ENERGY
TRANSITIONS
INITIATIVE
U.S. Department of Energy

Wainwright, Alaska

August 2023

Energy Transitions Initiative Partnership Project: Wainwright, Alaska

Cohort 1 Technical Assistance: Assessment of Energy Efficiency, Renewable Energy, and Energy Storage Options

Nathan Wiltse, Jal Desai, Khanh Nguyen Cu,
Kosol Kiatreungwattana[1] and David Schoenwold[2]

1. National Renewable Energy Laboratory
2. Sandia National Laboratories

Suggested Citation
Wiltse, Nathan, Jal Desai, Khanh Nguyen Cu, Kosol Kiatreungwattana, and David Schoenwold. 2023. *Energy Transitions Initiative Partnership Project: Wainwright, Alaska. Cohort 1 Technical Assistance: Assessment of Energy Efficiency, Renewable Energy, and Energy Storage Options.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5600-86238. https://www.nrel.gov/docs/fy23osti/86238.pdf.

Technical Report
NREL/TP-5600-86238
August 2023

NOTICE

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by DOE Office of Energy Efficiency and Renewable Energy, Energy Transitions Initiative, Geothermal Technologies Office, Solar Energy Technologies Office, Water Power Technologies Office, and Wind Energy Technologies Office.

Cover Photos: (clockwise, left to right): NREL 22255, iStock 185271146, Mulan Wind Farm – Flickr, iStock 516335799

Table of Contents

Executive Summary ..... **viii**
  Background viii
    Site Information viii
    Methodology ix
    Recommendations ix
    Next Steps xii
Section 1 Thermal and Energy Analysis of Energy Efficiency Measures **1**
  1.1 Background 2
    1.1.1 Roles and responsibilities 2
    1.1.2 Site Information 2
  1.2 Data Collection 4
  1.3 Baseline Compliance Model 4
  1.4 Evaluation of Energy Efficiency Measures 6
    1.4.1 Envelope 6
    1.4.2 Mechanical Systems 12
    1.4.3 Electrical Systems 16
    1.4.4 Appliances and Equipment 18
  1.5 Recommendations for Optimized Energy Efficiency Measures 20
    1.5.1 EnergyPlus Model Results 21
    1.5.2 Other Considerations: Thermal Resilience 23
Section 2 Solar Photovoltaic (PV) and Battery Energy Storage Systems (BESS) Techno-Economic Analysis **24**
  2.1 REopt Modeling of PV and BESS Systems 25
    2.1.1 Modeling Tool 26
  2.2 Site Description 26
    2.2.1 Constraints for PV and BESS Systems 26
    2.2.2 PV Size Potential 27
    2.2.3 PV Resource Availability 27
    2.2.4 Utility Rate Structure 28
  2.3 Load Analysis 28
    2.3.1 Energy Storage Sizing 29
  2.4 Scenario Analysis 29
    2.4.1 Scenario Assumptions 31
  2.5 Scenario Results 32
  2.6 Additional Analyses 34
    2.6.1 Exploration of Net Zero Requirements 34
  2.7 Suggested Next Steps 34
    2.7.1 Near Term 34
Appendices **35**
  Appendix A. REopt Scenario Outputs 35
  Appendix B. Load Profile Analysis 36

List of Figures

Figure 1. Comparison of the baseline and recommended annual energy use with colored breakdown by end-use. 22
Figure 2. Energy storage technologies and applications 25
Figure 3. Schematic of the REopt energy planning program 26
Figure 4. Fifteen-minute interval load profile of the projected building electrical usage showing the seasonal differences to electrical demand. 29
Figure B-1. Time series plot of daily electric load (Baseline) in kWh with annual mean, summer mean, and winter mean daily electric load values overlaid on the plot. 37
Figure B-2. Time series plot of daily electric load (with adoption of EEMs) in kWh with annual mean, summer mean, and winter mean daily electric load values overlaid on the plot. 38

List of Tables

Table 1. Optimized Option Selection of Energy Efficiency Measures x
Table 2. EnergyPlus Model Results for the Optimized Options xi
Table 3. EnergyPlus Input Assumptions for the Baseline Compliance Model 5
Table 4. EnergyPlus Modeling Results for the Baseline Compliance Model 6
Table 5. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Roof Options with Respect to the Baseline Energy Consumption 7
Table 6. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Wall Options with Respect to the Baseline Energy Consumption 8
Table 7. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Window Options with Respect to the Baseline Energy Consumption 9
Table 8. Energyplus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Door Options with Respect to the Baseline Energy Consumption 10
Table 9. Energyplus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Air Leakage Options with Respect to the Baseline Energy Consumption 12
Table 10. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Heating Options with Respect to the Baseline Energy Consumption 13
Table 11. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Ventilation Options with Respect to the Baseline Energy Consumption 14
Table 12. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the DHW Options with Respect to the Baseline Energy Consumption 15
Table 13. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Interior Lighting Options with Respect to the Baseline Energy Consumption 17
Table 14. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Exterior Lighting Options with Respect to the Baseline Energy Consumption 18
Table 15. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Interior Appliance Options with Respect to the Baseline Energy Consumption 19

Table 16. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Exterior Appliance Options with Respect to the Baseline Energy Consumption 20
Table 17. EEM Options Selected to Maximize Energy Savings and Fuel Use Reductions 21
Table 18. Energy and Model Results for the EEM Option Package Selected to Maximize Energy Savings and Fuel Use Reductions 22
Table 19. Basic PVWatts Data Inputs 27
Table 20. Monthly Generation from PV as Generated by PVWatts 28
Table 21. North Slope Borough Power & Light Tiered Usage Charge Structure for Monthly Electrical Rates 28
Table 22. Summary of Key Factors from the REopt Scenarios for PV and BESS 31
Table 23. Technical Assumptions for the Solar PV System 32
Table 24. Technical Assumptions for the BESS System 32
Table 25. Scenario Results 33
Table A-1. Basic Size and Output Parameters 35
Table A-2. Year 1 Utility Electricity Cost 35
Table A-3. Summary Financial Metrics 35
Table B-1. Statistics on Daily Electric Load in kWh with and Without Adoption of Energy Efficiency Measures (EEMs) 36
Table B-2. Statistics on Daily Electric Load in kWh for Summer (April 15–October 14) With and Without Adoption of EEMs 36
Table B-3. Statistics on Daily Electric Load in kWh for Winter (January 1–April 15, October 15–December 31) With and Without Adoption of EEMs 37
Table B-4. Statistics on Hourly Power Usage in kW With and Without Adoption of EEMs 38
Table B-5. Statistics on Hourly Power Usage in kW for Summer With and Without Adoption of EEMs 39
Table B-6. Statistics on Hourly Power Usage in kWh for Winter With and Without Adoption of EEMs 39
Table B-7. Statistics on AC Power Output from PV and BESS System in kW for Full Year, Summer, and Winter 39
Table B-8. Number of Hours Per Year, Summer, Winter, Respectively, for which there is Zero PV Output Power 40

List of Acronyms

A&E	TNHA’s contracted architecture and engineering team
ACH50	air changes per hour at 50 Pascals
AES	annual energy saved in kWh
ASHP	air source heat pumps
BESS	battery energy storage system
BTM	behind the meter
CAPEX	capital expenditures
CFM	cubic feet per minute
CHP	combined heat and power
CI	continuous insulation
COP	coefficient of performance
COVID-19	Coronavirus SARS CoV-2
DCV	demand-controlled ventilation
DHW	domestic hot water
ECM	energy conservation measures
EEM	energy efficiency measures
EPS	expanded polystyrene
ETIPP	Energy Transitions Initiative Partnership Project
ETS	electric thermal storage
EUI	energy utilization intensity
HRV	heat recovery ventilation
HVAC	heating, ventilation, and air conditioning
ITC	investment tax credit
kBTU	thousands of British Thermal Units

$kBTU/ft^2$	thousands of British Thermal Units per square foot
kW	kilowatt
kWh	kilowatt-hour
LAF	location adjustment factor
LCC	life cycle costs
LCUS	life cycle utility savings
LED	light emitting diode
NPV	net present values
NREL	National Renewable Energy Laboratory
OPEX	operating expenditures
PCE	Power Cost Equalization
PV	solar photovoltaics
R-value	The capacity of an insulating material to resist heat flow.
RC	replacement cost
SHGC	solar heat gain coefficient
SIP	structurally insulated panel
SNL	Sandia National Laboratories
TNHA	Taġiuġmiullu Nunamiullu Housing Authority
Toyo	direct-vent heaters
U-value	A measure of heat transmission through a building part or thickness of material.
UCS	utility cost savings
Wdc	The maximum watts a panel produces under idealized conditions.

Executive Summary

Background

Wainwright, Alaska, is an isolated coastal Arctic community (located at 70º38’21” North, 160º01’50” West) with a diesel-fired islanded power grid. Natural gas is not available to the community of Wainwright. The community buildings’ heating and power generation fuel costs are heavily subsidized by the regional municipality, which imports diesel in bulk by annual barge during the summer period when the Chukchi Sea is ice free.

This project identified pathways to reduce energy consumption and enhance indoor environmental quality and resilience of a 1,500-square-foot former federal armory building owned by the tribe as it is renovated as a community multipurpose facility. The building sits above grade and is designed with no attic space. The building has not been used in over 10 years and has been moved at least twice. There is a high likelihood that it will be moved at least twice more before retrofits. The scope included thermal evaluation of multiple building efficiency measures, and a techno-economic exploration of an on-site renewable energy and integrated energy storage systems.

This technical assistance was provided by the Energy Transitions Initiative Partnership Project (ETIPP) team composed of the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and Renewable Energy Alaska Project (REAP) working in collaboration with the Taġiuġmiullu Nunamiullu Housing Authority (TNHA) and their designated representatives.

In close communication and collaboration between the ETIPP team, TNHA, and TNHA’s architecture and engineering team (A&E) the roles and responsibilities were divided for the overall effort. This report summarizes the three main areas of evaluation by the ETIPP team. There are some unavoidable gaps that correspond to activities by TNHA, the A&E team, or TNHA’s civil engineering contractor.

Site Information

In view of issues around travel during COVID-19, the decision was made and agreed on by all parties to limit in-person visits to the community. TNHA’s A&E team provided the ETIPP team with interior and exterior photos, basic floorplans, a Sketch-Up model, and site notes. These were used throughout the ETIPP tasks.

Key factors of note:

- The site has been unused and without power for over 10 years. As such, no records of actual energy usage for the site existed.
- The building had been moved twice, which stressed the major joins, necessitating some assumed base repair and maintenance.
- The structure at bare minimum needed additions, such as a mechanical ventilation system, and many electrical and mechanical systems were out of code compliance, whether electrical code, plumbing code, or for a childcare facility.
- The structure was 17 inches off level and in need of additional civil engineering work.

- The site is in the primary drainage path for that portion of the village, necessitating additional civil work to redirect the drainage flow for water, as well as potentially temporary relocation of the building during this work.

Retrofits for the building are part of a $750,000 Housing and Urban Development grant. As such, the stated intent is to lower operations and maintenance costs, specifically energy costs. The tribe will be operating the building as a childcare facility and will not have access to technical resources or the financial resources for costly maintenance, or high fuel bills. Therefore, getting the electric and fuel oil use as low as possible, and when decisions between the two were needed, erring on the side of a fuel oil device was the primary accepted approach for the energy efficiency recommendations.

