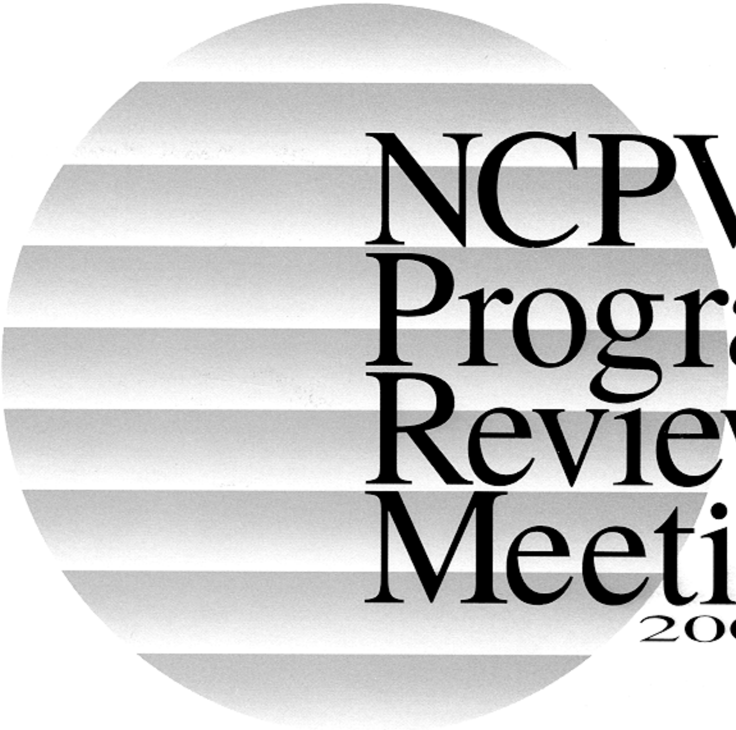
PROGRAM AND PROCEEDINGS



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Photovoltaics for Buildings: Case Studies of High-Performance Buildings with PV

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ABSTRACT

Energy efficiency maximizes the value of photovoltaics (PV) in buildings systems. A fixed-sized PV system will offset a much larger part of the electrical load in an energy-efficient building than in a building whose energy design has not been optimized. Integrating an energy-design process when designing buildings helps to evaluate strategies such as daylighting, passive solar heating and cooling, properly engineered heating, ventilating, and air-conditioning (HVAC) systems, improved envelope characteristics, and advanced control systems. These systems – working together – result in substantial energy reduction, making it possible for a reasonably sized PV system to meet a significant portion of the remaining electrical load. This paper focuses on three high-performance buildings whose electricity loads are almost entirely met by modest-sized PV systems.

1. Energy-Design Process

Designing and constructing low-energy buildings (buildings that consume 50% to 70% less energy than code-compliant buildings) require the design team to follow an energy-design process that considers how the building envelope and systems work together. The process requires a design team to set energy-efficiency goals at the beginning of the pre-design phase (Table 1) [1]. Detailed computer simulations used throughout the design and construction phases ensure that the building is optimized for energy efficiency and that changes to the design do not adversely affect energy performance. Properly commissioning the building and educating the building operators are the final steps to successfully constructing a low-energy building.

2. BigHorn Center

The BigHorn Center is a collection of five retail spaces in Silverthorne, Colorado. A design goal for the BigHorn Center was to create a sustainable retail environment. The complex was constructed in three phases. Phase III, completed in April 2000, houses a 17,000-ft^2 (1579-m^2) hardware store and support areas and a 22,000-ft^2 (2044-m^2) building materials warehouse. This phase incorporates the most aggressive sustainable design strategies of the three phases. These strategies include daylighting, advanced lighting technologies, natural ventilation for cooling, transpired solar collector, building-integrated PV, improved envelope features, and integrated controls.

Photovoltaic modules laminated onto the standing-seam metal roof panels were installed on the south-facing roof of the hardware store clerestory and the warehouse dormer [2]. The amorphous-silicon PV modules were wired into three arrays, each serving one phase of the three-phase building power system. The design capacity of the PV system is 8 kW, and the array covers all the available Phase III, south-facing roof area. The BigHorn Center developer/owner has a net-metering agreement with the utility to receive full credit for power that the PV system exports back to the grid.

The design team used the energy-design process to integrate daylighting opportunities, efficient mechanical systems, and improved building envelope features into an optimized building design. It is estimated that the resulting design saves about 21 kW in demand, making it possible for the 8 kW of PV power to meet a significant portion of the annual building electrical load. Designers anticipate that during sunny summer days, it will be possible for the building to export power to the grid during business hours. If daylighting and other design features had not been incorporated, it would not have been feasible to purchase and install enough PV power to offset an equivalent portion of the base-case building load.

