd. Ste. 212		Address:	3000 Mystic Valley Parkway			Created by:	JD
Andover, MA 01810			Medford, MA 02155			Checked by:	
(978) 208 - 0609							
General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$29,256	$29,256
2	R	2	Installation Labor	ea	1	$35,106	$35,106
3	R	5	Pad and Site Work	ea	1	$11,947	$11,947
4	R	2	Galvanized Chain Link Fence	ea	1	$6,436	$6,436
5	R	2	Battery Package 100kW/425kWh	ea	1	$273,064	$273,064
6	R	2	Microgrid Controller	ea	1	$40,000	$40,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$432,832**
Building Resiliency Upgrades							
9	R	6	Electrical Demolition	ea	1	$5,000	$5,000
10	R	6	Install New ATS	ea	1	$25,000	$25,000
11	R	6	Recircuiting: Intercept Circuits and Route to New ATS	ea	22	$2,000	$44,000
12	R	6	Recircuiting: Intercept Panels and Route to New ATS	ea	3	$10,000	$30,000
						Subtotal	**$104,000**
Battery Energy Storage System - Engineering and Procurement							
13	R	1	Battery Procurement	ea	1	$4,000	$4,000
14	R	1	Feasibility Study	ea	1	$32,728	$32,728
15	R	1	Design and Bid	ea	1	$39,550	$39,550
16	R	1	Commissioning Agent	ea	1	$8,000	$8,000
17	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
18	R	6	BESS Package Provider Commissioning & Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
19	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
20	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
21	PD	1	Facility ConneX - MBCx	ea	1	$14,953	$14,953
22	PD	1	BAS Peak Demand Strategy Programming and Integration	ea	1	$60,000	$60,000
23	M	3	LED Lighting Upgrades	ea	1	$265,000	$265,000
24	PD	3	Lighting Controls and Integration	ea	1	$90,000	$90,000
25	PD	1	Lighting Bid, Cx, and PM	ea	1	$11,853	$11,853
26	PD	3	Recommissioning Fixes Budget	ea	1	$18,000	$18,000
						Subtotal	**$469,256**
Demand Response and Energy Systems Integration - Engineering and Procurement							
27	PD	1	Peak Demand Response Systems Engineering	ea	1	$12,450	$12,450
28	PD	1	Peak Demand Response PM/CA	ea	1	$18,900	$18,900
29	PD	1	Peak Demand Response Systems Commissioning	ea	1	$6,950	$6,950
						Subtotal	**$38,300**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Consultant Opinion of Cost	
6	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	
M	City of Medford	Grand Total Resiliency & Peak Demand Project **$1,183,665**

Andrews School – 650kWh Energy Storage Capacity

Opinion of Probable Construction Cost							
ANDREWS SCHOOL RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT							
B2Q Associates, Inc. 100 Burtt Rd. Ste. 212 Andover, MA 01810 (978) 208 - 0609		Customer: Address:	City Of Medford 3000 Mystic Valley Parkway Medford, MA 02155			Created by: Checked by:	JD
General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$58,512	$58,512
2	R	2	Installation Labor	ea	1	$70,212	$70,212
3	R	5	Pad and Site Work	ea	1	$11,947	$11,947
4	R	2	Galvanized Chain Link Fence	ea	1	$12,872	$12,872
5	R	2	Battery Package 100kW/650kWh	ea	1	$358,378	$358,378
6	R	2	Microgrid Controller	ea	1	$40,000	$40,000
7	R	2	Crane	ea	2	$2,300	$4,600
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$591,244**
Building Resiliency Upgrades							
9	R	6	Electrical Demolition	ea	1	$5,000	$5,000
10	R	6	Install New ATS	ea	1	$25,000	$25,000
11	R	6	Recircuiting: Intercept Circuits and Route to New ATS	ea	22	$2,000	$44,000
12	R	6	Recircuiting: Intercept Panels and Route to New ATS	ea	3	$10,000	$30,000
						Subtotal	**$104,000**
Battery Energy Storage System - Engineering and Procurement							
13	R	1	Battery Procurement	ea	1	$4,000	$4,000
14	R	1	Feasibility Study	ea	1	$32,728	$32,728
15	R	1	Design and Bid	ea	1	$39,550	$39,550
16	R	1	Commissioning Agent	ea	1	$8,000	$8,000
17	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
18	R	6	BESS Package Provider Commissioning & Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
19	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
20	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
21	PD	1	Facility ConneX - MBCx	ea	1	$14,953	$14,953
22	PD	1	BAS Peak Demand Strategy Programming and Integration	ea	1	$60,000	$60,000
23	M	3	LED Lighting Upgrades	ea	1	$265,000	$265,000
24	PD	3	Lighting Controls and Integration	ea	1	$90,000	$90,000
25	PD	1	Lighting Bid, Cx, and PM	ea	1	$11,853	$11,853
26	PD	3	Recommissioning Fixes Budget	ea	1	$18,000	$18,000
						Subtotal	**$469,256**
Demand Response and Energy Systems Integration - Engineering and Procurement							
27	PD	1	Peak Demand Response Systems Engineering	ea	1	$12,450	$12,450
28	PD	1	Peak Demand Response PM/CA	ea	1	$18,900	$18,900
29	PD	1	Peak Demand Response Systems Commissioning	ea	1	$6,950	$6,950
						Subtotal	**$38,300**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Consultant Opinion of Cost	
6	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	
M	City of Medford	Grand Total Resiliency & Peak Demand Project **$1,342,077**

