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PRODUCTION AND CONSUMPTION OF ELECTRICITY IN OBERLIN COLLEGE'S LEWIS CENTER FOR ENVIRONMENTAL STUDIES: REALIZING THE GOAL OF A NET ZERO BUILDING

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ABSTRACT

Since its completion in 2000, the Adam Joseph Lewis Center for Environmental Studies on the Oberlin College Campus has served as something of an icon for the green building movement. One of the long-term design goals was to develop a building that would use on-site photovoltaic power to produce more electricity than the all-electric building consumed. The 60 kW array installed on the roof of the building in 2001 met slightly greater than half of the Center's electricity needs. A second 100 kW array was installed over the parking lot of the Center in June of 2006. Data from the first ten months of operation indicate that the building will likely achieve its goal of energy export. Further opportunities exist for improving the performance and educational value of the facility.

1. INTRODUCTION

The Adam Joseph Lewis Center for Environmental Studies (the AJLC), a 13,600 sf (1,260 m^2) classroom and office facility at Oberlin College, was designed to showcase and serve as a laboratory for the emerging field of ecological design. Ecological design is premised on the notion that human systems can and should be designed to mimic and integrate with natural ecosystems. In natural ecosystems solar energy powers internal processes. Therefore a key long-term design goal has been to produce a facility that captures the energy that it used on site from the sun. To achieve this, the building was designed as an energy efficient all-electric facility with the intention of adding and upgrading solar technology to meet the Center's energy needs. A 60 kW building integrated PV array was installed on the roof in the fall of 2000, approximately 10 months after the building was first occupied. In the spring of 2007, a 100 kW PV array was added over the Center's parking lot.

Previous papers and reports provide a detailed description of the building and building systems and evaluate the energetic performance of the AJLC during its first three years of operation (Scofield 2002, Pless and Torcellini 2004, Pless et al. 2006). An additional paper evaluated the time required to pay back the costs of the rooftop photovoltaic array in currencies of energy, CO_2 and money (Murray and Petersen 2004). The present paper summarizes six year patterns of electricity production and consumption in the AJLC, predicts future performance with the newly installed parking lot array and considers opportunities and impediments related to optimizing whole system performance including education.

2. BACKGROUND

2.1 Photovoltaic Technology

The AJLC's rooftop PV array covers 4,800 sq-ft (446 sq-m), uses monocrystalline silicon technology and has a rated output of 59 kilowatt (kW). It consists of 690 85 W modules manufactured by BP-Solar ("Saturn Cells", model #585). These are arranged in three 15 kW subarrays. The roof is elongated on an east-west axis and is tilted to the south but is curved so that the South-most of the ten rows is at an angle of 20° below horizontal while the North-most is at an angle of 9° North (average angle is 15º from South). Each sub-array feeds into a 15 kW inverter (Xantrex Technology). Each inverter is connected to an isolation transformer (Square- D). Power generated is directed to a main distribution panel. This rooftop array began operation on Nov. 14th, 2000. The total cost of the system was $386,000 (approximately $6.60/Watt), which included design fees, modules and installation costs.

In contrast to the rooftop array, the 8,800 sf (818 sq-m) parking lot array uses RW Schott's polycrystalline "edge film growth" (EFG) technology with a total rated output of 101 kW. The system consists of 336 modules, each 300 W (Schott model ASE-300-DGF/50). Three subarrays feed a single three-phase 75 kW inverter (Solectria Renewables). The Parking lot pavilion consists of a steel understory with structural supports that hold the entire array facing south at an angle of 5º. The total cost for the modules was on the order of $340,000. The infrastructure itself rendered this installation more expensive than the rooftop array. With a final price tag near $1,000,000, the cost of this second array was approximately $10/Watt. Both arrays are connected directly to the AJLC main panel and are grid interconnected through a city transformer; when total PV production exceeds building consumption, electricity is exported.