Methodology

ENERGY EFFICIENCY RECOMMENDATIONS

To complete this evaluation, information from the A&E team's site visit was used to create an "As-Is" physics-based building energy model using EnergyPlus™. This was then modified to create a "Baseline" energy model which brought the building up to code. "Code" here refers to electrical, plumbing, and state childcare facility requirements. From there, energy efficiency measures (EEMs) and energy conservation measures (ECMs) were modeled using EnergyPlus to identify additional energy savings opportunities. Where additional details were not obtained, the default values for the systems were used.

PV AND BESS SYSTEM ANALYSIS

The technical and economic feasibility of solar photovoltaic (PV) and battery energy storage system (BESS) were analyzed using NREL's REopt™ software. The REopt tool evaluates the economic viability of grid-connected solar photovoltaics, wind, combined heat and power (CHP), geothermal heat pumps, and energy storage at commercial and small industrial sites. It is an optimization model, formulated as a mixed-integer linear program, used to solve for the optimal selection, sizing, and dispatch strategy of technologies chosen from a candidate pool at minimum life cycle cost. In evaluating on-site PV and BESS system options, the annual projected thermal and electrical loads after EEM and ECM implementation were used.

Recommendations

RECOMMENDATIONS FOR OPTIMIZED ENERGY EFFICIENCY MEASURES

The following are the specific individual options from each category that went into the final recommended optimized package. These options were selected to maximize energy savings and fuel use reductions. The community should explore all options considered. Some options might be better choices if thermal resiliency or other factors are higher priorities for the community. These should be explored with the community. The following measures were selected based on their ability to reduce overall energy usage.

Wainwright, Alaska has subsidized electricity and heating oil. The current price of heating oil as of October 2022 is \$1.75/gallon.[1] The subsidy is paid by the North Slope Borough. From the perspective of the Village of Wainwright, there is no combination of energy efficiency measures that are considered cost-effective to implement. The statement of work requested that focus be placed on energy savings and fuel use reductions.

Table 1. Optimized Option Selection of Energy Efficiency Measures

Component	Description
Envelope	
Roof	Install exterior continuous insulation or rigid foam product (R-25).
Walls	Install exterior continuous insulation or rigid foam product (R-25).
Windows	Install quadruple-pane, high-gain window, with fiberglass frame. (0.13 U-value, 0.47 Solar Heat Gain Coefficient (SHGC)
Door	Install one exterior insulated metal door (U-value 0.16). Install one exterior arctic entry with two insulated metal doors (U-value 0.16).
Air leakage	Reduce air leakage to 0.5 air changes per hour at 50 pascals (ACH50) or equivalent.
Mechanical	
Heating	Install one direct-vent heater.
Ventilation	Install demand-controlled ventilation (DCV) fans. Install heat recovery ventilation (HRV).
DHW	Install a hybrid heat pump water heater with a coefficient of performance (COP) of 2.8. Install low-flow fixtures and appliances (50% reduction in flow).
Electrical	
Lighting, Interior	Install LED fixtures. Install occupancy sensors and daylighting dimming controls.
Lighting, Exterior	Install exterior LED lighting with timers.
Interior Equipment	Install ENERGY STAR® appliances and use smart power strips.
Exterior Equipment	Install climate controls on the heat tape.
Exterior Equipment	Install timer and climate controls on the head bolt heater plug-ins.

ENERGYPLUS MODEL RESULTS

Under the consideration of maximizing energy efficiency only, the optimum combination of evaluated energy efficiency measures would decrease overall site energy use, or total site energy utilization intensity (EUI), by 76%. This would include an 86% reduction in on-site fossil fuel use and a 48% reduction in on-site electrical use.

---

[1] https://www.olgoonik.com/fuel-cost-changes-effective-oct-1/

Table 2. EnergyPlus Model Results for the Optimized Options

Metric	Unit	Baseline	Optimum Combined EEM Options	Percent Reduction
Total site EUI	kBTU/ft^2	191.0	45.6	76%
End-use heating	kBTU	212,131	29,297	86%
End-use interior lighting	kBTU	22,226	7,175	68%
End-use exterior lighting	kBTU	5,981	559	91%
End-use interior equipment	kBTU	15,800	10,663	33%
End-use exterior equipment	kBTU	17,847	14,985	16%
End-use fans	kBTU	4,076	2,370	42%
End-use water systems	kBTU	8,455	3,289	61%
Fuel consumption fuel oil number 1	kBTU	212,131	29,297	86%
Fuel consumption electricity heating	kWh			
End-use electricity interior lighting	kWh	6,514	2,103	68%
End-use electricity exterior lighting	kWh	1,753	164	91%
End-use electricity interior equipment	kWh	4,631	3,125	33%
End-use electricity exterior equipment	kWh	5,231	4,392	16%
End-use electricity fans	kWh	1,194	694	42%
End-use electricity water systems	kWh	2,478	964	61%

PV AND BESS SYSTEM EVALUATION RESULTS

A total of seven scenarios were analyzed in REopt with different permutations. Please refer to Section 3 for a discussion on the differences between these scenarios. Please refer to Appendix A for detailed individual scenario results.

With different permutations of costs, the total lifecycle cost of the project gets impacted resulting in different net present values (NPV)[2]. Positive NPV is used to determine economic viability of the project. The same solar PV and BESS capacity was used across Scenarios 2 through 7, so the energy and economic benefits associated with them remain the same irrespective of the different costs of the Scenarios. The project is not economically feasible for Scenarios 2 through 6, and for Scenario 7 the NPV is marginally positive.

In Scenario 7, the solar PV size was capped at 15 kW and BESS capacity was capped at 20 kWh and 5 kW using the REopt default cost for operating expenditures (OPEX) while the initial capital expenditures (CAPEX) for PV and BESS and replacement cost for BESS is covered by other funds. In other words, these are constraints set up in REopt and the model is forced to size these capacities using these costs as one of the inputs and report out the metrics accordingly.

---

[2] Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. Positive NPV means the project is viable (cash inflow is greater than cash outflows).

Next Steps

BUILDING CODE CHANGES

Alaska in October 2022 enacted a non-residential building code. This code explicitly excludes energy efficiency and energy conservation. There are several provisions that deserve review. This code was enacted after the analyses in this report were completed and delivered to the ETIPP client.

OPTIONAL ANALYSES RECOMMENDED

As a concurrent path, it is recommended that the community's priorities for resilience, reliability, decarbonization, and cost be evaluated. Strong arguments can be made for a non-economically feasible option if the community places a high value on resilience, reliability, and/or decarbonization.

OTHER ENERGY EFFICIENCY CONSIDERATIONS - THERMAL RESILIENCE

One of the options evaluated for heating considers an electric thermal storage (ETS) heater system. ETS heaters can be equipped with multiple heating elements and storage cores to allow them to provide heat while charging the other core. They can hold heat for about 24 hours and can fully charge from a cold state (i.e., ambient outside air temperature) in about 48 hours. A single core is usually sized to provide 24 hours of heat to a structure, meaning a fully charged dual-core ETS can supply up to 48 hours of heat. There are exceptions and charging mechanisms that can speed up the charging or prolong the heat output of a single charge.

> ETS heaters are an electrical variant of a mass heater system. Electrical energy is stored in an insulated mass, usually composed of ceramic bricks or phase change materials. Heat is then drawn from this mass to heat the room.
>
> ETS heater units come in a variety of sizes and from multiple manufacturers. Technologically they have improved since their introduction several decades ago. Current ETS heaters have integrated temperature controls and fans making them a reasonable replacement for a direct vent oil-fired heater.

ETS heaters can be charged from batteries or from the utility grid. ETS heaters may be useful on islanded systems when adding variable renewable energy sources like wind turbines or solar PV, as they can absorb excess power that might otherwise be curtailed in winter months for later use. They can also be charged during off-peak times allowing for load leveling and provide some "down" frequency regulation.

Thermal resilience in the context of this report is about maintaining the hours of cold safety provided by a structure, that is, the number of hours a structure can maintain interior temperatures at or above the cold safety threshold.

Different populations and demographics have different temperature thresholds for measuring cold stress, however according to the Rocky Mountain Institute, approximately 64 degrees Fahrenheit is the minimum safe temperature for vulnerable populations and 60 degrees Fahrenheit is the minimum safe temperature for healthy populations.[3]

There are mechanical systems such as ETS heaters and BESS (batteries) that can assist with thermal resilience. Passive systems like increased insulation can also assist with thermal resilience. Passive House-rated systems usually maintain temperatures within cold safety thresholds for about 16 to 18 hours and may maintain internal temperatures above freezing for a week.

Conversations with TNHA have indicated there may be a desire by the community to use the structure as a back-up emergency shelter. Depending on how the community chooses to prioritize efficiency and thermal resilience, the slight efficiency loss for the ETS heater—and therefore higher energy consumption—may be offset by the resilience benefits for the emergency shelter secondary role.

PV AND BESS SYSTEM NEXT STEPS

The only economically viable path for installation of a rooftop solar PV and BESS system for the site is Scenario 7. Scenario 7 assumes that the CAPEX and replacement cost of the PV+BESS systems are paid for with other funding, and that OPEX can be paid for at a non-location adjusted rate. These cost assumptions will need to be evaluated by TNHA for their likelihood of occurrence and potentially revised to refine the analysis.

NEAR TERM

It is recommended that steps be taken in the near term to validate the assumptions used in the PV and BESS scenarios. This includes the assumptions regarding no net metering and no grid interconnection with the PV and BESS system. If grid interconnection is to be considered, there are several basic assumptions that will need to be confirmed with the utility prior to continued analysis. These have been shared with TNHA. Assuming no major changes are found for the assumptions, then discussions about proceeding with Scenario 7, or determining feasibility based on priorities other than cost, should be considered.

As a concurrent path it is recommended that the community's priorities for resilience, reliability, decarbonization, and cost be evaluated. Strong arguments can be made for a non-economically feasible option if the community places a high value on resilience, reliability, and/or decarbonization.

---

[3] Hours of Safety in Cold Weather: A Framework for Considering Resilience in Building Envelope Design and Construction, https://rmi.org/wp-content/uploads/2020/02/Hours-of-Safety-insight-brief.pdf

Section 1 Thermal and Energy Analysis of Energy Efficiency Measures

1.1 Background

Wainwright, Alaska, is an isolated coastal Arctic community (located at 70º38’21” North, 160º01’50” West) with a diesel-fired islanded power grid. Natural gas is not available to the community of Wainwright. The community buildings’ heating and power generation fuel costs are heavily subsidized by the regional municipality, which imports diesel in bulk by annual barge during the summer period when the Chukchi Sea is ice free. In October 2022 the price for heating oil was increased to $1.75/gallon. Wainwright has no existing renewable generation. The community’s 30-year (1981–2010) annual heating degree day average is approximately 18,600. Wainwright has a population of approximately 675.

This project identified pathways to reduce energy consumption and enhance indoor environmental quality and resilience of a 1,500-square-foot former federal armory building owned by the tribe as it is renovated as a community multipurpose facility. The building sits above grade and is designed with no attic space. The building has not been used in over 10 years and has been moved at least twice. There is a high likelihood that it will be moved at least twice more before retrofits. The scope included thermal evaluation of multiple building efficiency measures, and a techno-economic exploration of an on-site renewable energy and integrated energy storage systems.

This technical assistance was provided by the Energy Transitions Initiative Partnership Project (ETIPP) team composed of the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and the Renewable Energy Alaska Project (REAP) working in collaboration with the Taġiuġmiullu Nunamiullu Housing Authority (TNHA) and their designated representatives.

