Feasibility Study for a Net-Zero Energy Campus Retrofit

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ABSTRACT

In order to realize significant decreases in the United States' dependence on fossil fuels, many commercial buildings must become net-zero energy in the near future. In addition to net-zero energy new construction, many buildings must also be retrofit to be net-zero energy. Compared to new construction, which only represents about two percent of the existing building stock in any given year, retrofitting existing facilities to meet net-zero energy standards presents difficult technical and economical challenges (Brown, Southworth, & Stovall, 2005). Foremost among these challenges are the lack of usable space for renewable energy installations and the cost of both renewable energy systems and energy-efficiency improvement projects.

This paper first discusses a path to net-zero energy for the Akron Zoo campus that may be a model for other commercial facilities. This path includes aggressive energy-efficiency combined with on-site renewable energy installations. Next, the analysis focuses on major implementation constraints, particularly on limited usable space for renewable energy generation. Further, economic comparisons between energy-efficiency and renewable energy are used to determine optimal economic decisions. Next we present analysis of possible energy-efficiency opportunities and how we arrived at unexpected conclusions. Finally, we present conclusions that support the Akron Zoo's capability to achieve net-zero energy status.

Industry Focus on Net-Zero Energy

In the last decade there has been a major focus on net-zero energy buildings from a number of different organizations. The American Institute of Architecture (AIA) 2030 Challenge sets the goal achieving carbon-neutral new construction and major renovations by 2030 (AIA 2012). The US Army has a similar goal of net-zero energy use for all operational forces and permanent installations by 2030 (Lopez 2010). In its Vision 2020 report, ASHRAE sets the goal of developing tools by 2020 that can "enable the building community to produce market viable Net-Zero Energy Buildings (NZEBs) by 2030." (ASHRAE 2008). A number of other prominent entities, such as National Renewable Energy Laboratory (NREL), the Department of Energy (DOE), and the California Public Utilities Commission, have similar goals for net-zero buildings in the coming decades. All of these goals are focused on new buildings or major renovations, and do not address goals for retrofitting existing buildings for net-zero energy use.

Net-Zero Energy Definitions

NREL has identified four classifications of NZEBs (Pless & Torcellini 2010):

- **Net-Zero Site Energy:** A building produces, at a minimum, as much renewable energy that it uses in a year, with all of the energy being produced on-site.

- **Net-Zero Source Energy:** A building produces as much electricity as is produced at the utility source. This method takes into account the energy that is used to extract, process, generate, and deliver electricity to the site.
- **Net-Zero Energy Costs:** The goal of the building owner is to not spend any money per year on electricity (i.e., the amount the utility pays the building owner for generating renewable energy is equal to or greater than the amount the owner pays the utility company for various services).
- **Net-Zero Emissions:** A building either produces or purchases enough renewable energy to offset emissions from all building energy use on an annual basis.

The paths to net-zero energy occupy a spectrum between 100% renewable energy, and 100% energy-efficiency/conservation measures. 100% renewable energy is prohibitive due to high cost and limited usable land area. 100% energy-efficiency/conservation is not practical when there is a need for energy using equipment; which is a reality of modern society. Thus these two paths must be blended for NZEB project.

Campus Overview & Client Goals

The Akron Zoo campus is a 50-acre campus of buildings in Akron, OH. The annual electricity consumption is approximately 2.2 million kWh, across 13 different electricity meters. Annual natural gas consumption is over 77,000 ccf, across five different meters. The total utility bill is approximately $300,000 per year. The campus has over two dozen buildings on-site, one of which has achieved LEED Gold certification. The building types consist of animal exhibits, animal holding facilities, a visitor center, administrative offices, cooking & food services, and maintenance buildings.

The Akron Zoo has set a goal to achieve net-zero energy status for its entire campus. Through meetings and discussion with the client, the classification of “net-zero site energy” was chosen. In this preliminary discussion, it was also decided that the only feasible renewable energy options would be solar photovoltaic (PV) and wind power. Since the campus uses natural gas, it cannot be considered truly net-zero site energy unless all of the natural gas-using equipment is converted to electric equipment or eliminated. This effectively increases the annual campus electricity consumption, which requires additional generation or efficiency.