DPW – 85kWh Energy Storage Capacity

Opinion of Probable Construction Cost							
DPW RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT							
B2Q Associates, Inc. 100 Burtt Rd. Ste. 212 Andover, MA 01810 (978) 208 - 0609			Customer: Address:	City Of Medford 21 James St Medford, MA 02155	B2Q	Created by: Checked by:	JD
General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$14,628	$14,628
2	R	2	Installation Labor	ea	1	$17,553	$17,553
3	R	2	Pad and Site Work	ea	1	$10,824	$10,824
4	R	2	Galvanized Chain Link Fence	ea	1	$3,218	$3,218
5	R	2	Battery Package 100kW/85kWh	ea	1	$85,560	$85,560
6	R	2	Microgrid Controller	ea	1	$35,000	$35,000
7	R	2	Crane	ea	1	$2,300	$2,300
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$203,806**
Battery Energy Storage System - Engineering and Procurement							
9	R	1	Battery Procurement	ea	1	$4,000	$4,000
10	R	1	Feasibility Study	ea	1	$32,728	$32,728
11	R	1	Design and Bid	ea	1	$39,550	$39,550
12	R	1	Commissioning Agent	ea	1	$8,000	$8,000
13	R	2	BESS Package Provider Engineering	ea	1	$5,000	$5,000
14	R	5	BESS Package Provider Commissioning and Testing	ea	1	$50,000	$50,000
						Subtotal	**$139,278**
Demand Response and Energy Systems Integration - Construction							
15	PD	1	Automated DR Controller & Setup		1	$6,950	$6,950
16	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
17	PD	1	Facility ConneX - MBCx	ea	1	$3,738	$3,738
18	PD	3	BAS Peak Demand Strategy Programming and Integration	ea	1	$10,000	$10,000
19	PD	3	Lighting Systems Integration to BAS	ea	1	$10,000	$10,000
20	PD	3	Recommissioning Fixes Budget	ea	1	$5,000	$5,000
						Subtotal	**$38,188**
Demand Response and Energy Systems Integration - Engineering and Procurement							
21	PD	1	Peak Demand Response Systems Engineering	ea	1	$4,650	$4,650
22	PD	1	Peak Demand Response PM/CA	ea	1	$8,900	$8,900
23	PD	1	Peak Demand Response Systems Commissioning	ea	1	$3,250	$3,250
						Subtotal	**$16,800**

Sources		Notes	
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.	
2	Vendor Budget Quote		
3	B2Q Grant Budget		
4	CCERI Grant Documents		
5	Other		
Funding			
R	DOER Resiliency Grant		
PD	DOER Peak Demand Grant	Grand Total Resiliency & Peak Demand Project	$398,072

DPW – 170kWh Energy Storage Capacity

Opinion of Probable Construction Cost

DPW RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT

B2Q Associates, Inc.	Customer:	City Of Medford	
100 Burtt Rd. Ste. 212	Address:	21 James St	Created by: JD
Andover, MA 01810		Medford, MA 02155	Checked by:
(978) 208 - 0609			