2.2 Electrical Loads

The AJLC incorporates a variety of energy efficient features including: passive solar design, natural lighting, high efficiency electrical lighting, natural ventilation during the cooling season, energy recovery ventilation (ERV), an enhanced thermal envelope, integrated thermal mass and a North earth berm, and a ground source heat pump. Of special note is the "Living Machine", an ecologically engineered wastewater system that treats and then recycles water within the building. Though of great environmental value, the Living Machine adds an additional electrical load not present in other buildings.

Several changes were made in both the HVAC technology and management strategy during the first few years of operation. The specific technologies and changes are described in detail in a comprehensive report on the first three years of operation published by researchers from the National Renewable Energy Lab (Pless and Torcellini 2004, Pless et al. 2006).

2.3 Data Monitoring and Display System

First occupied in January of '00, the AJLC is an integrated building-landscape system that houses offices and classrooms for Oberlin College's Environmental Studies Program. From the outset, two key programmatic goals have been to study the ecology of the building-landscape system and to use the facility as a centerpiece for education on ecological design. Towards both ends, we sought to develop a data monitoring system capable of generating high resolution data for research and also capable of displaying real-time and historical data on the ecological performance in a format that is easily accessible and interpretable to a non-technical audience.

To achieve these goals, initially working with the National Renewable Energy Lab, between 2001 and 2004 150 environmental sensors were installed throughout the building and landscape. These sensors gather data on: energy production by photovoltaic panels on the roof of the building, energy consumption by each of the major end-uses within the building, weather conditions, soil temperature and moisture, on-site rainwater storage, biological activity and water flows within the on-site wetland-wastewater treatment system (the Living Machine) and a host of other variables.

The data acquisition system (DAS) was installed in Jan., 2001 and is comprised of current transducers (Continental Control Systems) and a host of other sensors, dataloggers (Campbell Scientific) and a PC server. Data received by dataloggers are uploaded to the server where they are archived, post-processed and delivered to a lobby display and to a publicly accessible web site within 1 minute of capture (www.oberlin.edu/ajlc). Since the DAS system was not functional prior to 2001, this report emphasizes an evaluation of the six years between January 2001 and March of 2007.

3. FINDINGS

3.1 Trends in Production and Consumption

Given Oberlin's temperate location (latitude 41.29º), it is not surprising that strong seasonal patterns are evident in electricity production and consumption in the Adam Joseph Lewis Center (fig. 1). Early design corrections outlined in previous publications (Pless et al. 2006) resulted in improvements in the performance of the HVAC system, but little has changed in terms of technology or management associated with energy consumption in the last four years of building operation.

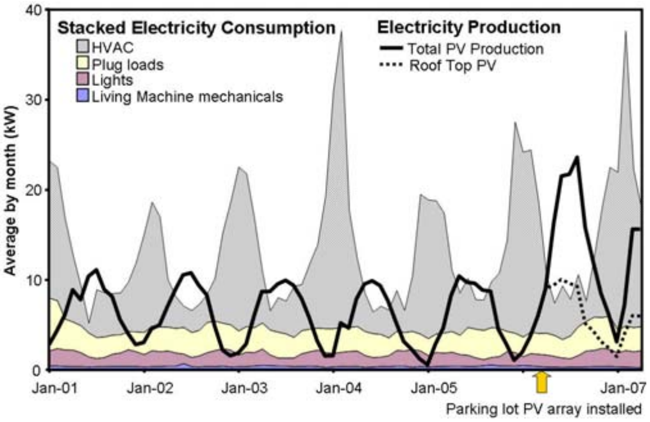


Fig. 1: Electricity production and electricity consumption by end use. An arrow marks the addition of the 100 kW photovoltaic array in June '06.

In contrast to southern climates, in the AJLC, peaks in production and consumption of electricity are entirely out of phase with each other, with maximum photovoltaic production occurring in June and maximum electricity consumption occurring in January. This means that although the building has been a net importer of electricity on an annual basis during its first six years of existence, it has actually exported an average of 15% of the total electricity produced by the photovoltaic system.

In spite of scatter in the data, heating loads are strongly related to heating degree days and analysis for individual years did not reveal changes in this pattern over the six year period of data examined (fig. 2). This implies that the inter-annual variability in electricity used for heating during this period is a function of variability in weather rather than a sign of changes in performance of the heating system.