Constraints of Net-Zero Energy Retrofit vs. New Construction

Net-zero energy projects are all subject to common constraints, which include budget, renewable energy location and production limitations, aesthetics, economics, and a lack of a true renewable source of natural gas, to name a few. There is a wealth of net-zero energy new-construction literature available that has already been published across peer-reviewed journals and conference proceedings. New construction projects have the luxury of almost limitless customizability of systems and design decisions. When working with a renovation of a building or campus, many of the luxuries in net construction are unavailable, such as envelope orientation, most envelope construction properties, and even some HVAC renovations. In this paper, we discuss the constraints specific to a zoological campus of buildings with a limited budget and land area. Similar constraints should be applicable to most net-zero campus retrofits.

First, we considered the campus' ability to install renewable energy. In all retrofit projects, site selection to maximize available wind or solar resources is impossible. The campus does have a limited amount of available south-facing roofs, un-covered parking lots, open grassy areas, and un-shaded walkways that could serve as PV mounting locations. Also, there is only one feasible location on the campus for a larger-scale wind turbine. Large, mature trees provide shade for animals and visitors while also causing PV and wind installation obstacles.

Second, aesthetics is a critical factor for the zoo's marketing efforts and ongoing ticket sales. According to facility staff, solar parking structures cannot be erected over the main parking corridor, as these would obstruct a visitor's initial view of the large opening gates. These obstructions would "make the zoo less welcoming" and might turn away visitors. Additionally, zoos across the country spend significant resources on exhibit and pedestrian area design. Many of these areas are not conducive to PV installations as they would detract from the look of the exhibits, which have been specifically designed to appear as natural habitat. Further, a prominent wind turbine located on the campus' tall monument hill will have community-based concerns, as the zoo is located in a residential neighborhood.

Third and most obviously, no project has an unlimited budget. Cost-effectiveness of all renewable energy and efficiency projects is crucial to success, especially for a publically funded site. In our analysis, simple payback and return on investment are utilized instead of lifecycle cost. With constantly changing prices for energy and the installation of renewable energy, these simple metrics are more than sufficient for project decision making. Also, there is no widely acceptable method of renewable natural gas production. Arguably, there are some biomass or landfill sources of methane, but these are very location-specific and are ignored here.

The combination of these constraints caused the need to establish a better-defined net-zero energy path.

Path to Net-Zero Energy

First, it was necessary to understand the availability of on-site renewable energy installation locations, disregarding budgetary concerns. We were astonished to determine that if all available renewable energy sites were utilized, that the resulting generation would not match the campus' electricity needs. Thus, the campus would not physically be able to implement just a few efficiency measures of their choosing and make up the rest of their needs through renewable generation. Aggressive efficiency would be fundamental to achieving net-zero energy

Second, PV economics must be calculated to provide a comparative benchmark. The calculations in this study are not exhaustive of all PV options available. However, they are based upon quoted data from vendors, test-case PV installations that the campus had already installed, and our past experience. On a flat roof, common PV systems are installed at a 10-degree tilt. While the most optimal PV tilt angle is roughly equal to the latitude of the site, a 10-degree tilt is typically associated with the cheapest bracketing and roof-mounting equipment. Using PVWatts[1], we simulated a PV system in Akron, OH at a 10-degree tilt and determined that it can generate an annual total of 10.64 kWh per square foot or 1,064 kWh per kW of installed PV. Using the Akron Zoo's test PV system installation cost and discussions with multiple installers, we can expect a large campus-wide PV installation to be about $4.50/watt. This cost includes some amount of bracketing and mounting over parking areas and walkways. Without these

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[1] http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

expensive mounting needs, the installation cost would decrease significantly. We calculate the cost per kWh of generation as:

($4.50 / Installed Watt) x (1000 W/kW) x (1 kW / 1,064 kWh/year) = $4.23 / kWh

The campus' avoided cost of electricity is $0.06/kWh. Thus, the simple payback and return on investment for such PV installations would be:

Simple payback (years) = Implementation Cost ($) / Annual Savings ($/year)
= ($4.23 / kWh) / $($0.06/kWh) = 70.5 years
Return on Investment (%) = 1 / Simple payback (years) = 1 / 70.5 = 1.42%