1.1.1 Roles and responsibilities

In close communication and collaboration between the ETIPP team, TNHA, and TNHA’s architecture and engineering team (A&E) the roles and responsibilities were divided for the overall effort. This report summarizes the three main areas of evaluation by the ETIPP team. There are some unavoidable gaps that correspond to activities by TNHA, the A&E team, or TNHA’s civil engineering contractor.

TNHA served as the community representative. They represented the community’s viewpoints and constraints. TNHA would conduct the retrofits and likely have a long-term operations and maintenance role for the building. The A&E team conducted site inspections, made plan sets, and provided guidance on systems that must be replaced for code or other issues.

1.1.2 Site Information

In view of issues around travel during COVID-19, the decision was made and agreed on by all parties to limit in-person visits to the community. TNHA’s A&E team provided the ETIPP team with interior and exterior photos, basic floorplans, a Sketch-Up model, and site notes. These were used throughout the ETIPP tasks.

Key factors of note:

- The site has been unused and without power for over 10 years. As such, no records of actual energy usage for the site existed.
- The building had been moved twice, which stressed the major joins, necessitating some assumed base repair and maintenance.
- The structure at bare minimum needed additions, such as a mechanical ventilation system, and many electrical and mechanical systems were out of code compliance, whether electrical code, plumbing code, or for a childcare facility.
- The structure was 17 inches off level and in need of additional civil engineering work.
- The site is in the primary drainage path for that portion of the village, necessitating additional civil work to redirect the drainage flow for water, as well as potentially temporary relocation of the building during this work.

Retrofits for the building are part of a $750,000 Housing and Urban Development grant. As such, the stated intent is to lower operations and maintenance costs, specifically energy costs. The tribe will be operating the building as a childcare facility and will not have access to technical resources or the financial resources for costly maintenance, or high fuel bills. Therefore, getting the electric and fuel oil use as low as possible, and when decisions between the two were needed, erring on the side of a fuel oil device was the primary accepted approach for the energy efficiency recommendations.

In the initial ETIPP project meetings and exchanges with TNHA several lists of options by component were brought up and discussed. Several options were outright vetoed. This specifically included air source heat pumps. This reduced the technical team's analysis options. The A&E team and TNHA were both interested in a series of structurally insulated panel retrofit products that came in various thicknesses from approximately 3 inches to 5 inches of insulation. As such these were the primary options they wanted to examine for roofs and walls. They were not interested in any options that reduced interior space. Choice of mechanical systems and size of the mechanical room were also constraints provided by TNHA. TNHA also emphasized that they preferred options with the lowest maintenance requirements possible, since the available local technical capacity of Wainwright is limited.

The A&E team identified several site issues, which led to a civil engineering contractor being brought in by TNHA for a more detailed inspection. This inspection identified the need for major site work. Very importantly for the balance of the ETIPP technical work, this changed the priority and timing of the project for TNHA as funding for the civil work needed to be found before the project could proceed. This necessary delay resulted in TNHA's procurement efforts being pushed to an indeterminant future point since costs are currently undergoing severe shifts. Because of these delays and the uncertainty about the future of the project, at that time TNHA was unable to iterate fully and recommended against engaging with other community leaders such as the Tribal Council on key project decision-points.

1.2 Data Collection

This thermal and energy analysis focused on EEMs affecting the envelope, heating, ventilation, and air conditioning (HVAC), lighting, and domestic hot water (DHW).

TNHA's A&E contractor conducted an on-site inspection of the site. Photos were taken of interior and exterior details. In damaged areas, interior and exterior wall structures were identified. A Sketch-Up model was generated. This information was all made available to the ETIPP team.

The on-site inspection data was compared with a previously generated set of AkWarm models provided by TNHA. Several details of the construction in the AkWarm models differed from the on-site inspection data and photos.

AkWarm is an energy modeling software developed and maintained by Alaska Housing Finance Corporation, a public corporation owned by the State of Alaska. AkWarm is the only state-certified energy modeling software for use on state-funded residential ratings and state-funded retrofit programs. As such, it has high market penetration and is well-accepted in Alaska.

The ETIPP team created a new AkWarm "As-Is" model, and a matching "As-Is" EnergyPlus model. The ETIPP team then modified the EnergyPlus model to bring various components into code compliance[4]. This model, named "Baseline Compliance" or "Baseline," represents a business-as-usual case for simply bringing the building back into working order, but not improving its energy performance or efficiency. It represents the baseline model the ETIPP team has used to evaluate the energy efficiency measures considered.

1.3 Baseline Compliance Model

Our initial model consisted of modeling the structure as it stood. This structure was unfit for use as a childcare facility due to a lack of mechanical ventilation, low lighting levels, a mixture of outdated heating systems in the central space and leftover appliances from when it was a healthcare facility, among others. In order to ensure that the retrofit options were being compared to a reasonable baseline, certain changes were needed to the armory building to renovate it into a childcare facility. Other changes were needed to comply with electrical and plumbing code. These changes included adding ventilation, increasing interior lighting, adding exterior lighting by doorways, increasing interior and exterior plug-ins, among others. This set of changes, to better reflect the baseline, deliberately did not include any of the energy efficiency measure options and represents the business-as-usual case of doing the least to get the structure back into a usable condition that complies with relevant electrical, plumbing, and childcare code requirements.

---

[4] "Code" here refers to electrical, plumbing, and state childcare facility requirements.

Table 3. EnergyPlus Input Assumptions for the Baseline Compliance Model

Component	Inputs and Assumptions
Envelope	
Roof	10-inch structurally insulated panel (SIP) with an extended polystyrene (EPS) core
Walls	5-inch SIP with an EPS core
Floor	10-inch SIP with an EPS core
Windows	Double-pane, clear, with metal frame (0.36 U-value, 0.67 SHGC)
Doors	Metal door (0.4 U-value)
Air Leakage	6 ACH50 or 0.5 natural infiltration
Mechanical	
Heating	2x direct-vent oil-fired heaters
Ventilation	240 cubic feet per minute, no demand-controlled ventilation
DHW	40-gallon electric storage tank, no insulation on tank or pipes
Electrical	
Lighting, Interior	T-12 fixtures
Lighting, Exterior	100W metal halide
Equipment, Interior	Non-ENERGY STAR appliances and equipment
Equipment, Exterior	Heat tape Head bolt heaters (x2)
Scheduling	
Occupancy	Monday to Friday: 7:30 a.m.–5:30 p.m., 6–9 p.m. Saturday: 10 a.m.–6 p.m.
Heating	No night setback
Lighting, Interior	Occupied hours, reduced use in summer
Lighting, Exterior	Not on in summer
Equipment, Exterior	Heat tape: On September 15–April 15 Head bolt heaters: Occupied hours October–March, 25% load factor

Table 4. EnergyPlus Modeling Results for the Baseline Compliance Model

Metric	Unit	Baseline
Total site EUI	kBTU/ft^2	191.0
End-use heating	kBTU	212,131
End-use interior lighting	kBTU	22,226
End-use exterior lighting	kBTU	5,981
End-use interior equipment	kBTU	15,800
End-use exterior equipment	kBTU	17,847
End-use fans	kBTU	4,076
End-use water systems	kBTU	8,455
Fuel consumption fuel oil number 1	kBTU	212,131
Fuel consumption electricity heating	kWh	
End-use electricity interior lighting	kWh	1,571
End-use electricity exterior lighting	kWh	6,514
End-use electricity interior equipment	kWh	1,753
End-use electricity exterior equipment	kWh	4,631
End-use electricity fans	kWh	5,231
End-use electricity water systems	kWh	1,194

1.4 Evaluation of Energy Efficiency Measures

For the purposes of this analysis the building envelope is divided into separate component categories. These are: roof, walls, floor, windows, doors, and air leakage. For each retrofit category a brief description of the option is given followed by a table of results. The tables only have values where options affect the energy use in those categories. A roof insulation retrofit, for example, should not affect the domestic hot water load and thus would have no values in that row. To simplify the comparisons, values in the tables show the percent reduction from the baseline compliance model in the previous section. Please note that every option also includes the impact on total site EUI.

1.4.1 Envelope

For the purposes of this analysis the building envelope is divided into separate component categories. These are: roof, walls, floor, windows, doors, and air leakage.

1.4.1.1 Roof

Consultation with A&E confirmed an external retrofit of insulation was possible for the roof system. Several commercially available products exist that allow adding a structurally insulated panel (SIP) layer to an existing building envelop component including roofs. The general method of installation would be: (1) remove the metal roofing, (2) attach the retrofit product, and (3) reapply the metal roofing. Attachment options for the retrofit portion vary based on product and include bonding agents as well as physical attachments and fasteners.

1.4.1.2 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Add exterior continuous insulation or rigid foam product (R-15).
- **Option 2:** Add exterior continuous insulation or rigid foam product (R-20).
- **Option 3:** Add exterior continuous insulation or rigid foam product (R-25).

Table 5 shows the results from the three options considered for roof retrofits. The results show that Option 3, adding the equivalent of R-25 continuous insulation to the roof has the greatest energy use reduction.

Table 5. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Roof Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	2.1%	2.6%	2.6%
End-use heating	kBTU	2.7%	3.3%	3.8%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	-	-	-
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	2.7%	3.3%	3.8%
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	-	-	-
End-use electricity water systems	kWh	-	-	-

1.4.1.3 Walls

Consultation with A&E confirmed furring out was possible for the walls. Several commercially available products exist for retrofits to SIP envelope components. The general method of installation would be: (1) pull the siding, (2) attach the retrofit product, and (3) reapply the siding. Attachment options for the retrofit portion vary based on product and include bonding agents as well as physical attachments.

1.4.1.3.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Add exterior continuous insulation or rigid foam product (R-15).
- **Option 2:** Add exterior continuous insulation or rigid foam product (R-20).
- **Option 3:** Add exterior continuous insulation or rigid foam product (R-25).

Table 6 shows the results from the three options considered for wall retrofits. The results show that Option 3, adding the equivalent of R-25 continuous insulation to the walls has the greatest energy use reduction.

Table 6. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Wall Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	5.8%	6.8%	7.3%
End-use heating	kBTU	7.7%	9.0%	10.1%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	-	-	-
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	7.7%	9.0%	10.1%
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	-	-	-
End-use electricity water systems	kWh	-	-	-

1.4.1.4 Windows

Consultation with A&E confirmed that keeping the existing windows was an option. The existing windows are double-pane, clear, with a metal frame. Options 1 and 2 look at full replacement. Option 3 evaluates keeping the existing windows and including a secondary exterior double pane window to improve their performance. There was some concern that an exterior storm window, or even a second exterior double-pane window, could impede egress for operable windows.

Current new construction and retrofit practice for TNHA calls for the use of triple-pane, two low-e coated windows with a U-value of 0.17 to 0.19. Interest in going beyond their usual but staying within the bounds of not creating an experiment, quadruple-pane, high-gain windows with fiberglass frames were chosen for examination.

1.4.1.4.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Quadruple-pane, high-gain window, with fiberglass frame. This window has an overall 0.13 U-value and 0.47 SHGC.
- **Option 2:** Triple-pane, clear window, with fiberglass frame. This window has an overall 0.23 U-value and 0.6 SHGC.
- **Option 3:** Existing double-pane, clear window, with metal frame plus a secondary exterior double-pane clear window with fiberglass frame. This additional window has an overall 0.36 U-value and 0.67 SGHC.

Table 7 shows the results from the three options considered for window retrofits. The results show that Option 1, replacing the existing windows with quadruple-pane, high-gain windows offer the greatest energy use reduction.

