July 2004 • NREL/CP-550-36273

Conference Paper

Oberlin College Lewis Center for Environmental Studies: A Low-Energy Academic Building

Preprint

S. Pless and P. Torcellini
National Renewable Energy Laboratory

J. Petersen
Oberlin College

To be presented at the World Renewable Energy Congress VIII and Expo
Denver, Colorado
August 29–September 3, 2004

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

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Oberlin College Lewis Center for Environmental Studies: A Low-Energy Academic Building

Shanti Pless and Paul Torcellini, National Renewable Energy Laboratory
John Petersen, Oberlin College

Introduction

The Adam Joseph Lewis Center for Environmental Studies is a building that houses classrooms and offices. The Lewis Center is located on the campus of Oberlin College in Oberlin, Ohio. It was designed to be an energy-efficient model for commercial design and to serve as a teaching tool for students. The design process, guided by Oberlin's Environmental Studies Program, started in February of 1996. Construction of the building began in September of 1998, and it was ready for occupancy in January of 2000. The long-term vision for the building was to export more energy than it consumes, sometimes referred to as a zero-energy building. To accomplish this, the Lewis Center was designed to minimize site energy use while producing electricity on-site.

After the building was constructed, the National Renewable Energy Laboratory (NREL) monitored and evaluated the energy performance.

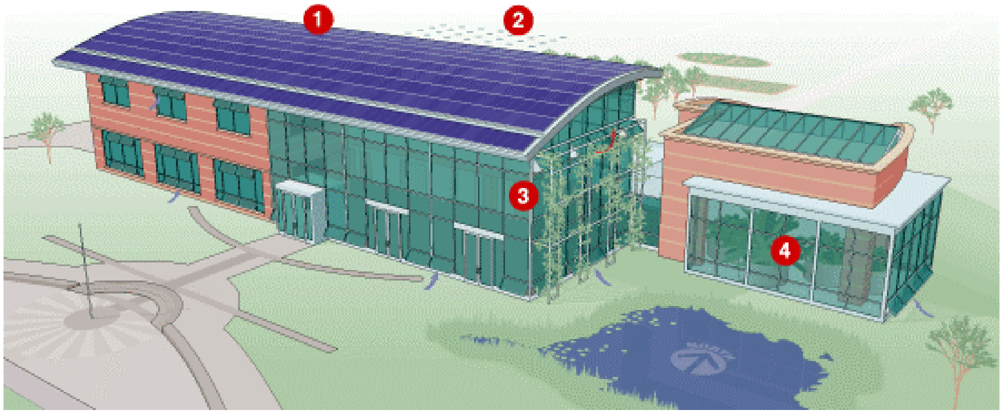
Building and Site Description

The Lewis Center is a two-story, 13,600-ft^2 (1,263-m^2) building with classrooms, offices, an auditorium, an atrium, and an on-site wastewater treatment system. Winters in Ohio are typically cold and cloudy with 6,107 HDD (65ºF [18ºC] base) and 617 CDD (65ºF [18ºC] base). Summers are hot and humid.

The design team incorporated numerous energy saving design characteristics into the building. One of the most prominent among them is a roof-integrated, 60-kW photovoltaic (PV) system (Number 1 in Figure 1). The system, which covers most of the roof, is connected to the building's electrical bus and does not have a battery backup system. The PV system exports power to the utility grid when the PV system produces more power than the building is using. Likewise, the building imports electricity from the utility when the PV system cannot meet the load. Electricity meets all energy needs, including mechanical systems and domestic hot water. This all-electric system was a requirement in order to meet the net energy producing vision for the building.

The building orientation, combined with window overhangs and fenestration, contributes to the solar heat gain in the winter, solar load avoidance in the summer, and the increased use of natural light. Thermal mass is integrated into the design with exposed masonry in the atrium floors. The thermal mass stores heat from the sun in the winter and moderates summer temperatures to reduce peak loads on the building. Well-insulated walls, roof, and slab combined with triple pane low-e atrium glass result in an enhanced thermal envelope.

An ecologically engineered on-site wastewater treatment system, called a "Living Machine" by the manufacturer, was designed to be an educational tool and research laboratory (Number 4 in Figure 1). This on-site wastewater treatment system combines conventional wastewater treatment with the purification processes of a natural wetland ecosystem to remove organic wastes and nutrients from wastewater. A complete description can be found in the DOE High Performance Building Database (DOE 2004).