Third, wind economics must be calculated to provide an additional benchmark. Analysis began with an in-depth search for wind turbine sizes, installation costs, and performance curves. Through discussions with multiple installers, we determined that two 200-kW turbines might be most appropriately sized for the campus. According to our research, such turbines might each cost about $387,000 to install, and annually save $22,601. The simple payback for wind would be:

$387,000 / ($22,601/year) = 17 years

Following preliminary campus analysis and renewable energy economic calculations, the team was prepared to lay out a path for the Akron Zoo to achieve net-zero site energy. This path is comprised of a combination of a detailed investigation and analysis followed by implementation. Investigation and analysis would allow the team to compare energy efficiency investments and renewable energy installations to fit the economic and physical constraints of the campus and determine an appropriate implementation plan.

Investigation and Analysis of Energy Consumption Characteristics

The investigation and analysis phase began with detailed utility analysis. As mentioned previously, there are two dozen buildings, 13 electrical meters, and five natural gas meters serving the campus. The team analyzed the utility data and the applicable rate structures to determine avoided costs of electrical energy, electrical demand, and natural gas consumption. We use the avoided costs throughout the analysis to convert energy or demand savings into cost savings. In Table 1, we present electric and natural gas avoided costs.

Table 1. Electric and natural utility avoided costs

Energy Component	Avoided Cost
Electrical Energy ($/kWh)	$0.060
Electrical Demand ($/kW)	$6.58
Natural Gas ($/ccf)	$1.28

After completing the utility analysis, our team created temperature change-point models, also known as energy signatures, for each meter (Kissock, Reddy, & Claridge 1998). Energy signatures are useful in several ways; they serve as normalized baselines of current energy use, can be evaluated to identify savings opportunities, can be used to conduct past-performance and multi-facility benchmarking, and can be used in the measurement of energy savings.

We typically work with a minimum of twelve months of monthly electricity or natural gas usage to determine an energy signature. This allows us to fully capture a year's worth of usage for analysis with the change in seasonal temperatures. Once the energy signatures are created, we normalize utility consumption to account for annual weather changes. Then, we "drive" the energy signature with typical meteorological data (TMY3) to determine the percentage of electricity use for air-conditioning, space heating, and temperature-independent loads.

Next, we create a campus energy-use breakdown using the energy signature models, utility analysis, and data from our site visit, which will be explained shortly. The energy use breakdown was a crucial tool during the net-zero campus study. The breakdown both assigned specific energy use to 14 separate end-use categories and helped our team to focus analysis. We present the electricity use breakdown in Figure 1 and the natural gas use breakdown in Figure 2.