Table 7. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Window Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	2.6%	1.6%	1.6%
End-use heating	kBTU	3.2%	1.8%	2.0%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	-	-	-
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	3.2%	1.8%	2.0%
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	-	-	-
End-use electricity water systems	kWh	-	-	-

1.4.1.5 Doors

Consultation with A&E confirmed doors would need replacement. A&E is considering adding a wraparound deck to the building. This would be intended to be an elevated play area. A&E is intending to solicit feedback from the community on this. If a wraparound deck is chosen, then an arctic entry cannot be installed, although a partial deck for the other side of the structure might be considered which would still allow for an arctic entry. Option 1 assumes no arctic entry is possible. Option 2 assumes an arctic entry can be included with one entrance.

1.4.1.5.1 Option Descriptions

Two options were considered for the purposes of ECM evaluation.

- **Option 1:** Both exterior doors replaced by insulated metal doors with a 0.16 U-value.
- **Option 2:** One exterior door replaced by an insulated metal door with a 0.16 U-value, and the other replaced by an exterior arctic entry with an insulated metal door (U-value 0.16) to the interior space and an insulated metal door (U-value 0.16) to the outside.

Table 8 shows the results from the two options considered for door retrofits. The results show that Option 2, replacing the existing doors and installing an arctic entry for one of the doors, has the greatest energy use reduction. If the community decides to install a wraparound deck, then the arctic entry option may not work, depending on the dimensions of the deck. This will be a decision-point for the community.

Table 8. Energyplus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Door Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction	
		Option 1	Option 2
Total site EUI	kBTU/ft^2	1.0%	1.6%
End-use heating	kBTU	1.3%	2.0%
End-use interior lighting	kBTU	-	-
End-use exterior lighting	kBTU	-	-
End-use interior equipment	kBTU	-	-
End-use exterior equipment	kBTU	-	-
End-use fans	kBTU	-	-
End-use water systems	kBTU	-	-
Fuel consumption fuel oil number 1	kBTU	1.3%	2.0%
Fuel consumption electricity heating	kWh	-	-
End-use electricity interior lighting	kWh	-	-
End-use electricity exterior lighting	kWh	-	-
End-use electricity interior equipment	kWh	-	-
End-use electricity exterior equipment	kWh	-	-
End-use electricity fans	kWh	-	-
End-use electricity water systems	kWh	-	-

1.4.1.6 Floor

Consultation with A&E confirmed that no floor retrofits were being considered, despite its above-grade nature. Cited reasons included: (1) Furring in/up would make internal heights difficult and would require moving or resizing interior doors, and (2) Furring out/down would require custom jigging around all the structural supports and beams leading to a large number of thermal bridges and gaps, greatly increasing cost while decreasing performance.

1.4.1.7 Air leakage

Consultation with A&E confirmed that the use of the baseline estimate for air leakage was an acceptable starting point. Reduction in air leakage is expected from fixes to the envelope (e.g., caulking, weatherstripping, etc.) in conjunction with the over-cladding from insulation and potential window retrofits.

TNHA has successfully built new construction to 0.32 ACH50 as far back as 2009, and has a history over the last decade of TNHA and other regional housing authorities successfully building new construction with air leakage rates of between 0.5 and 0.8 ACH50 for non-SIP construction, as well as successfully reaching 0.8 ACH50 for non-SIP air sealing retrofits. Retrofitting a SIP building through resealing and adding additional SIP layers should allow for reducing air leakage below 0.8 ACH50 and be within TNHA's capabilities. Ultimately TNHA's team would be expected to provide guidance on the level at which air sealing would become cost prohibitive for them.

1.4.1.7.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Reduce air leakage to 1.5 ACH50 or equivalent.
- **Option 2:** Reduce air leakage to 1.0 ACH50 or equivalent.
- **Option 3:** Reduce air leakage to 0.5 ACH50 or equivalent.

Table 9 shows the results from the three options considered for air leakage retrofits. The results show that Option 3, reducing air leakage to 0.5 ACH50 or the equivalent, has the greatest energy use reduction.

Table 9. Energyplus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Air Leakage Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	29.3%	32.5%	35.6%
End-use heating	kBTU	39.1%	43.4%	47.8%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	8.6%	10.7%	12.8%
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	39.1%	43.4%	47.8%
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	8.5%	10.6%	12.7%
End-use electricity water systems	kWh	-	-	-

1.4.2 Mechanical Systems

Mechanical systems are divided into heating, ventilation, and DHW for the purposes of this analysis. Air conditioning is not considered.

1.4.2.1 Heating

Consultation with A&E confirmed that the existing heating systems would be replaced. A&E suggested two new direct-vent heaters to replace the existing furnace, direct-vent heater, and electric baseboards. The Baseline case uses the two direct-vent heaters option. The options presented here were explored as ways to reduce energy use while still meeting the building's heating demands. Option 1 removes one of the Baseline model's direct-vent heaters, reducing the building to a single direct-vent heater. Option 2 evaluates the impact of a using a single direct-vent heater with a night setback. Option 3 replaces one of the direct vent heaters with a seasonal ETS heater.

Air source heat pumps (ASHP) were specifically not recommended by the A&E mechanical engineer for this environment. Wainwright has severe seasonal icing issues that would exacerbate issues with low efficiency during very cold temperatures. While ASHPs are improving, and are even seeing adoption in Kotzebue, the A&E team also felt the site was sufficiently unstable that there would be no location to accommodate the exterior unit of the system safely. TNHA's position indicated a desire to observe performance and lessons learned from Kotzebue before considering implementation on the North Slope. In keeping with the intent to not treat a childcare facility as an experiment, when TNHA does pilot an ASHP, it will be on another facility.

1.4.2.2 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Use only one direct-vent heater.
- **Option 2:** Use only one direct-vent heater with night setback.
- **Option 3:** Use one direct-vent heater and one seasonal ETS heater.

Table 10 shows the results from the three options considered for heating retrofits. The results show that Option 1, using only one direct-vent heater, has the greatest energy use reduction. Note that Option 3, which replaces one of the two direct-vent heaters of the Baseline with an ETS heater, shows a shifting of space heating load to electric from diesel and an actual increase in total site EUI. This is partially driven by the efficiency losses ETS heaters suffer from heat loss over time. ETS heaters can be very useful for thermal resilience during power outages and storms. This a decision-point for the community since the secondary purpose for the structure is as a backup emergency shelter.

Table 10. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Heating Options with Respect to the Baseline Energy Consumption

Metric	**Unit**	**Percent Energy Use Reduction**		
		Option 1	**Option 2**	**Option 3**
Total site EUI	kBTU/ft^2	8.4%	6.3%	-2.6%
End-use heating	kBTU	11.2%	8.7%	-3.2%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	-	9.5%	-
End-use water systems	kBTU	-	-0.9%	-
Fuel consumption fuel oil number 1	kBTU	11.2%	8.7%	12.6%
Fuel consumption electricity heating	kWh			-15.8%
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	-	9.5%	-
End-use electricity water systems	kWh	-	-0.9%	-

1.4.2.3 Ventilation

Consultation with A&E confirmed that the required fans will be: two bath fans, one range hood, and one dryer vent. The Baseline model uses this as its basis. The following are the options considered beyond that.

1.4.2.3.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Use demand-controlled ventilation (DCV) for all fans.
- **Option 2:** Install a heat recovery ventilator (HRV).
- **Option 3:** Use DCV for all fans and install an HRV.

Table 11 shows the results from the three options considered for ventilation retrofits. The results show that Option 3, using DCV for all fans and installing an HRV has the greatest energy use reduction.

Table 11. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Ventilation Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	7.3%	20.9%	22.0%
End-use heating	kBTU	9.8%	28.2%	29.8%
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	-	-	-
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	1.4%	8.6%	9.8%
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	9.8%	28.2%	29.8%
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	-	-	-
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	1.3%	8.5%	9.7%
End-use electricity water systems	kWh	-	-	-

1.4.2.4 Domestic Hot Water

Consultation with A&E confirmed that the existing DHW system would need to be replaced.

1.4.2.4.1 Option Descriptions

Four options were considered for the purposes of ECM evaluation.

- **Option 1:** Install new electric water heater (40-gallon tank) and add tank and pipe insulation (add R-10 to tank, add R-3 to pipes).
- **Option 2:** Install new electric water heater (40-gallon tank) and add tank and pipe insulation (add R-10 to tank, add R-3 to pipes). Install low-flow fixtures and appliances to reduce DHW flow rate by 50%.
- **Option 3:** Install a hybrid heat pump water heater with a co-efficient of performance (COP) of 2.8 that draws heat from the utility room.
- **Option 4:** Install a hybrid heat pump water heater with a COP of 2.8 that draws heat from the utility room. Install low-flow fixtures and appliances to reduce DHW flow rate by 50%.

Table 12 shows the results from the four options considered for DHW retrofits. The results show that Option 4, installing a hybrid heat pump water heater has the greatest energy use reduction. The option has a higher need for technical expertise to maintain the systems and a higher annual maintenance cost than Option 2, installing a new electric water heater, adding insulation to the plumbing system, and installing low flow appliances and fixtures. This a decision-point for the community.

Table 12. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the DHW Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction			
		Option 1	Option 2	Option 3	Option 4
Total site EUI	kBTU/ft^2		1.0%	0.5%	1.6%
End-use heating	kBTU	-0.3%	-0.3%	-1.2%	-0.3%
End-use interior lighting	kBTU	-	-	-	-
End-use exterior lighting	kBTU	-	-	-	-
End-use interior equipment	kBTU	-	-	-	-
End-use exterior equipment	kBTU	-	-	-	-
End-use fans	kBTU	-	-	-1.2%	-0.7%
End-use water systems	kBTU	9.5%	47.9%	44.1%	57.7%
Fuel consumption fuel oil number 1	kBTU	-0.3%	-0.3%	-1.2%	-0.3%
Fuel consumption electricity heating	kWh	-	-	-	-
End-use electricity interior lighting	kWh	-	-	-	-
End-use electricity exterior lighting	kWh	-	-	-	-
End-use electricity interior equipment	kWh	-	-	-	-
End-use electricity exterior equipment	kWh	-	-	-	-
End-use electricity fans	kWh	-	-	-1.2%	-0.8%
End-use electricity water systems	kWh	9.5%	47.9%	44.1%	57.7%

1.4.3 Electrical Systems

Electrical systems are divided into interior lighting, exterior lighting, interior appliances and equipment, and exterior appliances and equipment for the purposes of this analysis. Appliances and equipment, whether interior or exterior, were not part of the scope for the task but represent large energy consumers and places with energy savings potential. As they needed to be examined to create more accurate and complete models, EEMs that affect appliances and equipment are part of this analysis.

1.4.3.1 Interior Lighting

Consultation with A&E confirmed that the existing T-12 fixtures should be replaced. Option 1 considers an all-light-emitting-diode (LED) replacement. Option 2 combines LEDs with energy conservation controls.

1.4.3.1.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Replace all interior fixtures with LED fixtures.
- **Option 2:** Replace all interior fixtures with LED fixtures. Install occupancy sensors and daylighting dimming controls.

Table 13 shows the results from the two options considered for interior lighting retrofits. The results show that Option 2, replacing all interior fixtures with LED fixtures and installing occupancy and daylighting controls has the greatest energy use reduction.