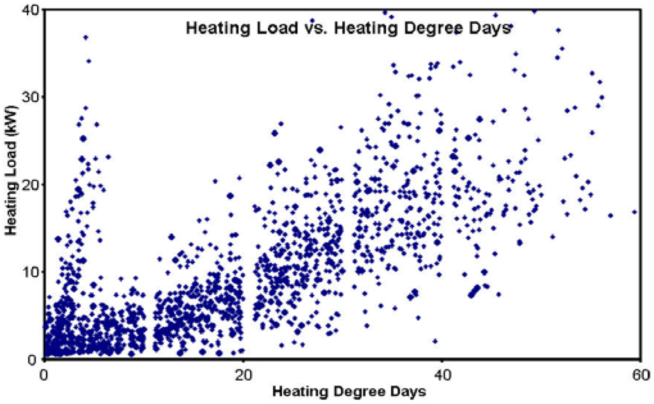


Fig. 2: Heating load as a function of heating degree days between June '01 and March '07. Each data point represents the heating degree days for a single day.

3.2 Long Term Performance of the Rooftop Array and Relative Performance of the Parking Lot Array

A previous paper (Murray and Petersen 2004) examining the "payback" time of the rooftop photovoltaic array assumed that the panels would degrade in output at 1% per year. Although a strong relationship is evident between photovoltaic efficiency and temperature, no degradation in performance is evident after six years of operation (fig. 3).

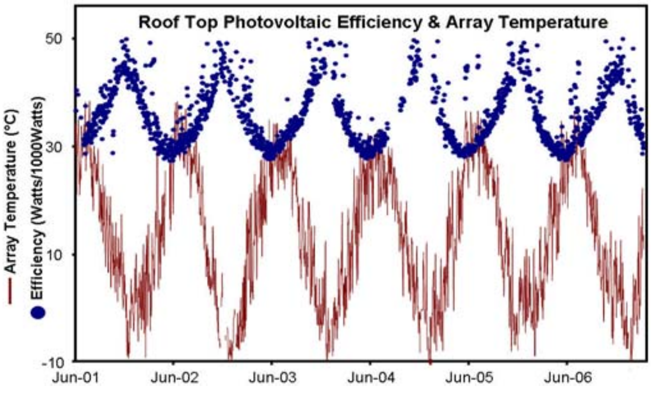


Fig. 3: Photovoltaic efficiency (blue dots) and array temperature (red lines). Efficiency = average daily DC output of entire rooftop array per unit of average daily (24 hr) light normal to the average 15º angle of the array. Scattered values above 50 (associated with low light levels) are not shown.

Although the angles of the two solar arrays are different from each other, the strong linear relationship in the output of the panels does not appear to be substantially related the season (fig. 4). Since the parking lot array has an angle of 5º and the curved rooftop array has an average angle of 15º, one might logically expect the parking lot array to perform better near the spring solstice and the rooftop array to perform better near the winter solstice. Contrary to these expectations, the parking lot array has a slightly higher relative output in September than in June.

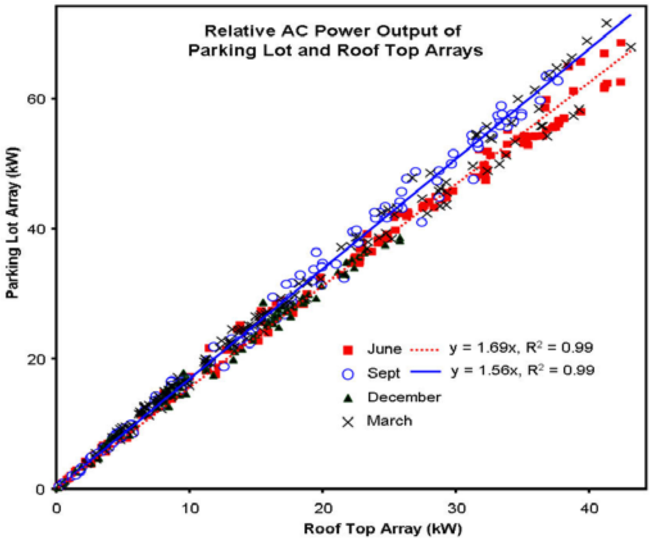


Fig. 4: Relative AC power output of the two arrays shown for June, September, December and March. Regression of average daily AC power output of parking lot array vs. rooftop array for September and June.