General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$18,285	$18,285
2	R	2	Installation Labor	ea	1	$21,941	$21,941
3	R	2	Pad and Site Work	ea	1	$13,530	$13,530
4	R	2	Galvanized Chain Link Fence	ea	1	$4,023	$4,023
5	R	2	Battery Package 100kW/170kWh	ea	1	$136,734	$136,734
6	R	2	Microgrid Controller	ea	1	$50,000	$50,000
7	R	2	Crane	ea	1	$2,875	$2,875
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$282,111**
Battery Energy Storage System - Engineering and Procurement							
9	R	1	Battery Procurement	ea	1	$4,000	$4,000
10	R	1	Feasibility Study	ea	1	$32,728	$32,728
11	R	1	Design and Bid	ea	1	$39,550	$39,550
12	R	1	Commissioning Agent	ea	1	$8,000	$8,000
13	R	2	BESS Package Provider Engineering	ea	1	$6,250	$6,250
14	R	5	BESS Package Provider Commissioning	ea	1	$50,000	$50,000
						Subtotal	**$140,528**
Demand Response and Energy Systems Integration - Construction							
15	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
16	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
17	PD	1	Facility ConneX - MBCx	ea	1	$3,738	$3,738
18	PD	3	BAS Peak Demand Strategy Programming and Integration	ea	1	$10,000	$10,000
19	PD	3	Lighting Systems Integration to BAS	ea	1	$10,000	$10,000
20	PD	3	Recommissioning Fixes Budget	ea	1	$5,000	$5,000
						Subtotal	**$38,188**
Demand Response and Energy Systems Integration - Engineering and Procurement							
21	PD	1	Peak Demand Response Systems Engineering	ea	1	$4,650	$4,650
22	PD	1	Peak Demand Response PM/CA	ea	1	$8,900	$8,900
23	PD	1	Peak Demand Response Systems Commissioning	ea	1	$3,250	$3,250
						Subtotal	**$16,800**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	Grand Total Resiliency & Peak Demand Project **$477,627**

DPW – 250kWh Energy Storage Capacity

Opinion of Probable Construction Cost

DPW RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT

B2Q Associates, Inc. 100 Burtt Rd. Ste. 212 Andover, MA 01810 (978) 208 - 0609	Customer: Address:	City Of Medford 21 James St Medford, MA 02155
B2Q	Created by: JD Checked by:	

General				Materials			
Number	**Funding**	**Source**	**Item**	**Type**	**Quantity**	**Unit Cost**	**Total Cost**
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$21,942	$21,942
2	R	2	Installation Labor	ea	1	$26,330	$26,330
3	R	2	Pad and Site Work	ea	1	$16,236	$16,236
4	R	2	Galvanized Chain Link Fence	ea	1	$4,827	$4,827
5	R	2	Battery Package 100kW/250kWh	ea	1	$188,212	$188,212
6	R	2	Microgrid Controller	ea	1	$50,000	$50,000
7	R	2	Crane	ea	1	$3,450	$3,450
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$345,719**
Battery Energy Storage System - Engineering and Procurement							
9	R	1	Battery Procurement	ea	1	$4,000	$4,000
10	R	1	Feasibility Study	ea	1	$32,728	$32,728
11	R	1	Design and Bid	ea	1	$39,550	$39,550
12	R	1	Commissioning Agent	ea	1	$8,000	$8,000
13	R	2	BESS Package Provider Engineering	ea	1	$7,500	$7,500
14	R	5	BESS Package Provider Commissioning	ea	1	$50,000	$50,000
						Subtotal	**$141,778**
Demand Response and Energy Systems Integration - Construction							
15	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
16	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
17	PD	1	Facility ConneX - MBCx	ea	1	$3,738	$3,738
18	PD	3	BAS Peak Demand Strategy Programming and Integration	ea	1	$10,000	$10,000
19	PD	3	Lighting Systems Integration to BAS	ea	1	$10,000	$10,000
20	PD	3	Recommissioning Fixes Budget	ea	1	$5,000	$5,000
						Subtotal	**$38,188**
Demand Response and Energy Systems Integration - Engineering and Procurement							
21	PD	1	Peak Demand Response Systems Engineering	ea	1	$4,650	$4,650
22	PD	1	Peak Demand Response PM/CA	ea	1	$8,900	$8,900
23	PD	1	Peak Demand Response Systems Commissioning	ea	1	$3,250	$3,250
						Subtotal	**$16,800**

Sources		Notes
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.
2	Vendor Budget Quote	
3	B2Q Grant Budget	
4	CCERI Grant Documents	
5	Other	
Funding		
R	DOER Resiliency Grant	
PD	DOER Peak Demand Grant	Grand Total Resiliency & Peak Demand Project **$542,485**

DPW – 389kWh Energy Storage Capacity

Opinion of Probable Construction Cost

DPW RESILIENCY AND PEAK DEMAND COMPREHENSIVE PROJECT

B2Q Associates, Inc.	Customer:	City Of Medford		
100 Burtt Rd. Ste. 212	Address:	21 James St	Created by:	JD
Andover, MA 01810		Medford, MA 02155	Checked by:	
(978) 208 - 0609				