Figure 1. Electricity Use Breakdown

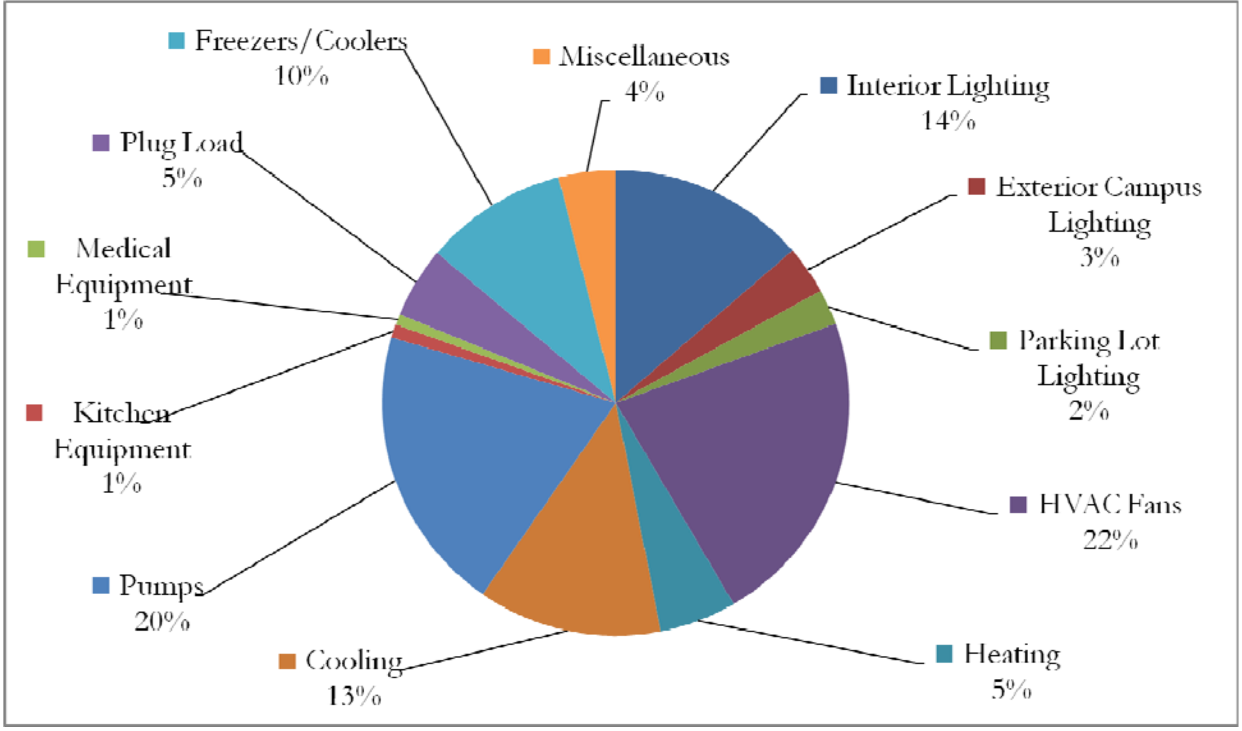
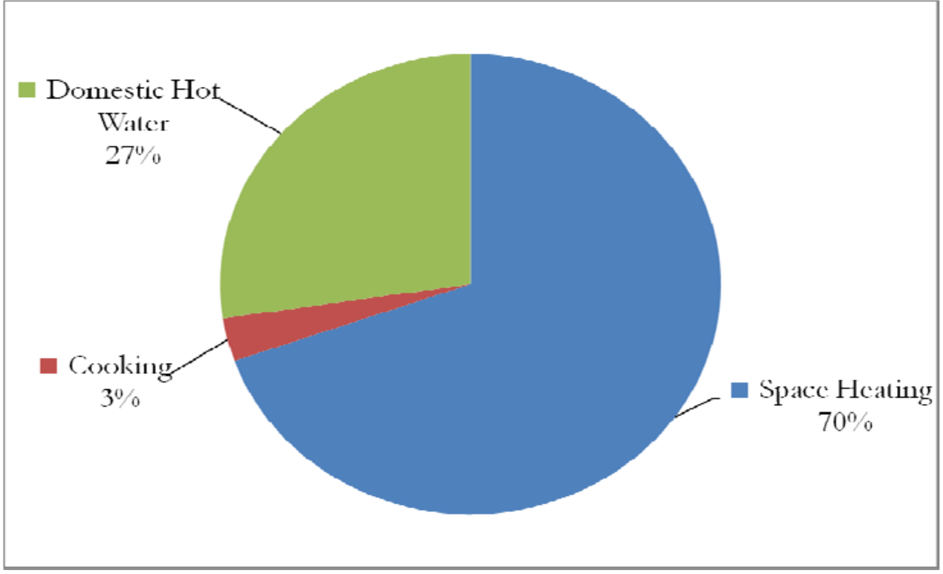


Figure 2: Natural Gas Use Breakdown



Informed with detailed knowledge of how the campus consumes energy, the next step was the energy audit & data collection phase. During the energy audit, our team scrutinized all energy using equipment on campus during daytime and nighttime site visits. We used an array of tools to collect data including spot readings and data loggers. Typical data collection included light level, temperature, relative humidity, equipment current draw, plug load power consumption, et cetera. In addition, we reviewed mechanical, electrical, plumbing, and architectural construction drawings for more detailed data about systems. Finally, we discussed systems and campus operations with facility staff.

Following the energy audit, our team performed energy simulations and calculations. We created and calibrated energy models for almost every building on campus using eQuest[2]. These models were used to simulate a variety of lighting, HVAC, and envelope recommendations. In addition to these energy models, our team also used custom energy simulation software tools to analyze individual systems. Finally, we performed custom spreadsheet and hand calculations to both “sanity-check” our energy modeling results and to support additional recommendations.