The business plan for the project encompassed the ability to sell "green" products in the retail environment. To that end, the building became a statement to the sustainable mission, and the energy features were an integral part of the

Table 1. Energy-Design Process Steps

Pre-Design	Design	Construction/Occupation
1. Simulate a base-case model, establish energy-use targets 2. Complete parametric analysis 3. Brainstorm solutions 4. Perform simulations on base-case variants considering economic criteria	5. Prepare preliminary architectural drawings 6. Design the heating, ventilating, and air conditioning (HVAC) and lighting systems 7. Finalize plans and specifications	8. Rerun simulations before construction design changes 9. Commission all equipment and controls. Educate building operators to ensure that they operate the building as is intended

building. Photovoltaic modules integrated into the roofing was an additional cost; however, the marketing value of this investment, coupled with the other features, created a total cost-effective business plan. Even before construction of the BigHorn Center was completed, the owner/developer saw increased sales in his existing facility, which he attributed to the publicity he received for installing the PV system and other sustainable design features.

The BigHorn Center is the first commercial building in the State of Colorado to have a standing-seam metal roof-integrated PV system, and it is the largest building-integrated PV system in Colorado. The grid-tied PV system is one of the first net-metered commercial buildings in Colorado. The BigHorn Center is also one of the first examples in the United States of truly integrated daylighting and natural ventilation cooling systems in a retail space.

3. Zion National Park Visitor Center

The Zion National Park Visitor Center and Comfort Station, under construction at the time this paper was written, will be two of the National Park Service's (NPS) most efficient buildings. The design team optimized the performance of the aggressive low-energy design strategies into the 7600-ft^2 (706-m^2) Visitor Center and 1100-ft^2 (102-m^2) Comfort Station. Design features in both buildings include daylighting, Trombe walls for passive solar heating, downdraft cooling towers for natural ventilation cooling, energy-efficient lighting, and advanced building controls. It is estimated that these features result in about 10 kW of electrical demand savings.

Zion National Park is located in a remote area of southern Utah, where power reliability is an issue. For this reason, the NPS required an uninterrupted power system (UPS) for the buildings. The only additional cost to convert the UPS to a PV-for-buildings system was PV array because the battery storage and balance-of-system components were already a part of the UPS design.

A 7.5-kW roof-mounted PV system is planned to be installed on the south-facing roof of the Visitor Center. Because of the daylighting and natural ventilation cooling systems, designers anticipate that the building's PV system will export power to the utility grid during the summer. During power outages, the building control system will shut down nonessential electrical loads so that the PV/UPS system will be capable of supporting enough building operations to continue business for at least one-half hour without any additional PV power, or all day if PV capacity is available.

Officials at Zion National Park are negotiating a net-metering agreement with the local utility. When an agreement has been reached, this will be the first net-metered system in the State of Utah.

4. Van Geet Residence

The Van Geet Residence is a 3000-ft^2 (279-m^2) home constructed off the utility grid at an elevation of 9200 ft (2804 m) near Idaho Springs, Colorado. The design of the house was optimized to incorporate passive solar heating (including direct solar gain and Trombe walls), natural ventilation cooling, daylighting, and a good thermal envelope. Mass was incorporated into the building shell and some internal walls using dry-stack concrete blocks filled with concrete. Insulation was attached to the external surface of the block. Solar domestic hot-water (SDHW) heating and supplementary space heating needs are met by a solar hot-water system. Energy-efficient lighting and appliances (the refrigerator uses 75% less energy than a conventional refrigerator) minimize electrical loads in the house.

A 1000-W (rated) PV array provides electric power for the house and powers the well pump. Power from the PV array is stored in a battery bank, and an inverter converts the 24V DC from the PV array to 120V AC. An automatic propane generator meets the remaining loads when PV/battery power is not available. During the two years since the house was completed, the occupants have relied on the generator to meet less than 10% of their total power needs.

The Van Geet house is two miles from the power line. It was less expensive to incorporate energy-efficient and renewable energy technologies into the design than it would have been to extend the power line to the house.

5. Summary

In all three examples discussed in this paper, the PV system initial cost and physical size were minimized because aggressive energy-efficiency design measures were first incorporated into the building designs. It is more cost effective to reduce building loads through good design than it is to meet building loads with renewable energy technologies. Photovoltaic and other renewable energy technologies can be viable solutions to meeting today's building energy needs only when combined with measures to minimize building energy loads.

6. Acknowledgements

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7. References

[1] Torcellini, P.A., S.J. Hayter, R. Judkoff: "Low-Energy Building Design—the Process and a Case Study," *ASHRAE Transactions*, V 105, Part 2, (1999) 802-810.

[2] Ovonic, *UniSolar* Web Site, www.ovonic.com/unisolar, accessed March 27, 2000.