General				Materials			
Number	Funding	Source	Item	Type	Quantity	Unit Cost	Total Cost
Battery Energy Storage System - Construction							
1	R	2	Pipe and Wire	ea	1	$21,942	$21,942
2	R	2	Installation Labor	ea	1	$26,330	$26,330
3	R	2	Pad and Site Work	ea	1	$16,236	$16,236
4	R	2	Galvanized Chain Link Fence	ea	1	$4,827	$4,827
5	R	2	Battery Package 100kW/3890kWh	ea	1	$256,524	$256,524
6	R	2	Microgrid Controller	ea	1	$50,000	$50,000
7	R	2	Crane	ea	1	$3,450	$3,450
8	R	4	Utility Interconnection	ea	1	$34,723	$34,723
						Subtotal	**$414,031**
Battery Energy Storage System - Engineering and Procurement							
9	R	1	Battery Procurement	ea	1	$4,000	$4,000
10	R	1	Feasibility Study	ea	1	$32,728	$32,728
11	R	1	Design and Bid	ea	1	$39,550	$39,550
12	R	1	Commissioning Agent	ea	1	$8,000	$8,000
13	R	2	BESS Package Provider Engineering	ea	1	$7,500	$7,500
14	R	5	BESS Package Provider Commissioning	ea	1	$50,000	$50,000
						Subtotal	**$141,778**
Demand Response and Energy Systems Integration - Construction							
15	PD	1	Automated DR Controller & Setup	ea	1	$6,950	$6,950
16	PD	3	Utility Meter Upgrade	ea	1	$2,500	$2,500
17	PD	1	Facility ConneX - MBCx	ea	1	$3,738	$3,738
18	PD	3	BAS Peak Demand Strategy Programming and Integration	ea	1	$10,000	$10,000
19	PD	3	Lighting Systems Integration to BAS	ea	1	$10,000	$10,000
20	PD	3	Recommissioning Fixes Budget	ea	1	$5,000	$5,000
						Subtotal	**$38,188**
Demand Response and Energy Systems Integration - Engineering and Procurement							
21	PD	1	Peak Demand Response Systems Engineering	ea	1	$4,650	$4,650
22	PD	1	Peak Demand Response PM/CA	ea	1	$8,900	$8,900
23	PD	1	Peak Demand Response Systems Commissioning	ea	1	$3,250	$3,250
						Subtotal	**$16,800**

Sources		Notes	
1	Vendor Firm Quote	1) Project Labor based on prevailing wage rates for trades.	
2	Vendor Budget Quote		
3	B2Q Grant Budget		
4	CCERI Grant Documents		
5	Other		
Funding			
R	DOER Resiliency Grant		
PD	DOER Peak Demand Grant	Grand Total Resiliency & Peak Demand Project	**$610,797**

APPENDIX B – COMMON ACRONYMS

ADR	Automated Demand Response	**ISO-NE**	Independent System Operator of New England
AC	Air Conditioning	**ITC**	Investment Tax Credit
ACCU	Air-Cooled Condensing Unit	**LCP**	Lighting Control Panel
AHU	Air Handling Unit	**LED**	Light-Emitting Diode
ATS	Automatic Transfer Switch	**Li-Ion**	Lithium Ion
BAS	Building Automation System	**MBCx**	Monitoring-Based Commissioning
BESS	Battery Energy Storage System	**NO**	Normal Operation
BMS	Battery Management System	**OA**	Outside Air
CCERI	Community Clean Energy Resiliency Initiative	**PD**	Peak Demand
CHW	Chilled Water	**PDR**	Peak Demand Response
CSP	Curtailment Service Provider	**PLC**	Programmable Logic Controller
Cx	Commissioning	**PPA**	Power Purchase Agreement
DAT	Discharge Air Temperature	**PV**	Photovoltaic
DER	Distributed Energy Resource	**PVIS**	Photovoltaic Inverter System
DHW	Domestic Hot Water	**RCx**	Retro-Commissioning
DR	Demand Response	**RTDR**	Real-Time Demand Response
DX	Direct Expansion	**RTO**	Regional Transmission Organization
EF	Exhaust Fan	**RTU**	Roof Top Unit
ERV	Energy Recovery Ventilator	**SG**	Standby Generator
ESP	Electric Service Provider	**SLA**	Sealed Lead Acid
EUI	Energy Use Intensity	**SO**	Standby Operation
FTR	Fin Tube Radiation	**SSC**	System Supervisory Controller
H&V	Heating and Ventilating	**UV**	Unit Ventilator
HVAC	Heating, Ventilation, and Air Conditioning	**VAV**	Variable Air Volume
HW	Hot Water	**VFD**	Variable Frequency Drive

APPENDIX C – GLOSSARY

Air Handling Unit (AHU) – HVAC equipment which contains a fan or fan(s) and heat transfer coils for heating and/or cooling air as well as a system of dampers and controls for providing ventilation air to a building.

Automated Demand Response – a method of participating in demand response programs so that load curtailment does not require day to day human management. ADR enables customers to automate HVAC, lighting, energy storage and other systems to receive curtailment signals from a CSP, ISO/RTO, or utility.