Recommendations & Observations

Our efforts for finding energy-efficiency improvements were focused in six main categories; lighting, pumps, HVAC, kitchen and food cooling, domestic hot water, and office/plug loads. In each category, the efficiency improvements ranged from low-to-no-cost recommendations all the way through expensive capital expenditures. Due to the aggressive requirements of a net-zero energy building, even equipment that had a low energy use, such as office plug loads, were thoroughly analyzed.

Other authors have published papers about energy audits, auditing techniques, energy savings and economic calculations; this is not the purpose of this paper. We emphasize that an independent, unbiased energy audit of an existing facility can yield significant energy savings. We briefly summarize some of the recommendations from the energy audit by category:

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[2] http://www.doe2.com/equest/

- Lighting – Efforts focused on upgrading lighting technologies, employing dimming or occupancy sensor controls, eliminating fixtures, and reducing runtime. Initially, installing skylights in many spaces looked to be a sound recommendation. However, when compared to the reduced roof area for PV installation and the project's area constraint, skylights were eliminated.
- Pumps – Pumping energy is consumed to move water for waterfalls, animal exhibits, and heating and cooling systems. Our efforts focused on reducing runtime, throttling, optimizing variable-frequency drive (VFD) operation, high-efficiency pumps & motors, and even a potential re-design of piping for low-friction and pump motor size and power reduction.
- HVAC – HVAC energy is used to keep occupants comfortable and to ensure that they have sufficient air quality. HVAC energy is often consumed unnecessarily when a facility is unoccupied, under-occupied, or when equipment does not operate correctly. We focused on fan scheduling to reduce operating hours, temperature setbacks, fixing economizer operations, demand control ventilation, and whole-system retrofits with high-efficiency units. We even found excessively high water-loop temperature in the campus' LEED-Gold certified ground-source heat pump system, which was causing this highly-efficient system to operate very inefficiently. In addition, the same system was experiencing simultaneous heating and cooling, which is wasteful.
- Food Services – In the campus freezers, we found opportunities to raise setpoint temperature, upgrade fan & lighting controls, and perform demand-based defrost control. In the kitchens, VFD kitchen exhaust could significantly decrease fan and space conditioning energy as the exhaust would only run when cooking is actually occurring. Additionally, a variety of fan motors were inefficient and vending machines did not have occupancy sensors. Unlike a traditional energy audit, we also found that using outdoor air to "economize" in large walk-in freezers was more cost effective than installing PV.
- Domestic Hot Water - Due to the PV area constraint, solar thermal DHW could not be recommended, due to offset PV generation. Therefore we recommended replacing gas fired water heaters with electric heat pump water heaters. This both accomplishes an increase in DHW efficiency and aids in the conversion of natural gas equipment to electric.
- Plug Loads: Computers, printer, copiers, and other electricity using equipment exists across campus. There are opportunities to employ occupancy sensors, schedules, energy-efficiency settings, and to replace equipment with lower power equivalents. While some of these recommendations have small impacts, they allow the campus to avoid the installation of a significant amount of PV.

Net-Zero Energy Breakdown Summary

We identified over 40 energy-efficiency recommendations that result in a 30% decrease in campus-wide energy consumption for an average simple payback of about 7 years. This reduction takes into account increased electricity needs after converting all natural gas-fired equipment to electric. A total of 1.36 MW of PV will provide 45% of the electricity needs while two 200-kW wind turbines will provide the remaining 25% of the electricity needs. We present the net-zero site energy breakdown in

Figure 3.