Over the first ten months of operation, the parking lot array had an average output of 1.68x the output of the rooftop array which is close to the relative output one would expect from the ratings of the two systems (101kW/59kW = 1.71).

3.3. The Annual Pattern of Electricity Production and Consumption and Future Predictions

If nothing else changes, what do the last six years tell us about future performance of the AJLC with its newly installed 100 kW array? To answer this question, average monthly production and consumption data were calculated from data collected between June of '01 and March of '07 (fig. 5). The long-term average production of the parking lot array was estimated by using the 1.68x relative output factor generated during the first ten months of its operation. Although the rooftop and parking lot arrays use different technology, the lack of evident degradation in the rooftop array (fig. 3) at least suggests that the parking lot array is likely to maintain efficiency for some years to come.

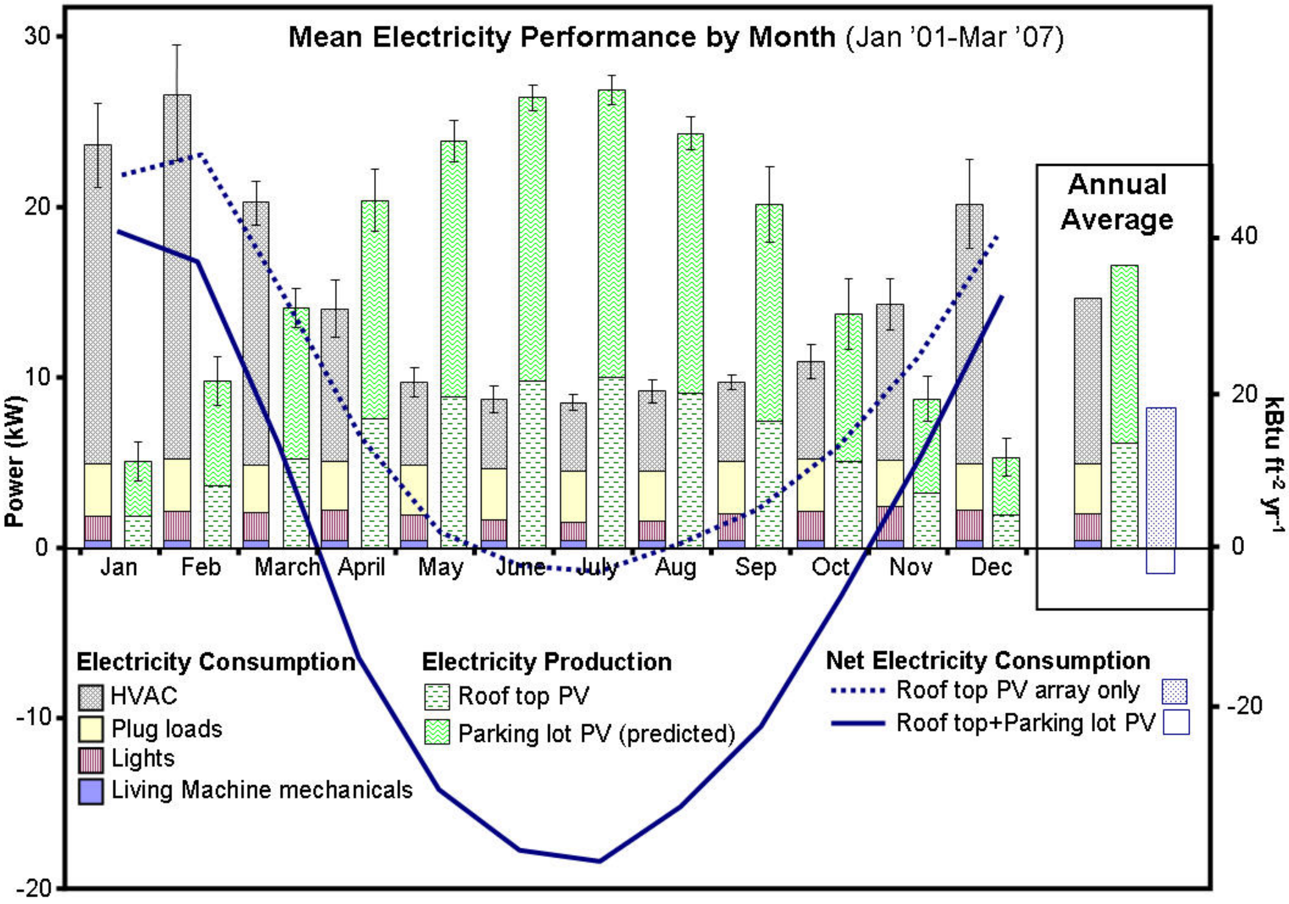


Fig. 5: Average monthly patterns in electricity production and consumption between June '01 and March'07. Gross electricity consumption for each month is depicted as a stacked bar graph of mechanical equipment associated with the Living Machine, lights, plug loads and HVAC. Error bars are calculated as the standard deviation of inter-annual variability in total site energy consumption. Average photovoltaic production by the rooftop array is depicted as the lower green bar; the upper bar is an estimate of additional production anticipated from the new parking lot array based on its performance during the first ten months of operation. Error bars on total solar production are estimates of standard error for total PV production based on the inter-annual variability of the rooftop array. The dotted line represents average net site energy consumed in the building between June '01 and March '07 considering only the rooftop array. The solid line represents predicted future net site energy with the addition of the parking lot array and no further changes in building performance. The inset depicts annual averages in production, consumption and net use for the entire periods of time investigated. The unfilled bar extending below zero in the inset is negative net use (export) anticipated with the addition of the new array.