Building Automation System (BAS) - Computerized control system for a building HVAC system. Most have trend capability allowing for patterns of equipment behavior to be analyzed by technicians and HVAC engineers. An EMS is also frequently referred to as an EMS – Energy Management System.

Cooling Degree Day - A term used in HVAC and energy engineering field to quantify the correlation between energy use for cooling and weather. The general definition is the daily average temperature minus 65°F. These can be added over days, months, or years to analyze the impact of weather on energy consumption. There also can be custom based cooling degree days but generally weather reporting uses 65°F.

Demand management – Demand Management is utility technology and program deployments designed to help customers change their electricity usage, including the timing of use and customer amount of use. These are activities that Influence consumption behaviors and don't include changes based on government-mandated energy efficiency standards. DM contains two components: Energy Efficiency and Demand Response.

Demand Resource – Demand side resource is and electricity consumer that can decrease its power consumption in response to a price signal or direction from a System Operator.

Demand Response – Demand Response means "the ability of customers to respond to either a reliability trigger or a price trigger from their utility system operator, load-serving entity, independent system operator(ISO), or the demand response provider by lowering their power consumption."

Demand Response Events – are the time periods, deadlines and transitions during which demand resources perform. The system operator shall specify the duration and applicability of demand response event. All deadlines, time periods and transitions may not be not applicable to all demand response products or services.

Demand Response Potential- it is the estimation of how many MW of curtailment are feasible. Four types to consider: technical potential, economic potential, maximum achievable potential (MAP), and realistic achievable potential.

Demand Response Program is a company's service/program/tariff related to demand response, or the change in customer electric usage from normal consumption patterns in response to changes in the price of electricity over time or in response to incentive payments designed to include lower electricity use at times of high wholesale market prices, or in a change in electric usage by end use customers at the direction of a system operator or an automated preprogrammed control system when system reliability is jeopardized. Includes both time-based rate programs and invective based programs.

Dispatchable DR load- Is Electricity consumption load that can be reduced based on communication from control center. It includes direct load control, interruptible demand, CPP with control, Load as a capacity resource, spinning and non-spinning reserves, regulation and energy-voluntary and energy price resources.

Electric Grid - it is a system of synchronized power providers and consumer connected by transmission and distribution lines and operated by one or more control centers.

Emergency or Backup generation – are electric power systems that located at a customer site and are typically used for the purposes of supporting DR programs in that when the system's reliability is threatened, the system operator may automatically dispatch the generator at the customer site.

Energy Efficiency means "using less energy to provide the same or improved level of service to the energy consumer in an economically efficient way." In other words, a permanent change in energy consumption, generally with no decrease in service level.

End-Use Customer is a firm or individual that purchases electricity for its own consumption and not for resale; an ultimate consumer of electricity.

Heating Degree Day - Similar to a cooling degree day but used to quantify energy use for heating. A heating degree day is generally defined as 65°F minus average daily temperature. Heating degree days with different bases do exist but they are generally reported base 65°F.

ISO –NE (ISO New England) is the independent, not-for-profit company authorized by FERC to perform three critical, complex, interconnected roles for the region spanning Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and most of Maine. Grid operation: coordinate and direct the flow of electricity over the region's high voltage transmission system; Market administration: design, run, and oversee the billion-dollar markets where wholesale electricity is bought and sold; Power system planning: the studies, analyses, and planning to make sure New England's electricity needs will be met over the next 10 years.

Load Curtailment is when customers are paid a specified amount per kW curtailed in response to a call that is made on a day-of basis. This requires the specification of a baseline or normal usage.

Load Shedding is the reduction of electricity use or "load" by participants to alleviate pressure on the grid. Usually in response to a DR event.

Load Shifting is the shift of electricity use from peak to off-peak times.

Manual Demand Response involves a labor-intensive approach such as having the building operator manually turn of or change comfort set points at each equipment switch or controller upon receipt of request from the system operator.

Outage is the time period when some part of the electric transmission and distribution system is not functioning for planned reasons, such as repairs, or unplanned reasons, such as weather or component failure. Synonymous with loss of grid power, loss of utility grid, grid outage

Peak Demand is the maximum electricity load required for a period of time, which can be a specific point in time or averaged over a period of time. It is also known as Peak Load.

Real Time Pricing is a rate and price structure in which the retail price for electricity typically fluctuates hourly or more often, to reflect changes in the wholesale price of electricity on either a day ahead or hour ahead basis.

Response Time is the maximum time allowed in a demand response program for a program participant to react to the program sponsor's notification, in hours.

Retro-Commissioning - Commissioning is a process to ensure that building systems perform interactively to meet the owner's current operational needs with the overall goal of improving system efficiency and/or effectiveness. Retro-commissioning is the process of commissioning an existing building which has never been commissioned. Retro-commissioning is often abbreviated as "RCx". RCx activities were performed as part of this energy project at the Centerville Elementary School.