Table 13. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Interior Lighting Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction	
		Option 1	Option 2
Total site EUI	kBTU/ft^2	-0.5%	-0.5%
End-use heating	kBTU	-6.9%	-7.7%
End-use interior lighting	kBTU	60.0%	67.7%
End-use exterior lighting	kBTU	-	-
End-use interior equipment	kBTU	-	-
End-use exterior equipment	kBTU	-	-
End-use fans	kBTU	-2.1%	-2.3%
End-use water systems	kBTU	-	-
Fuel consumption fuel oil number 1	kBTU	-6.9%	-7.7%
Fuel consumption electricity heating	kWh	-	-
End-use electricity interior lighting	kWh	60.0%	67.7%
End-use electricity exterior lighting	kWh	-	-
End-use electricity interior equipment	kWh	-	-
End-use electricity exterior equipment	kWh	-	-
End-use electricity fans	kWh	-2.1%	-2.3%
End-use electricity water systems	kWh	-	-

1.4.3.2 Exterior Lighting

Consultation with A&E confirmed existing exterior lighting would be replaced and that the minimum lighting would include exterior lighting at each entrance.

1.4.3.2.1 Option Descriptions

Three options were considered for the purposes of ECM evaluation.

- **Option 1:** Install exterior LED lighting.
- **Option 2:** Install exterior LED lighting with photo sensors.
- **Option 3:** Install exterior LED lighting with timers.

Table 14 shows the results from the three options considered for exterior lighting retrofits. The results show that Option 3, replacing all exterior fixtures with LED fixtures with timers, has the greatest energy use reduction.

Table 14. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Exterior Lighting Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction		
		Option 1	Option 2	Option 3
Total site EUI	kBTU/ft^2	1.6%	1.6%	2.1%
End-use heating	kBTU	-	-	-
End-use interior lighting	kBTU	-	-	-
End-use exterior lighting	kBTU	70.1%	85.1%	90.7%
End-use interior equipment	kBTU	-	-	-
End-use exterior equipment	kBTU	-	-	-
End-use fans	kBTU	-	-	-
End-use water systems	kBTU	-	-	-
Fuel consumption fuel oil number 1	kBTU	-	-	-
Fuel consumption electricity heating	kWh	-	-	-
End-use electricity interior lighting	kWh	-	-	-
End-use electricity exterior lighting	kWh	70.1%	85.1%	90.6%
End-use electricity interior equipment	kWh	-	-	-
End-use electricity exterior equipment	kWh	-	-	-
End-use electricity fans	kWh	-	-	-
End-use electricity water systems	kWh	-	-	-

1.4.4 Appliances and Equipment

1.4.4.1 Interior Appliances and Equipment

Consultation with A&E confirmed that all appliances should be replaced with appliances that at minimum meet or exceed ENERGY STAR requirements.

1.4.4.1.1 Option Descriptions

Two options were considered for the purposes of ECM evaluation.

- Option 1: Install ENERGY STAR appliances.
- Option 2: Install ENERGY STAR appliances and use smart power strips.

Table 15 shows the results from the two options considered for interior appliances and equipment retrofits. The results show that Option 2, replacing all exterior fixtures with LED fixtures with timers, has the greatest electricity use reduction. However, the reduction in waste heat from the more efficient appliances increases the need for space heating, resulting in no reduction in total site EUI. Whether to look for high efficiency electric appliances and equipment and consume more heating oil or have less efficient electric appliances and equipment and consume more electricity is a decision-point for the community.

Table 15. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Interior Appliance Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction	
		Option 1	Option 2
Total site EUI	kBTU/ft^2	-	-
End-use heating	kBTU	-2.0%	-2.6%
End-use interior lighting	kBTU	-	-
End-use exterior lighting	kBTU	-	-
End-use interior equipment	kBTU	25.0%	32.5%
End-use exterior equipment	kBTU	-	-
End-use fans	kBTU	-0.7%	-0.9%
End-use water systems	kBTU	-	-
Fuel consumption fuel oil number 1	kBTU	-2.0%	-2.6%
Fuel consumption electricity heating	kWh	-	-
End-use electricity interior lighting	kWh	-	-
End-use electricity exterior lighting	kWh	-	-
End-use electricity interior equipment	kWh	25.0%	32.5%
End-use electricity exterior equipment	kWh	-	-
End-use electricity fans	kWh	-0.8%	-1.0%
End-use electricity water systems	kWh	-	-

1.4.4.2 Exterior Appliances and Equipment

Consultation with A&E confirmed that heat tape will be needed for the municipal water and sewer lines. A&E also confirmed that plug-ins for head bolt heaters will also be needed.

1.4.4.2.1 Option Descriptions

Two options were considered for the purposes of ECM evaluation.

- Option 1: Install climate controls on the heat tape.
- Option 2: Install timer and climate controls on the plug-ins for the head bolt heaters.

Table 16 shows the results from the two options considered for exterior appliances and equipment retrofits. The results show that Option 2, installing timers and climate controls on the plug-ins for the head bolt heaters, has the greatest electricity use reduction.

Table 16. EnergyPlus Modeling Results Showing the Percent Reduction in Energy Consumption for Each of the Exterior Appliance Options with Respect to the Baseline Energy Consumption

Metric	Unit	Percent Energy Use Reduction	
		Option 1	Option 2
Total site EUI	kBTU/ft^2	-	1.0%
End-use heating	kBTU	-	-
End-use interior lighting	kBTU	-	-
End-use exterior lighting	kBTU	-	-
End-use interior equipment	kBTU	-	-
End-use exterior equipment	kBTU	2.1%	14.0%
End-use fans	kBTU	-	-
End-use water systems	kBTU	-	-
Fuel consumption fuel oil number 1	kBTU	-	-
Fuel consumption electricity heating	kWh	-	-
End-use electricity interior lighting	kWh	-	-
End-use electricity exterior lighting	kWh	-	-
End-use electricity interior equipment	kWh	-	-
End-use electricity exterior equipment	kWh	2.1%	14.0%
End-use electricity fans	kWh	-	-
End-use electricity water systems	kWh	-	-

1.5 Recommendations for Optimized Energy Efficiency Measures

Table 17 shows the specific individual options from each category that went into the final recommended optimized package. These options were selected to maximize energy savings and fuel use reductions. The community should explore all options considered. Some options might be better choices if thermal resiliency or other factors are higher priorities for the community. These should be explored with the community. The following measures were selected based on their ability to reduce overall energy usage.

Table 17. EEM Options Selected to Maximize Energy Savings and Fuel Use Reductions

Component	Option	Description
Envelope		
Roof	3	Install exterior continuous insulation (R-25).
Walls	3	Install exterior continuous insulation (R-25).
Windows	1	Install quadruple-pane, high-gain window, with fiberglass frame (0.13 U-value, 0.47 SHGC).
Door	2	Install one exterior insulated metal door (U-value 0.16). Install one exterior arctic entry with two insulated metal doors (U-value 0.16).
Air leakage	3	Reduce air leakage to 0.5 ACH50 or equivalent.
Mechanical		
Heating	1	Install one direct-vent heater.
Ventilation	3	Install DCV fans. Install an HRV.
DHW	4	Install a hybrid heat pump water heater (COP 2.8). Install low-flow fixtures and appliances (50% reduction in flow).
Electrical		
Lighting, Interior	2	Install LED fixtures. Install occupancy sensors and daylighting dimming controls.
Lighting, Exterior	3	Install exterior LED lighting with timers.
Interior Equipment	2	Install ENERGY STAR appliances and use smart power strips.
Exterior Equipment	1	Install climate controls on the heat tape.
Exterior Equipment	2	Install timer and climate controls on the head bolt heater plug-ins.

1.5.1 EnergyPlus Model Results

Under the consideration of maximizing energy efficiency only, the optimum combination of evaluated energy efficiency measures would decrease overall site energy use, or total site EUI, by 76%. This would include an 86% reduction in on-site fossil fuel use and a 48% reduction in on-site electrical use. Table 18 shows how energy use is impacted by end-use category. Figure 1 provides a more visual understanding of the change from Baseline to the optimum EEM package.

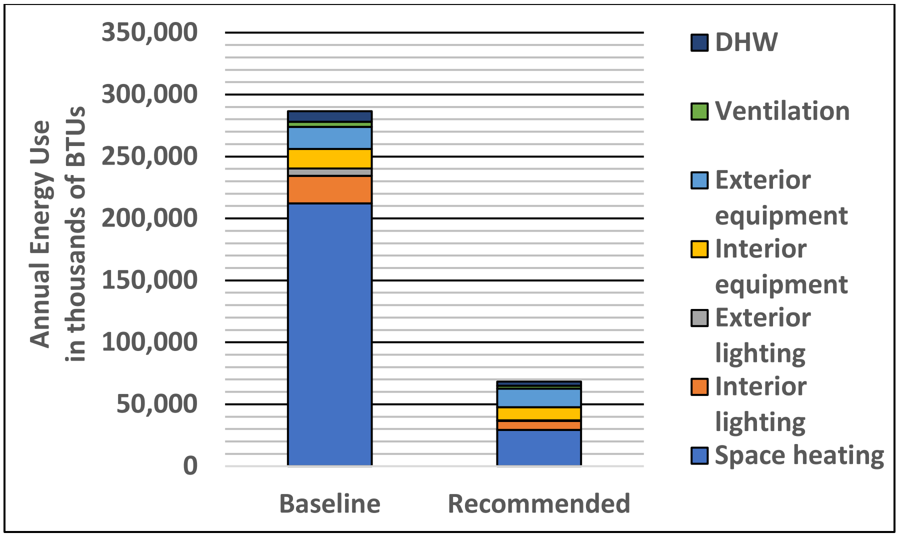

Figure 1. Comparison of the baseline and recommended annual energy use with colored breakdown by end-use.

Table 18. Energy and Model Results for the EEM Option Package Selected to Maximize Energy Savings and Fuel Use Reductions

Metric	Unit	Baseline	Optimum Combined	Percent Reduction
Total site EUI	kBTU/ft^2	191.0	45.6	76%
End-use heating	kBTU	212,131	29,297	86%
End-use interior lighting	kBTU	22,226	7,175	68%
End-use exterior lighting	kBTU	5,981	559	91%
End-use interior equipment	kBTU	15,800	10,663	33%
End-use exterior equipment	kBTU	17,847	14,985	16%
End-use fans	kBTU	4,076	2,370	42%
End-use water systems	kBTU	8,455	3,289	61%
Fuel consumption fuel oil number 1	kBTU	212,131	29,297	86%
Fuel consumption electricity heating	kWh			
End-use electricity interior lighting	kWh	6,514	2,103	68%
End-use electricity exterior lighting	kWh	1,753	164	91%
End-use electricity interior equipment	kWh	4,631	3,125	33%
End-use electricity exterior equipment	kWh	5,231	4,392	16%
End-use electricity fans	kWh	1,194	694	42%
End-use electricity water systems	kWh	2,478	964	61%

1.5.2 Other Considerations: Thermal Resilience

Option 3 for heating considers an ETS system. ETS can be equipped with multiple heating elements and storage cores to allow them to provide heat while charging the other core. They can hold heat for about 24 hours and can fully charge from a cold house (i.e., ambient outside air temperature) in about 48 hours. A single core is usually sized to provide 24 hours of heat to a structure, meaning a fully charged dual-core ETS can supply up to 48 hours of heat. There are exceptions and charging mechanisms that can speed up the charging or prolong the heat output of a single charge.

ETS heaters can be charged from batteries or other similar energy storage systems. As such, they can be either grid enabled or attached to rooftop solar as well.