1 = PV array
2 = Location of ground wells for heat pump loop
3 = Passive solar heating and ventilation; daylighting
4 = Sunspace for ecological wastewater system

Figure 1. High-performance building features

Additional energy-efficient design features are passive solar heating and ventilation, daylighting and efficient lighting designs, ground source heat pump loops, energy recovery from exhaust air, and an energy management system for controlling these systems (DOE 2004). The primary intent of the heating, ventilating, and air-conditioning (HVAC) design was to decouple ventilation from the heating and cooling systems. As a result, the heating and cooling systems were decentralized by zone. To accomplish this, room heat pumps were used for the individual classrooms and offices. A single, large, standard-range water source heat pump, coupled to an energy recovery ventilator, handles ventilation supply air. Another water source heat pump and energy recovery ventilator provides heating, cooling, and ventilation to the auditorium and atrium. A closed loop, geothermal well system acts as heat source and sink for the glycol-water source side of the heat pumps. A set of variable speed drive pumps circulates the glycol-water mix through 24 240-ft (73-m) deep wells and to the heat pumps. A hydronic loop provides additional heating through radiant floor tubing in the atrium and unit heaters in the Living Machine. A water-to-water ground source heat pump with an electric boiler back up provides the heating to the hydronic loop. The energy management system is used to control the operation of these HVAC systems.

The highly occupied classroom lighting zones are located on the south side of the building to maximize the daylighting potential. A north-facing clerestory allows diffuse daylight to assist in illuminating the second-floor corridor, north-facing offices, and south-facing classrooms. The electrical lighting systems include direct-indirect fixtures with 2 linear T-8 fluorescent lamps, dimming ballasts, and sensors to provide automatic and occupancy control of lighting levels. The building lighting power density is 0.79 W/ft^2 (8.5 W/m^2). The classrooms, offices, restrooms, and corridors have motion sensors that turn lights on when the spaces are occupied. The hallway and classroom lights are also connected to photo sensors, which override the occupancy sensors when enough daylighting is available.

Energy Performance Evaluation

The energy performance of the Lewis Center was evaluated extensively from March 2001 to March 2003 by continuous end use monitoring, analysis of utility bills, walk through inspections, spot measurements, and computer simulations. A dedicated data acquisition system was designed to monitor and archive the performance data.

Energy simulations of the as-built building were completed to better understand the energy performance and compare it to an energy code compliant baseline building model. The baseline building model was developed to reflect the size and functionality of the as-built building and meet the minimum thermal efficiency requirements of ASHRAE Standard 90.1-2001 (ASHRAE 2001). The baseline building model was created following the guidelines of the proposed Addendum-e to ASHRAE 90.1-2001. Both building models were calibrated with the building operations and measured energy and weather data from March 2002 to March 2003. All of the building simulations were conducted with DOE-2.1E (DOE-2 2003).

After the calibration process, the two simulation models were run with a weather file based on the long-term average weather conditions to show the performance and energy cost savings for an average weather year. The PV system simulation model PVSyst 3.2 (Mermoud 1996) was used to predict the PV production for an average weather year. The annual site energy consumption by end use for the two building models is shown in Figure 2 and Table 1. The net site energy saving was 47% and the net source energy saving was 77%, which includes the simulated energy production from the PV system. Source energy is the sum of the energy directly consumed at the site and the energy consumed by producing and delivering energy products. On an annual basis, the building and PV simulations show that on-site PV production meets 57% of the building load for an average weather year. The energy cost saving was 35%.

Of these annual site energy savings, the lighting system provided the greatest saving. The lighting design combined with daylighting saved 74% in lighting energy use. Daylighting and occupancy sensors minimize lighting consumption when spaces are unoccupied or daylighting provides adequate illumination. The cooling system saves 77% when compared to the base case. The cooling system saving is due to the increased COP of the ground source heat pumps, reduced internal heating gains from the lights, and a better thermal envelope. With these site energy savings, the PV system is able to meet 57% of the energy loads.

At a net site energy use intensity of 12.3 $kBtu/ft^2 \cdot yr$ (139.7 $MJ/m^2 \cdot yr$), increased PV production and additional site savings are required to reduce the net use to zero. Site energy reduction would have to be increased to 70% or 26-kW of PV panels added to the current array (or a combination of both) would be required for the Lewis Center to reach its net zero-energy vision.