Roof Top Unit (RTU) – HVAC equipment similar to an AHU but is generally located on the roof. Many RTUs have built-in digital controls, as is the case with the RTUs at the Main Library in Beverly. These controls can be integrated with a new EMS using a communication protocol such as BACnet or LonWorks, allowing the EMS to optimize the efficiency of the RTU operation.

RTO (Regional Transmission Organization) is a regulated entity similar to an ISO and has similar functions to monitor system loads and voltages, operate transmission, oversee generation, create and deploy contingency plans and emergency procedures. The difference between an ISO and a RTO is that the RTO covers a larger geographic area.

Sequence of Operations- A statement of intent for the software control algorithms used to control a specific piece of HVAC equipment. This tells the equipment how and when it should change its mode of operation (i.e. heating vs. cooling). For AHUs and RTUs the Sequence of Operations dictates when valves should be modulated, fan speed should be increased/decreased, or dampers should be opened/closed.

Service Provider coordinates resources to deliver electricity products and services to a market or distribution operator.

Tariff is a published volume of all effective rate schedules, terms and conditions under which a product or service will be supplied to customers.

Time-Based Rate/Tariff is a retail rate or Tariff in which customers are charged different prices for using electricity at different times during the day. Examples are time-of-use rates, real time pricing, hourly pricing, and critical peak pricing. Time based rates do not include seasonal rates, inverted block, or declining block rates.

Time of use is a rate where usage unit process vary by time period, and where the time periods are typically longer than one hour within a 24-hour day. Time of use rates reflect the average cost of generating delivering power during those time periods.

Variable Frequency Drive – A set of solid state electronics which allows modulation from a 60 Hz AC signal (full speed) to a frequency which is generally not lower than a 20 Hz (33% speed) for HVAC applications, for the purpose of driving AC motors at various speeds. This is useful for reducing power consumption at times when the motor for the system which is being driven is not needed to run at full capacity.