Figure 3. Net-Zero Site Energy Breakdown

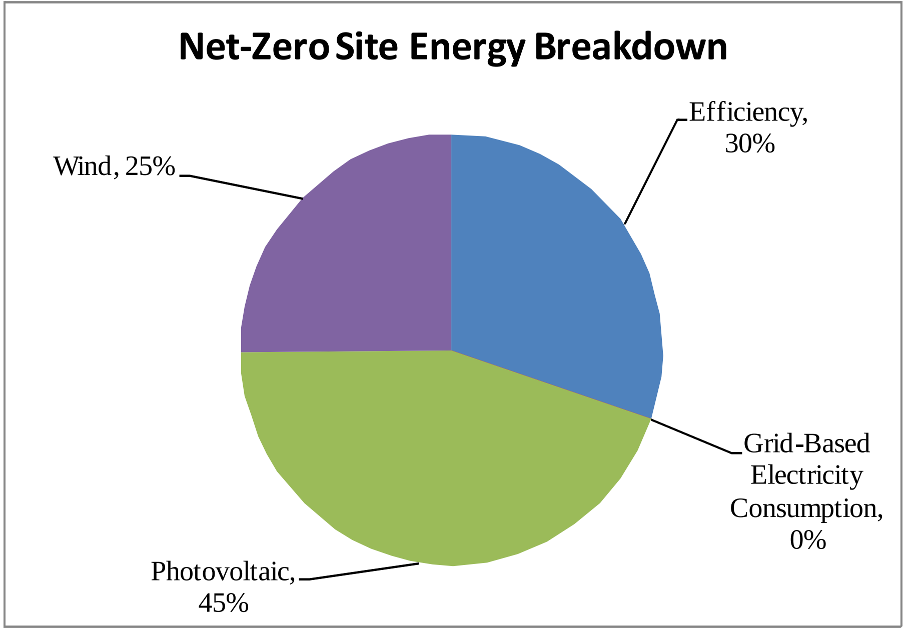


Table 2 provides a summary of the energy savings from each category of efficiency recommendations. Total annual savings of $107,077 can be achieved through implementation of these recommendations. The average rate of return for all recommendations is approximately 13.6%. The category that provided the greatest amount of savings was lighting. There were also considerable savings from the HVAC and envelope and pump recommendations.

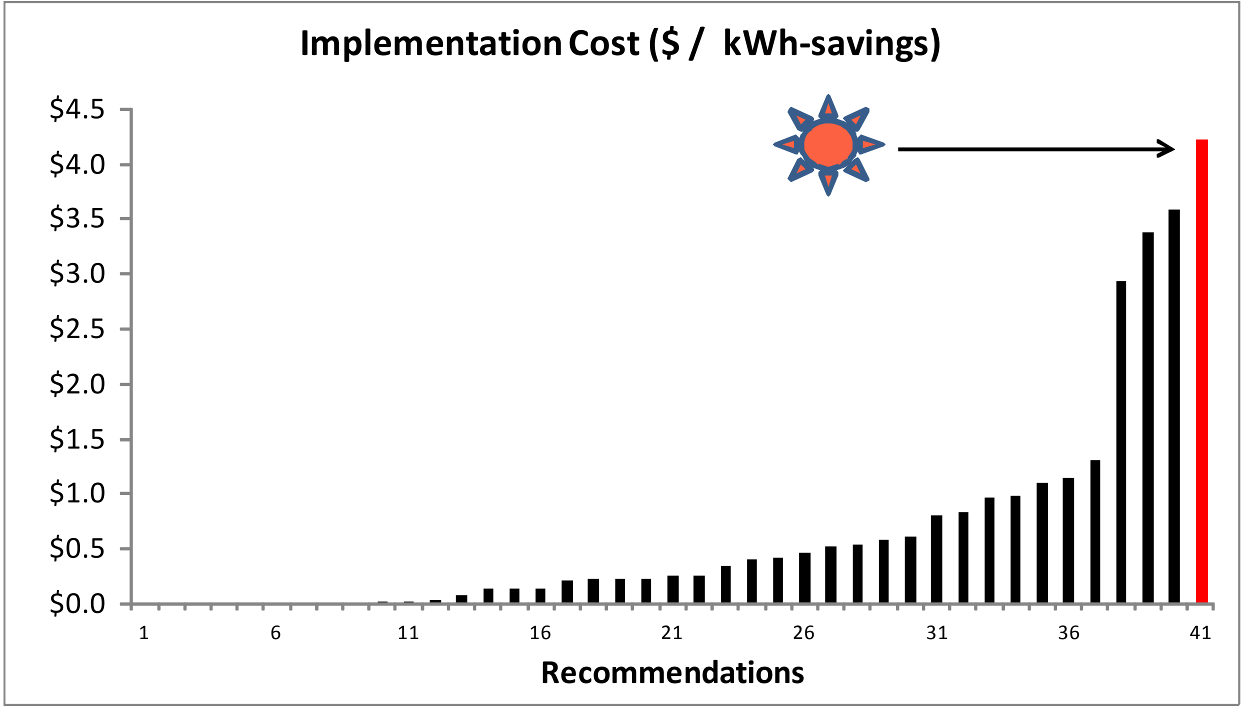
Table 2. Summary of Energy Savings by Category