Energy use in commercial buildings varies considerably by region, by end use, and by the design and management choices made. Commercial buildings in the Midwestern U.S. have an average site energy consumption of 90.0 kBtu ft^{-2} yr^{-1} (1020 MJ m^{-2}yr^{-1}), with educational buildings having a site intensity of 79.1 kBtu ft^{-2} yr^{-1} (898 MJ m^{-2}yr^{-1}, EIA 1999). Academic buildings at Oberlin College average 88.5 kBtu ft^{-2} yr^{-1} (1,010 MJ MJ m^{-2}yr^{-1}, Heede and Swisher 2002).

The 32.2 kBtu ft^{-2} yr^{-1} (365 MJ m^{-2}yr^{-1}) site energy consumed in AJLC during the last six years (Table 1) is a testament to energy efficient design. This number drops to a net site energy of 15.26 kBtu ft^{-2} yr^{-1} (173 MJ m^{-2}yr^{-1}) if rooftop photovoltaic production is credited. Past performance suggests that with the addition of the new parking lot array the building will, indeed, achieve the designers' goal of becoming a net exporter of electricity; with no further changes in technology or management it appears that the Center will produce greater than 110% of its annual electricity consumption.

Loads in the AJLC are dominated by HVAC which accounts for 66% of total electricity consumption in the building (Table 1). Although the mechanical energy necessary to run the Living Machine amounts to only 3% of electricity consumption, this does not include the considerable heat energy (included in the HVAC %) that is supplied to the greenhouse.

TABLE 1: AVERAGE ELECTRICITY PRODUCTION AND CONSUMPTION FOR JUNE '01-MARCH '07 AND PREDICTED PV PERFORMANCE

Electricity by End Use	**kW**	**kBtu ft^{-2}yr^{-1}**	**%Total**
Living Machine Mech.	0.42	0.91	3%
Lighting	1.57	3.44	11%
Plug load	2.95	6.48	20%
HVAC	9.72	21.36	66%
Total site energy	14.65	32.20	100%
Electricity Production			
Rooftop PV	7.71	16.95	
Rooftop + Parking lot PV (predicted)	16.58	36.43	
Net Consumption			
Net site energy with rooftop PV only	6.94	15.26	
Net site energy combined PV systems (predicted)	-1.93	-4.23	
% Site energy met with rooftop PV			53%
% Site Energy met with combined PV			113%