Appendix D – Flood Planes Maps

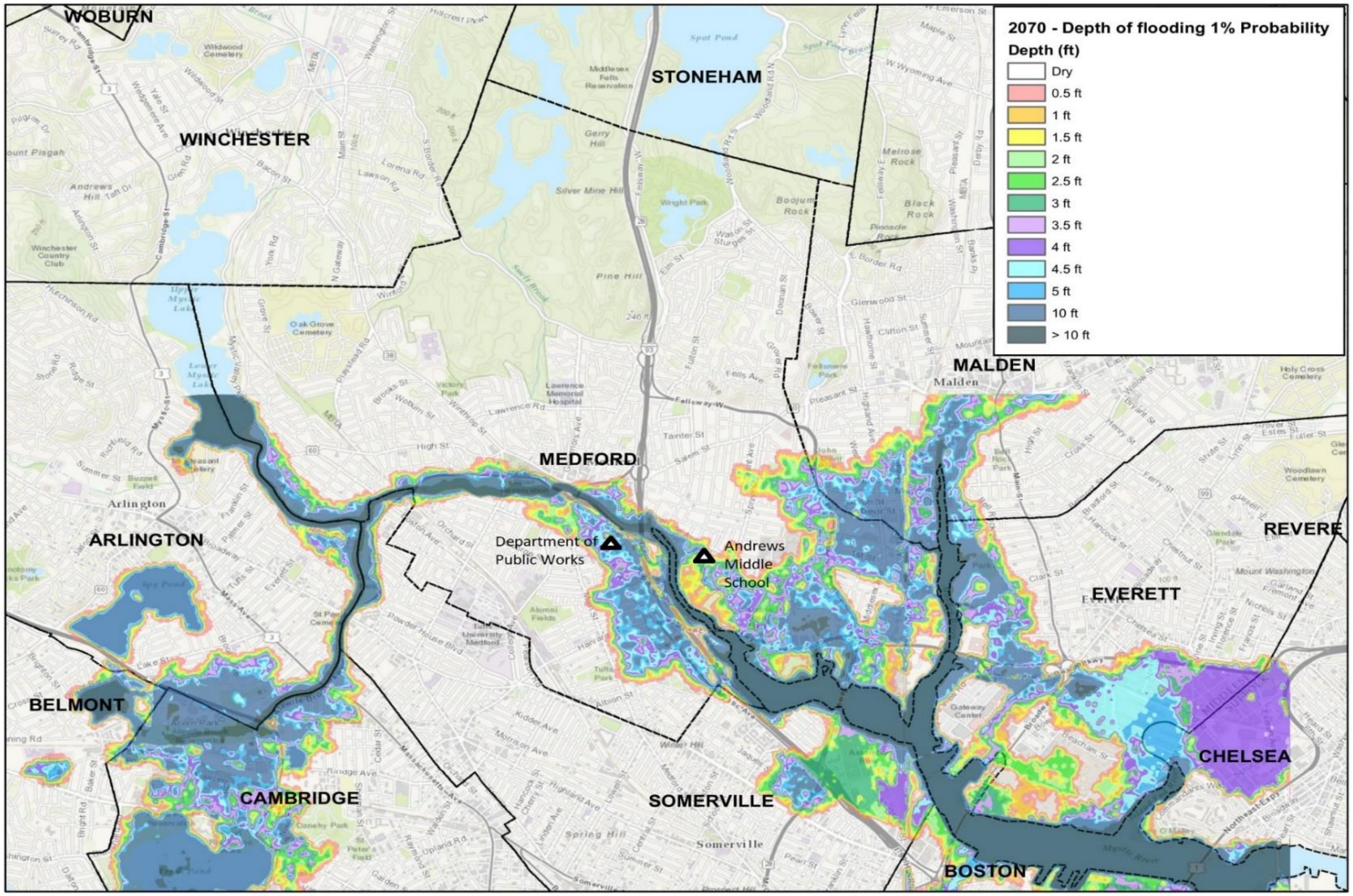

Figure 27 Map showing sites Andrews Middle School and DPW under Depth of Flooding - 100 year (1% Probability) by 2070

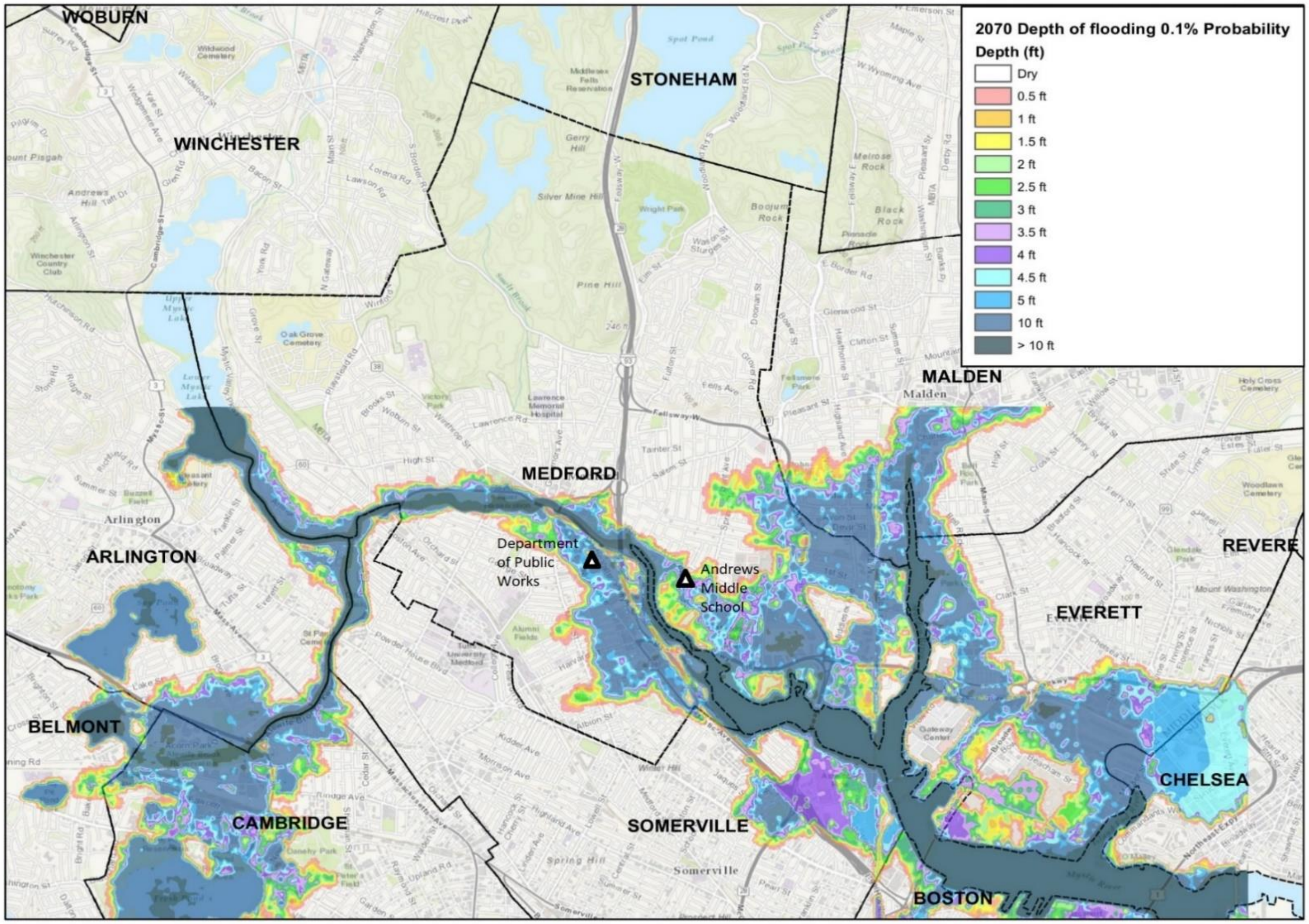

Figure 28 Map showing sites Andrews Middle School and DPW under Depth of Flooding - 1000 year (0.1% Probability) by 2070