Islanded grids find ETS heaters a useful addition when adding variable renewable energy sources like wind, as they can push excess power in winter months to homes with these heaters. Because of their ability to absorb and hold a heating load, they can be charged during off-peak times allowing for load leveling and frequency regulation.

Depending on how the community chooses to prioritize efficiency and thermal resilience, the slight efficiency loss for the ETS may be worth it for the resiliency gains.

Section 2 Solar Photovoltaic (PV) and Battery Energy Storage Systems (BESS) Techno-Economic Analysis

2.1 REopt Modeling of PV and BESS Systems

Per the community's application and the statement of work (SOW), the site was evaluated for the practical installation of a solar PV and BESS behind the meter (BTM)5 system under direct purchase financing scenario at a 1,500-square-foot former federal armory building owned by the tribe as it is renovated as a community multipurpose facility. Unlike a traditional BTM BESS system where load shifting is intended to take advantage of rate differences, this BESS system is intended to capture as much solar PV for use on site during the shoulder and summer months as possible and provide support to critical systems in the winter months when storm-caused power outages could affect heating and ventilation. The summer use is intended to reduce utility electrical use and shoulder fossil fuel use, while the winter use is intended to enhance thermal resilience.

Technology Overview – Battery Energy Storage Systems

BESS are transforming the energy sector through their ability to support renewable energy and reduce grid reliance on carbon-intensive resources. By storing excess energy during demand lulls and discharging it as electricity at the later time during demand peaks, BESS may cost-effectively lower consumers' utility bills, relieve stress on the grid, lower carbon emissions, and provide resilient power. There are many forms of energy storage, each with its own costs, challenges, and benefits. In this report the focus is on BESS.

Figure 2 shows several energy storage technologies and their suitability for distributed applications including pairing with distributed solar photovoltaic (DPV) power generation. This figure is not a comprehensive list of all existing and emerging storage technologies.[6]

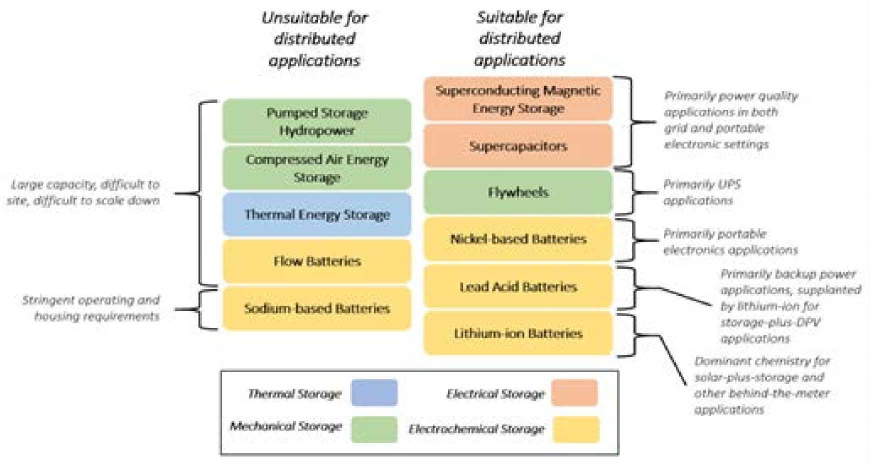

Figure 2. Energy storage technologies and applications

---

[5] BTM systems in this context are solar PV and BESS systems interconnected behind the utility meter (i.e., the customer side) of a commercial customer. This is done to minimize impact on the grid from such systems.

[6] Zinaman, Owen, Thomas Bowen, and Alexandra Aznar. 2020. *An Overview of Behind-the-Meter Solar-Plus-Storage Program Design: With Considerations for India*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy20osti/74131.pdf

2.1.1 Modeling Tool

The modeling tool used to assess the PV and BESS feasibility was the Renewable Energy Integration and Optimization tool, REoptTM. The REopt tool evaluates the economic viability of grid-connected solar photovoltaics, wind, combined heat and power (CHP), and storage at commercial and small industrial sites. It is an optimization model, formulated as a mixed-integer linear program, used to solve for the optimal selection, sizing, and dispatch strategy of technologies chosen from a candidate pool such that loads are met at every time-step at the minimum life cycle cost. Figure 3 shows a schematic of the REopt model.

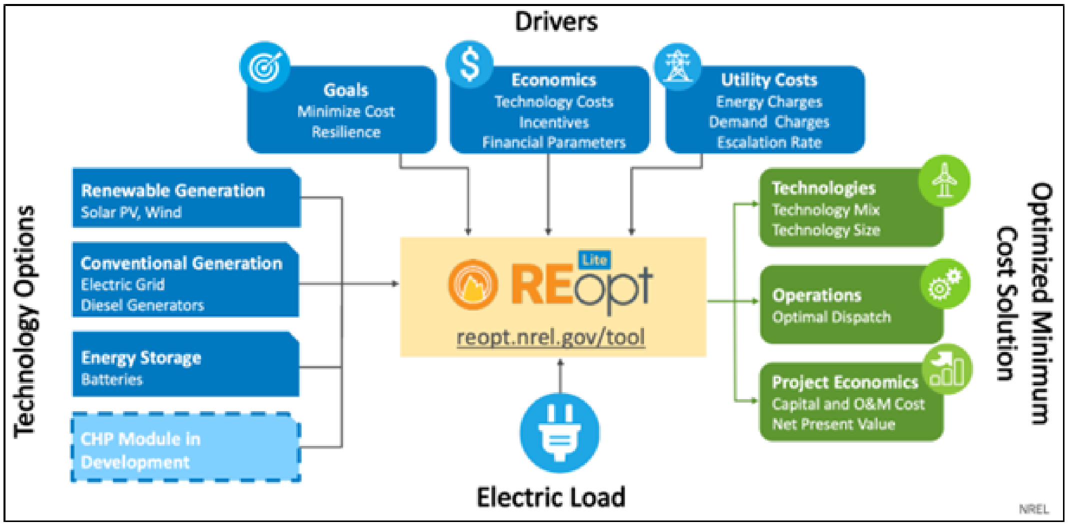

Figure 3. Schematic of the REopt energy planning program

2.2 Site Description

2.2.1 Constraints for PV and BESS Systems

In determining whether the PV systems should be roof-mounted or ground-mounted, there were several considerations. Findings for site shading, ground conditions, and lot use suggested a ground mounted system was not advisable for the site. Among the findings were:

- **Site shading -** The A&E contractor’s photos identified several surrounding structures that could impede low angle light in the shoulder seasons for ground-mounted systems on the site. This would lower the electrical production of the system and shorten its usable season.
- **Ground conditions -** The site is in the primary drainage path for that side of the village. Surface conditions are not stable and are deteriorating. Ground-mounted systems would require excessive engineering.
- **Lot use -** Plans for the structure suggest that the lot’s open areas may have other uses that ground-mounted solar would block or impede. These uses include areas for children to play, a requirement for childcare facilities.

2.2.2 PV Size Potential

Given the square footage of the roof, a roof-mounted solar PV system is limited to 15 kW. Some roof-mounted configurations would be smaller. For the purposes of analysis, the system size was assumed to be 15 kW.

2.2.3 PV Resource Availability

A roof-mounted solar PV system with the parameters found in Table 19 would produce an estimated 10,915 kWh annually at the facility in Wainwright, Alaska. Solar production can be assumed to be unavailable due to frost accumulation on roof-mounted panels for some winter months. Table 20 shows monthly PV production for the facility without accounting for these possible losses.

Table 19. Basic PVWatts Data Inputs

PVWatts: Performance Data	
Requested Location:	Wainwright, Alaska
Location:	Barrow Wiley-Post Will Rogers Airport, Alaska
Latitude (degrees North):	71.32
Longitude (degrees West):	156.62
Elevation (m):	10
DC System Size (kW):	15
Module Type:	Standard
Array Type:	Fixed (open rack)
Array Tilt (deg):	18.4
Array Azimuth (deg):	180
System Losses:	14.08
Invert Efficiency:	96
DC to AC Size Ratio:	1.2

Table 20. Monthly Generation from PV as Generated by PVWatts

Month	AC Energy (kWh)
January	4
February	218
March	1,212
April	1,839
May	2,034
June	1,760
July	1,827
August	1,199
September	533
October	272
November	17
December	0
Annual	10,915

2.2.4 Utility Rate Structure

North Slope Borough Power & Light utility serves this building. It is on a commercial rate schedule[7]. Table 21 shows the tiered energy usage charge structure. There is no demand charge. These rates were used to model the rate schedule in REopt.

Table 21. North Slope Borough Power & Light Tiered Usage Charge Structure for Monthly Electrical Rates

Tier	Use (kWh/month)	Cost ($/kWh)
1	<= 1,000	$0.20/kWh
2	<= 10,000	$0.30/kWh
3	> 10,000	$0.35/kWh

2.3 Load Analysis

The total site load consumption is approximately 11,489 kWh and 5.5 kW demand. Figure 4 shows the 15-minute interval load profile of the building. This load data was estimated from EnergyPlus building energy simulation modeling of the facility with optimum combination EEMs for energy savings and reduced fossil fuel use. The average daily demand is approximately 2 kW in winter, suggesting that with smart controls, timers and scheduling it may be possible to decrease the daily peak demand of 5 kW further. Detailed information on load profiles can be found in Appendix B. As seen in the figure here, the electrical load drops in summer as there is no electric heating demand or calls from the heat tape on the water line and it picks up in the winter months.

---

[7] https://apps.openei.org/USURDB/rate/view/539f72d1eB4f024411ecf539#3__Energy

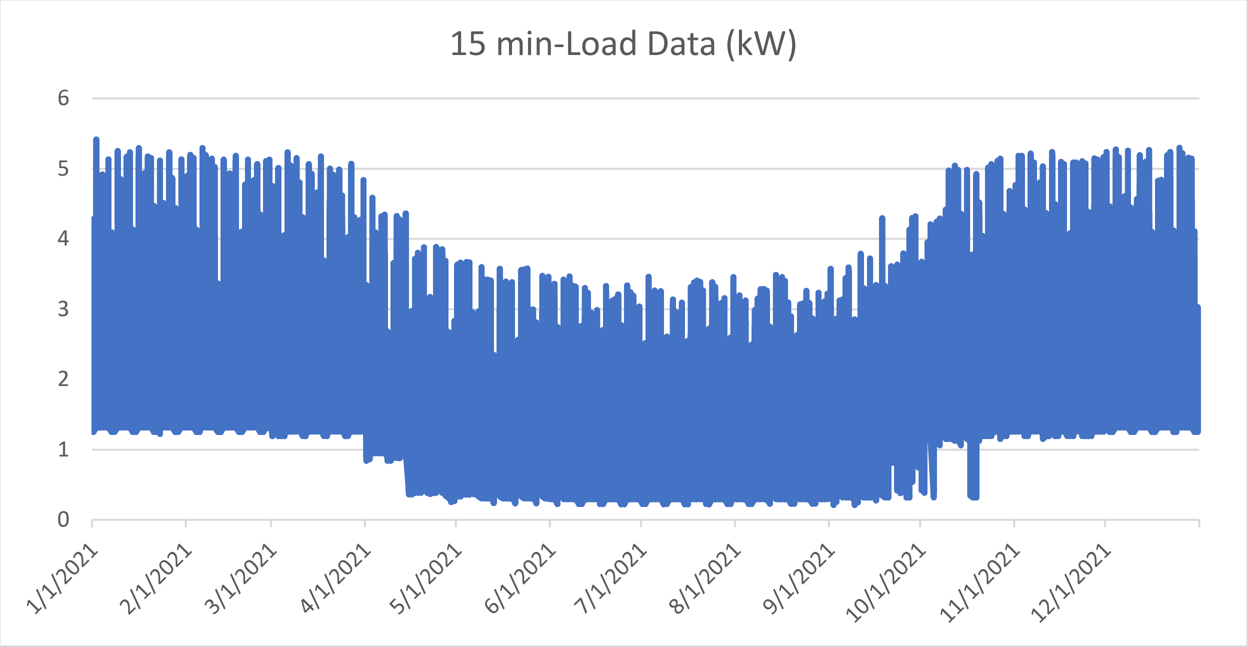

Figure 4. Fifteen-minute interval load profile of the projected building electrical usage showing the seasonal differences to electrical demand.