Description	Electricity Savings (kWh/year)	Electric Cost Savings ($/year)	Gas Savings (ccf/year)	Gas Savings ($/year)	Total Savings ($/year)	Savings (lbs CO_2 /year)	Imp. Cost ($)	Simple Payback (years)	Rate of Return (%)
Domestic Hot Water									
	-191,505	-$18,606	20,344	$26,040	$7,435	-231,640	$40,180	5.4	18.5%
Lighting									
	371,867	$27,044	0	$0	$27,044	896,199	$370,505	13.7	7.3%
Office and Plug Loads									
	8,808	$655	0	$0	$655	21,227	$5,200	7.9	12.6%
Kitchen and Food Cooling									
	67,051	$4,286	0	$0	$4,286	161,593	$47,208	11.0	9.1%
Pumping									
	201,900	$13,170	0	$0	$13,170	486,579	$17,199	1.3	76.6%
HVAC and Envelope									
	301,860	$19,455	27,317	$34,966	$54,487	1,041,390	$304,965	5.6	17.9%
SubTotal	**759,981**	**$46,005**	**47,661**	**$61,006**	**$107,077**	**2,375,349**	**$785,257**	**7.3**	**13.6%**

Implementation Plan

Our analysis shows that every energy-efficiency recommendation costs less per kWh of savings than installing solar PV. All 40 efficiency recommendations cost less than $3.58/kWh-savings while PV costs $4.23/kWh-generation. The average efficiency recommendation costs four times less per kWh-savings than PV. Compared to the 100% PV option, the energy-efficiency recommendations reduced the potential net-zero site energy budget by about $2.4 million. This highlights the need for aggressive energy-efficiency as a primary focus ahead of renewable energy. We present the implementation cost vs. electricity savings for all 40 efficiency recommendations compared to PV in Figure 4.

Figure 4. Implementation Cost ($/kWh-savings)



Using this knowledge, the team developed an implementation plan that started in the end of 2011 and will continue over the next few years as funding becomes available. Low and no-cost opportunities are prioritized before larger capital improvements. In addition, purchasing and specification plans are being edited to ensure that the net-zero energy goals for the campus are integrated into the campus' purchasing policies.

Renewable Energy Summary

Although the original intent of the project was to use only PV as a renewable energy source, our analysis shows that the campus cannot achieve net-zero site energy without the use of wind power. One reason for this is the lack of available space to put up the required solar panels. A wind turbine offers higher energy density for a small footprint, which is necessary considering campus space constraints. There are also not enough energy-efficiency opportunities available in this campus retrofit. Additionally, requiring that all natural gas equipment be converted to electrical equipment added a significant electrical load that could not be overcome by solar or energy-efficiency alone.

With the continuing lower cost of PV, installing solar panels may become more economical. However, costs would still need to decrease significantly in order to compete with the payback of energy-efficiency recommendations. Even if the DOE SunShot[3] program is successful at reducing the total costs of solar energy systems by 75% before the end of the decade, energy-efficiency opportunities will still be fundamental to net-zero energy.

Conclusions

We identified several criteria for success in order for the Akron Zoo campus to become net-zero site energy. First, contractors who install energy-efficiency features must understand how to successfully install and implement each recommendation. In our experience, we often find that energy-efficiency recommendations are misunderstood by the team performing implementation. The campus will need on-going measurement and verification (M&V) of its energy use. This is crucial to ensure that efficiency savings are being realized and any operational recommendations are fully understood by the zoo's facility staff. Lastly, all future campus expansions must be designed to net-zero site energy standards. Given all of these criteria for success, we have found that with significant cost and effort the Akron Zoo can become a net-zero site energy campus.

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[3] http://www1.eere.energy.gov/solar/sunshot/index.html