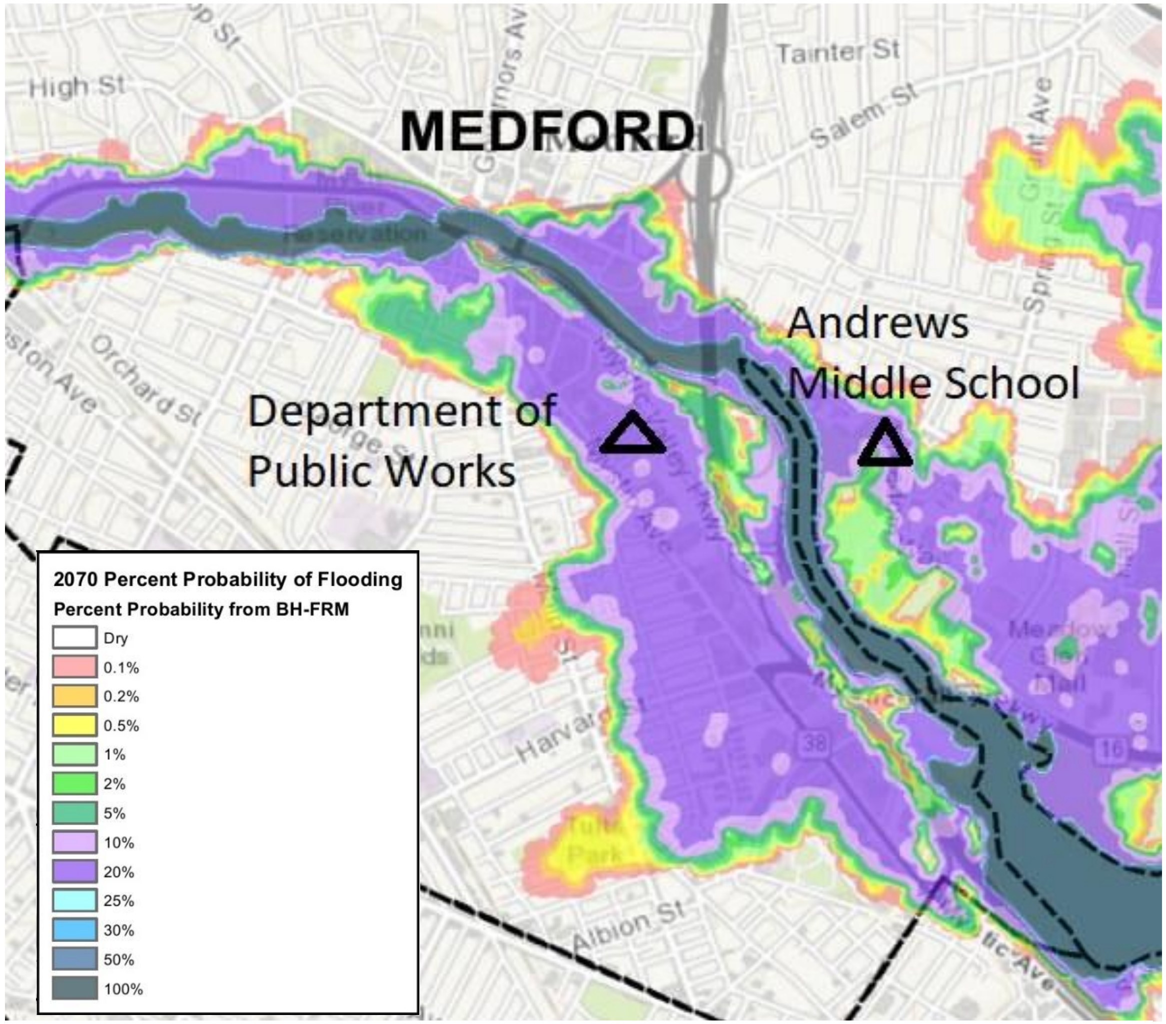

Figure 29 Map showing sites Andrews Middle School and DPW – Percent probability from SLR and Storm surge by 2070