2.3.1 Energy Storage Sizing

The initial methodology for sizing of the electrical storage system was derived from the average monthly residential electrical consumption for Wainwright in winter as found in the Power Cost Equalization (PCE) data. While less accurate, it provided a baseline to be refined. The average daily usage was calculated, and a 50% increase was applied arriving at approximately 20 kWh. This sizing held for early planning purposes.

Once the EnergyPlus modeling of the structure with ECMs was completed, Sandia National Laboratories analyzed the 15-minute load data generated for the optimized model and determined that 20 kWh was an appropriate sizing of the BESS for winter use. If the childcare facility must be used for its secondary purpose as a backup emergency shelter in winter, a 20-kWh system would be capable of providing power to critical systems for an extended period when just powering the space heating (Toyo) and the ventilation (HRV). The exact length of time it could support would depend on the specific systems chosen as critical.

To fully capture all PV generation in the summer, the BESS system would need to be much larger, even after subtracting the electrical consumption of the structure over the same period.

2.4 Scenario Analysis

First it is important to note that the initial analysis by REopt showed that the best solution was to not install either PV or BESS systems. In both a preliminary run that used REopt’s default Lower 48 cost inputs with Wainwright power outputs, and in Scenario 1 which used location adjusted cost inputs, REopt found that no options for system size that were cost effective. However, the community had expressed an interest in the impact a PV and BESS integrated system could have on reducing utility electrical use. Scenarios were developed to explore the costs around the system.

A total of seven scenarios were examined for economic feasibility, including Scenario 1. For six of these scenarios the energy output and storage capacity of the PV and BESS systems were held constant. That is, the PV was sized at 15 kW and the BESS was sized at 20 kWh and 5 kW. The financial assumptions were then changed. Specifically, the capital expenditures (CAPEX), operating expenditures (OPEX), location adjustment factor (LAF), and replacement costs (RC). For the purposes of some scenarios a LAF of 2.5 was applied to default financial assumptions in REopt for CAPEX, OPEX, and RC.

Scenario 1 utilized a LAF of 2.5 for all CAPEX, OPEX, and RC. Scenario 1 was the only scenario where the PV and BESS sizing was not fixed and REopt was allowed to optimize for size. REopt did not find a cost-effective solar PV and BESS systems size under the scenario conditions.

Scenario 2 utilized a LAF of 2.5 all CAPEX, OPEX, and RC, but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was not cost-effective in REopt under the scenario conditions.

Scenario 3 utilized default REopt costs for all CAPEX, OPEX, and RC, but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was not cost-effective in REopt under the scenario conditions.

Scenario 4 assumed that CAPEX would be paid by other funding sources. It utilized a LAF of 2.5 for all OPEX and RC but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was not cost-effective in REopt under the scenario conditions.

Scenario 5 assumed that CAPEX would be paid by other funding sources. It assumed there was no LAF for RC and utilized a LAF of 2.5 for all OPEX but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was not cost-effective in REopt under the scenario conditions.

Scenario 6 assumed that CAPEX and RC would be paid by other funding sources. It utilized a LAF of 2.5 for all OPEX but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was not cost-effective in REopt under the scenario conditions.

Scenario 7 assumed that CAPEX and RC would be paid by other funding sources. It assumed there was no LAF all OPEX but fixed the system sizes for PV and BESS as mentioned above. The PV and BESS was cost-effective in REopt under the scenario conditions.

Table 22 summarizes the key changes for these seven scenarios as described above.

Table 22. Summary of Key Factors from the REopt Scenarios for PV and BESS

Scenario	Description	Inputs	Cost-effective
1	Optimized size PV+BESS and all costs location-adjusted	LAF = 2.5 for CAPEX, OPEX, and R Sizing = Not capped	No
2	Fixed size PV+BESS and all costs location-adjusted	LAF = 2.5 for CAPEX, OPEX, and RC Sizing = Capped	No
3	Fixed size PV+BESS and no location-adjusted costs	No LAF for CAPEX, OPEX, and RC Sizing = Capped	No
4	Fixed size PV+BESS with CAPEX by other funding, all other costs location-adjusted	CAPEX paid for by other funding LAF = 2.5 for OPEX, and RC Sizing = Capped	No
5	Fixed size PV+BESS with CAPEX by other funding, no location-adjustment for RC, OPEX location-adjusted	CAPEX paid for by other funding No LAF for RC LAF = 2.5 for OPEX Sizing = Capped	No
6	Fixed size PV+BESS with CAPEX and RC by other funding, OPEX location-adjusted	CAPEX and RC paid for by other funding LAF = 2.5 for OPEX Sizing = Capped	No
7	Fixed size PV+BESS with CAPEX and RC by other funding, no location-adjustment for OPEX	CAPEX and RC paid for by other funding No LAF for OPEX Sizing = Capped	Yes

Specific additional details on the inputs for each scenario can be found in Appendix A.

2.4.1 Scenario Assumptions

The following tables summarize the major assumptions utilized in the scenario models that are site-specific or that diverge from REopt default assumptions. The scenario assumes no net-metering. If that situation were to change, there are several assumptions that have been shared with TNHA regarding the grid that would need to be verified with the utility.

Table 23. Technical Assumptions for the Solar PV System

Input	Assumption
System type	Fixed tilt, Roof mount
PV Tilt	18.4 degrees (4/12 roof pitch)
PV degradation	0.5%/year
Technology costs	LAF Cost = $6.00/Wdc
Incentives	Applicable under direct pay option (Inflation Reduction Act) 30% Investment Tax Credit (ITC)
O&M cost	LAF Cost = $42.5/kWdc-year

Table 24. Technical Assumptions for the BESS System

Input	Assumption
Battery type	Lithium-ion
AC-AC round trip efficiency	90%
Minimum state of charge	20%
Battery charging rules	Analysis assumes BESS only charges from PV
Technology costs	Capital costs: LAF Cost = $970/kWh +$1938 /kW Replacement (at year 10): LAF Cost = $550/kWh + $1100/kW
Incentives	Applicable under direct pay option (Inflation Reduction Act); 30% Investment Tax Credit (ITC)

2.4.1.1 Financial Assumptions

A direct purchase, or self-ownership, financing scenario was considered for this analysis. A direct purchase scenario is an arrangement when the customer directly installs, owns, operates, and maintains an energy system (solar PV and BESS in this case) on its property. Under the Inflation Reduction Act (IRA), tribes are eligible for a 30% ITC when a system is installed under direct purchase scenario but are ineligible for depreciation.

2.5 Scenario Results

With different permutations of costs, the total life cycle cost of the project is impacted, resulting in different net present values (NPV). NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. Positive NPV means the project is viable (cash inflow is greater than cash outflows). Positive NPV is used to determine economic feasibility of a project.

The same solar PV and BESS capacity was used across Scenarios 2 through 7, so the electrical generation and offsets associated with the system remain the same irrespective of the changes in costs. As seen from Table 25, the project is not economically feasible for Scenarios 1 through 6, and for Scenario 7 the NPV is marginally positive, which means the project is economically feasible if the assumptions hold true.

Table 25. Scenario Results

Scenario	PV CAPEX	BESS CAPEX		Replacement BESS CAPEX		PV OPEX	PV Capacity	BESS Capacity		Year 1 UCS	AES	Total LCUS	Total LCC for BAU	Total LCC	NPV
	$/Wdc	$/kWh	$/kW	$/kWh	$/kW	$/kW	kW	kWh	kW	($)	kWh	($)	($)	($)	($)
1	6.00	970	1,938	550	1,100	42.50	0	0	0	NA	NA	NA	42,587	NA	NA
2	6.00	970	1,938	550	1,100	42.50	15	20	5	282	4,475	6,227	42,587	143,265	(100,678)
3	10.60	388	775	220	440	17	15	20	5	282	4,475	6,227	42,587	70,548	(27,961)
4	0	0	0	550	1,100	42.50	15	20	5	282	4,475	6,227	42,587	58,181	(15,594)
5	0	0	0	220	440	42.50	15	20	5	282	4,475	6,227	42,587	52,138	(9,551)
6	0	0	0	0	0	42.50	15	20	5	282	4,475	6,227	42,587	48,110	(5,523)
7	0	0	0	0	0	17	15	20	5	282	4,475	6,227	42,587	41,060	1,527

AES = annual energy saved

BAU = business as usual

CAPEX = capital expenditures

LCC = life cycle costs

LCUS = life cycle utility savings

NPV = net present value

UCS = utility cost savings

2.6 Additional Analyses

2.6.1 Exploration of Net Zero Requirements

2.6.1.1 PV Capacity Needed to Reach 100% Net Zero

The structure with the optimum EEMs is estimated to need 29,297 kBTUs of fuel oil, or approximately 8,600 kWh if converted to electricity. When added to the 11,489 kWh of electrical consumption, that is just over 20,000 kWh annually. The roof-mounted 15 kW array generates 10,915 kWh annually, so a properly placed array twice the size of the roof array, or 30 kW, would generate sufficient electricity to displace the fuel oil consumed on a net annual basis.

2.7 Suggested Next Steps

The only economically viable path for installation of a rooftop solar PV and BESS system for the site is Scenario 7. Scenario 7 assumes that the CAPEX and RC of the PV and BESS systems are paid for with other funding, and that OPEX can be paid for at a non-location adjusted rate. These cost assumptions will need to be evaluated by TNHA for their likelihood of occurrence and potentially revised to refine the analysis.

2.7.1 Near Term

It is recommended that steps be taken in the near term to validate the assumptions used in the scenarios. This includes the no net-metering and no grid interconnection with the PV and BESS system. If grid interconnection is to be considered, there are several basic assumptions that will need to be confirmed with the utility prior to continued analysis. These have been shared with TNHA. Assuming no major changes are found for the assumptions, then discussions about proceeding with Scenario 7, or determining feasibility based on priorities other than cost should be considered.

2.7.1.1 Optional Analyses Recommended

As a concurrent path it is recommended that the community's priorities for resilience, reliability, decarbonization, and cost be evaluated. Strong arguments can be made for a non-economically feasible option if the community places a high value on resilience, reliability, and/or decarbonization.