An obvious feature of fig. 5 is that in the months from April through October, and probably on many sunny days in the winter, the building will export electricity onto the grid. Indeed, it appears that well over half of the total electricity produced on an annual basis will be exported to the grid during the summer months. Most of this electricity will then be re-imported during the heating season. In North East Ohio, peak rates of electricity consumption on the grid (and peak wholesale prices of electricity) occur in the summer months and coincide with peak export from the AJLC. Thus, although the Center certainly represents a small source of power, in a general sense, the seasonal patterns of photovoltaic production strongly complement the local demand curve. Large scale installation of solar might enable a reduction in the sizing of traditional power generation facilities.

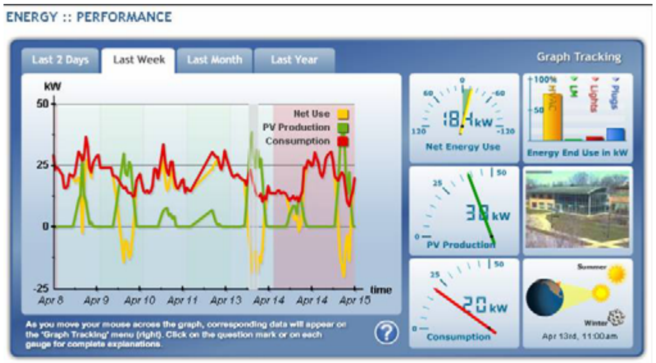
4. CONCLUSIONS

4.1 What Does Being a Net Exporter Mean?

North East Ohio is not a particularly favorable location for demonstrating zero energy buildings. Winters are cold and heavily overcast. Oberlin professor David Orr and others have made a Herculean effort to bring this example of a zero energy building to fruition. On one hand, critics can justifiable point to the substantial price tag for the solar system to suggest that solar is not yet an economically feasible option in this region of the country. On the other hand, the project successfully demonstrates that even in this very sun-challenged environment, it is possible to achieve the goal of energy export. From this latter perspective, the appropriate measure of success is the degree to which the AJLC serves as an effective educational tool.

4.2 Real-Time Data Display as a Mechanism for Education

The designers of the AJLC conceived of it as a building that would serve not just as a place in which learning occurs, but as a laboratory for environmental stewardship. The development of a system for displaying the environmental performance of the building in real-time has been one mechanism for making this laboratory accessible to Oberlin and to the larger community (fig. 6). A website and public lobby display provide building visitors, occupants and the larger community with a view into the invisible flows of energy, cycles of matter and environmental resources necessary to support activities in the built environment. The premise of this work is that real-time performance data can be used to engage, educate, motivate and empower conservation of resources and appreciation of solar resources.



As you move your mouse across the graph, corresponding data will appear on the 'Graph Tracking' menu (right). Click on the question mark or on each gauge for complete explanations.

Fig. 6. Screen shot of real-time building performance data featured on the web site for the Adam Joseph Lewis Center (www.oberlin.edu/ajlc). Gauges and time series graphs are combined with time-lapse photography to allow visitors to easily view and explore the environmental performance of the building.

4.3 Future Directions

By definition, a solar building becomes a net exporter of electricity when photovoltaic production exceeds electricity consumption. This is achieved by using technology and management to minimize electricity consumption and to maximize production. Early commissioning and post-commissioning efforts lead to some important changes in both the technology and management of the AJLC that dramatically reduced electricity consumption and increased solar production (Pless et al. 2006). The recent transition to net exporter status has been achieved as a result of the installation of additional solar capacity. Data presented in this paper suggest that patterns and magnitudes of consumption have changed little in the last several years. Further improvements in system performance are possible and critical to enhancing the educational value of the facility. Such improvements require a second focus on consumptive technology and more importantly a focus on continuous adaptive management of the existing technologies.

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