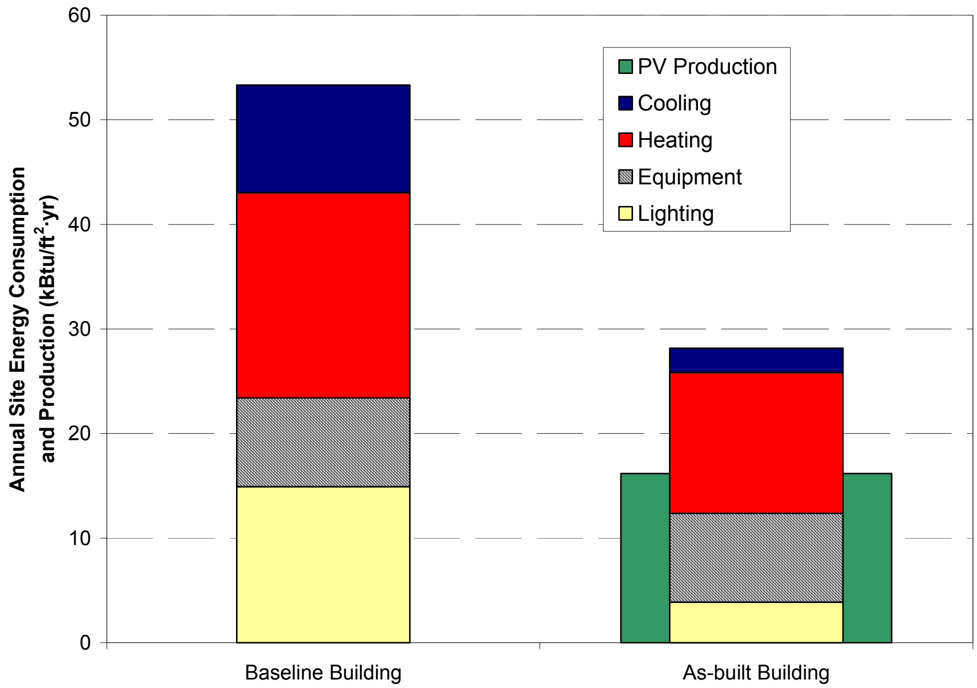


Figure 2 **Annual site energy consumption and production for the Baseline Building and As-Built Building models using an average year weather file.**

Table 1 **Annual Facility Energy Use from the As-Built Simulations (end use numbers are for site energy use)**

Performance Metric	Units	Baseline	As-Built	% Saving
Lighting	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	14.9 *169.2*	3.9 *44.3*	74%
Equipment	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	8.5 *96.5*	8.5 *96.5*	0%
Heating	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	19.6 *222.6*	13.5 *153.3*	31%
Cooling	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	10.3 *117.0*	2.3 *26.1*	77%
PV Production normalized by building area	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	0.0 *0.0*	16.2 *184.0*	N.A.
Total Site Energy Use Intensity	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	53.3 605.3	28.5 *323.7*	47%
Net Site Energy Use Intensity	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	53.3 *605.3*	12.3 *139.7*	77%
Net Source Energy Use Intensity	$kBtu/ft^2 \cdot yr$ $MJ/m^2 \cdot yr$	172.2 *1,955.6*	39.7 *450.9*	77%
Total Energy Cost Intensity	$\$/ft^2 \cdot yr$ $\$/m^2 \cdot yr$	$1.29 *$13.89*	$0.84 *$9.04*	35%

The source energy saving is highly dependent on the PV production. On-site energy production offsets electricity that would otherwise be delivered from a power plant as well as the associated production and delivery inefficiencies. Although the site saving of 47% is due to efficient use of site energy, the source saving of 77% is due to PV production combined with efficient use of site energy.

The energy cost saving at 35% is less than the total site energy savings. A net metering agreement with the utility allows the Lewis Center to receive financial credit for electricity exported to the grid. The 60-kW PV system typically exports up to half of the total annual production to the utility. Although the PV exports increase cost savings for electricity purchased, it does not substantially change the demand charges. During the summer months when PV production meets the entire monthly building load, the utility costs consist solely of demand charges. During the winter months, demand charges are up to 50% of the monthly utility bill. The best opportunity to increase the energy cost savings is to take full advantage of the PV system. Currently, the PV system does not significantly reduce the building demand. Integrating on-site generation with HVAC controls would enable the PV system to reduce the building demand.

Conclusions

The Environmental Studies Program at Oberlin College worked with NREL to monitor, document, and evaluate the energy performance of the Lewis Center. Using whole-building and PV simulation models combined with a dedicated monitoring system, we have shown that the Lewis Center is an example of a low-energy academic building. Overall, the building uses 54% less site energy and has 50% lower energy costs than typical educational buildings of similar size. The extensive use of daylighting has reduced the lighting energy requirements by 74%, which contributes significantly to the reduced energy loads in the building. Reduction in the lighting and cooling has lowered the site energy use so that on-site PV production is able to meet 57% of the remaining loads. Energy cost savings can be increased through demand responsive controls, as the PV system does not significantly reduce the building demand. Although the Lewis Center is a low-energy building and one of the better performing academic buildings in the country, additional site energy savings and PV production are required to help the building reach its vision of net-zero energy consumption.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
July 2004	Conference Paper	

4. TITLE AND SUBTITLE
Oberlin College Lewis Center for Environmental Studies: A Low-Energy Academic Building; Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
S. Pless, P. Torcellini, and J. Petersen

5d. PROJECT NUMBER
NREL/CP-550-36273

5e. TASK NUMBER
BEC3.1001

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-550-36273

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
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15. SUBJECT TERMS
Oberlin; High-Performance Buildings; daylighting; World Renewable Energy Congress; commercial buildings; high-performance design; academic building; low-energy academic building

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER (*Include area code*)