Appendices

Appendix A. REopt Scenario Outputs

Table A-1. Basic Size and Output Parameters

Parameters	**BAU**	**PV+ BESS**
PV Size	Not applicable (N/A)	15 kW
PV Energy Production	N/A	10,284 kWh
Battery Power	N/A	5 kW
Battery Capacity	N/A	20 kWh
Average Annual Energy Supplied from the Grid	11,449 kWh	6,974 kWh

Table A-2. Year 1 Utility Electricity Cost

Parameter	**BAU**	**PV+BESS**
Utility Energy Cost	$722	$440
Utility Fixed Cost	$1,207	$1,207
Total year 1 Utility Cost	$1,929	$1,647
Total Life Cycle Utility Electric Cost	$42,587	$36,361

Table A-3. Summary Financial Metrics

Parameter	**BAU**	**Scenario**					
		2	**3**	**4**	**5**	**6**	**7**
Total CAPEX + RC with ITC	n/a	$95,156	$29,488	$10,072	$4,029	$0	$0
Total Life Cycle OPEX	n/a	$11,749	$4,700	$11,749	$11,749	$11,749	$4,700
Total Life Cycle Costs	$42,587	$143,265	$70,548	$58,181	$52,138	$48,110	$41,060
Net Present Value	$0	**-$100,678**	**-$27,961**	**-$15,594**	**-$9,551**	**-$5,523**	**$1,527**
Payback Period (years)	N/A	>25	>25	>25	>25	>25	>25

Appendix B. Load Profile Analysis

In the subsequent tables and figures that follow, “summer” refers to the period between April 15 and October 14, and “winter” refers to the period between October 15 and April 14.

Tables B1 through B3 characterize the daily electrical loads. Table B1 presents basic statistics of daily electrical load variations for an entire year. Tables B2 and B3 present the electrical load for the summer and winter, respectively. During the summer months, the electrical load is significantly less than in the winter months. All three tables show that if the EEMs are adopted, the electrical load is reduced by approximately 50%. This does vary with time of year, but the key point is that the adoption of EEMs represents a significant electrical savings over the course of a year. Figures B1 and B2 make this point graphically clear. Two points are worth noting. The first, as already mentioned, is the significant reduction in electrical load when EEMs are adopted. The second point is made clear by comparing Figures B1 and B2 to see that the spread in electrical load from day to day is considerably less when EEMs are adopted. That is, the day-to-day variance in electric load is significantly reduced.

Table B-1. Statistics on Daily Electric Load in kWh with and Without Adoption of Energy Efficiency Measures (EEMs)

Daily Load	Baseline Electric Load, kWh	Electric Load with EEMs, kWh
Maximum	87	53
75th Percentile	86	47
Mean	60	31
Median	54	35
25th Percentile	45	17
Minimum	16	7
48 Hour Battery Sizing	173	105
Total Yearly Load	21,801	11,449

Table B-2. Statistics on Daily Electric Load in kWh for Summer (April 15–October 14) With and Without Adoption of EEMs

Summer Daily Load	Baseline Electric Load, kWh	Electric Load with EEMs, kWh
Maximum	86	48
75th Percentile	50	21
Mean	45	19
Median	45	17
25th Percentile	39	16
Minimum	16	7
48 Hour Battery Sizing	173	97
Total Season Load	8,190	3,401

Table B-3. Statistics on Daily Electric Load in kWh for Winter (January 1–April 15, October 15–December 31) With and Without Adoption of EEMs

Winter Daily Load	Baseline Electric Load, kWh	Electric Load with EEMs, kWh
Maximum	87	53
75th Percentile	86	50
Mean	74	44
Median	86	47
25th Percentile	54	38
Minimum	27	13
48 Hour Battery Sizing	173	105
Total Season Load	13,612	8,048

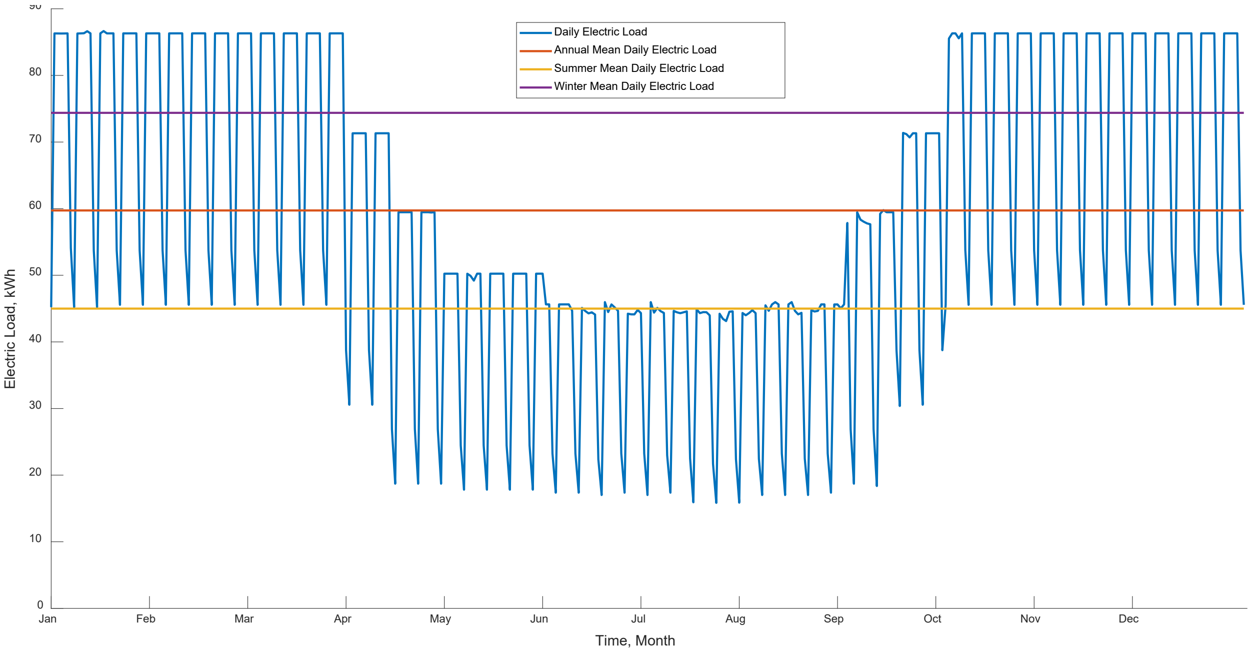

Figure B-1. Time series plot of daily electric load (Baseline) in kWh with annual mean, summer mean, and winter mean daily electric load values overlaid on the plot.

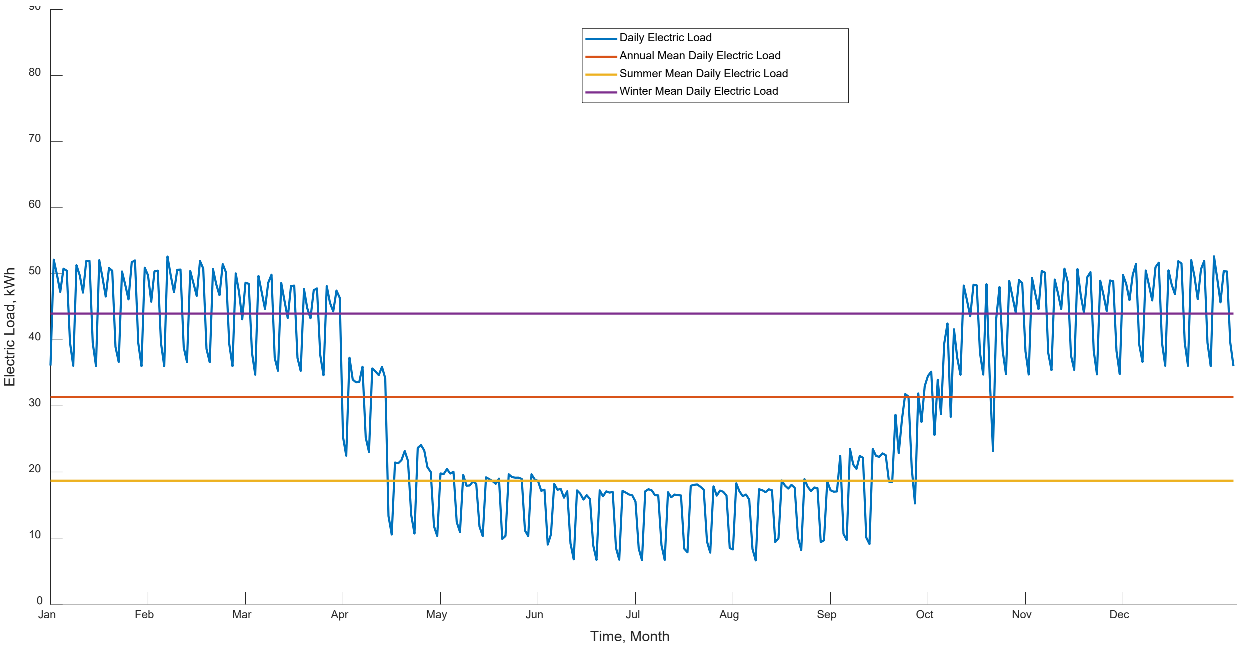

Figure B-2. Time series plot of daily electric load (with adoption of EEMs) in kWh with annual mean, summer mean, and winter mean daily electric load values overlaid on the plot.

Tables B4 through B6 present statistics of the electrical load on an hourly basis. Significant reductions in hourly electrical load are very clear with EEMs adopted. In Tables B4 through B6, the statistics presented show the improvements with EEMs.

Table B-4. Statistics on Hourly Power Usage in kW With and Without Adoption of EEMs

Hourly Power Usage	Baseline Electric Power Usage, kW	Electric Power Usage with EEMs, kW
Maximum	5.9	5.4
75th Percentile	3.7	1.8
Mean	2.5	1.3
Median	2.0	1.3
25th Percentile	1.2	0.5
Minimum	0.6	0.2

Table B-5. Statistics on Hourly Power Usage in kW for Summer With and Without Adoption of EEMs

Summer Hourly Power Usage	Baseline Electric Power Usage, kW	Electric Power Usage with EEMs, kW
Maximum	5.9	5.0
75th Percentile	2.6	1.0
Mean	1.9	0.8
Median	1.3	0.6
25th Percentile	0.8	0.3
Minimum	0.6	0.2

Table B-6. Statistics on Hourly Power Usage in kWh for Winter With and Without Adoption of EEMs

Winter Hourly Power Usage	Baseline Electric Power Usage, kWh	Electric Power Usage with EEMs, kWh
Maximum	5.9	5.4
75th Percentile	4.4	2.4
Mean	3.1	1.8
Median	2.1	1.6
25th Percentile	1.9	1.3
Minimum	0.8	0.3

Table B7 presents the statistics for the PV+BESS system. The much longer periods of daylight in the summer compared to the winter are numerically characterized in Table B7. It should be noted that in these tables the AC output power of the PV+BESS system is the primary focus. This does involve some losses in the DC to AC inverter (about 4%), but it also is the power source that is directly used by the facility.

Table B-7. Statistics on AC Power Output from PV and BESS System in kW for Full Year, Summer, and Winter

Hourly PV Power Output	PV+BESS System AC, kW	Summer PV+BESS System AC, kW	Winter PV+BESS System AC, kW
Maximum	11.4	11.4	10.3
75th Percentile	1.6	3.0	0
Mean	1.2	2.0	0.5
Median	0	1.0	0
25th Percentile	0	0.1	0
Minimum	0	0	0
Total Annual PV Power Output, kWh	10,915	8,713	2,202

Table B8 shows the number of hours of zero PV power output for a year and for both summer and winter. As one might expect, there are more than three times as many hours in the winter half of the year of zero PV power than in the summer half of the year.

Table B-8. Number of Hours Per Year, Summer, Winter, Respectively, for which there is Zero PV Output Power

No. of Hours of	Annual PV Output Power	Summer PV Output Power	Winter PV Output Power
Zero Output Power	4,464	1,011	3,453
Non-Zero Output Power	4,296	3,369	927
Total No. of Hours	8,760	4,380	4,380