

DRAFT

**Energy Efficient and Affordable Small
Commercial and Residential Buildings
Research Program**

*a Public Interest Energy Research Program
sponsored by the California Energy Commission*

**Project 5.1 – Building Integrated
Photovoltaics**

**Task 5.1.3c
Economic Assessment of Building Integrated
Photovoltaics in California**

Vernon A. Smith, Architectural Energy Corporation
Fred W. Porter, Architectural Energy Corporation

September 2003

Prepared for
California Energy Commission

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Table of Contents

Introduction.....	4
Building Model Description	4
Building Integrated Photovoltaic Panels.....	5
PV Panels:.....	6
Inverters:	6
Climate Zones	6
Simulation Results	7
Baseline.....	7
Unshaded (Orientation A).....	7
Shaded (Orientation B)	8
First Cost Estimates	9
Conclusions.....	9
Recommendations.....	10

List of Figures

Figure 1 Sketch of Simulated Building.....	4
Figure 2 Plan View of Simulated Building Orientations	5

List of Tables

Table 1 Simulated Panel and PV Cell Characteristics	6
Table 2 General Inverter Characteristics for DOE 2.2 Simulations	6
Table 3 Climate Zones and Representative Cities	6
Table 4 Baseline Building Energy Simulation Results.....	7
Table 5 Economic Assessment Simulation Results.....	8
Table 6 Self-shading Degradation Limits for Orientation B.....	9

Introduction

Building integrated photovoltaics (BIPV) is a new alternative construction technology that serves as an exterior architectural finish and produces electric power from sunlight. Part of the promise of BIPV is to offset partially or wholly the PV cost by the cost of the replaced envelope material. BIPV assemblies are relatively new and there are few case studies with measured performance. There are, however, good modeling tools that should allow insight into the potential performance of BIPV in California.

This report documents a simulation study of BIPV on a small office building in four California climate zones. The following sections describe the key modeling assumptions, the BIPV characteristics, and the climate zones. The simulation results section compares the predicted energy savings against the baseline mode, followed by conclusion and recommendations sections.

Building Model Description

A 30,000 sf, three-story office building was selected as the assessment baseline building type. It has an “L” shaped floor plan with 10,000 sf per floor. The construction is structural steel with a typical curtain wall consisting of glazing and insulated opaque sections. Floor-to-floor height is 14 feet, with a 4-foot plenum section between each floor. The long sides of the “L” floor plate are 120 feet in length. Figure 1 is a 3-D rendering of the building.

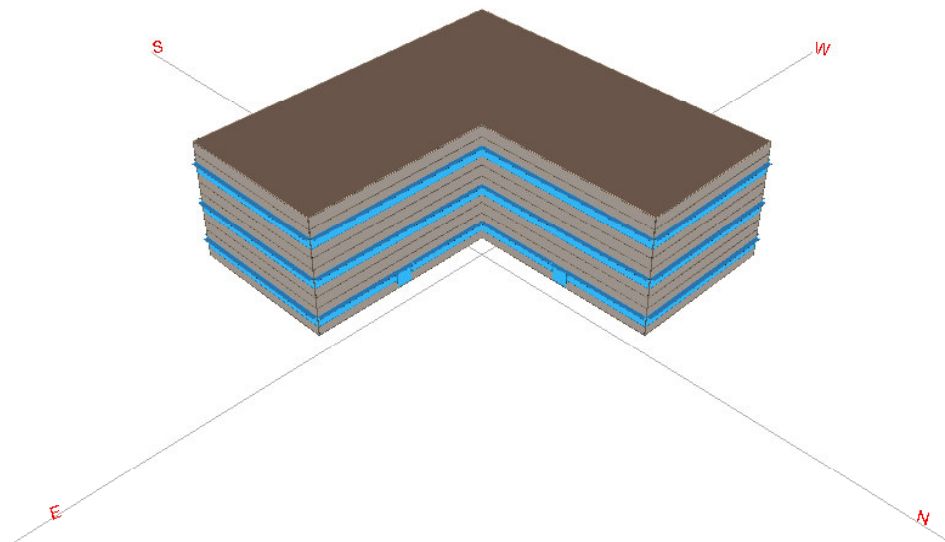


Figure 1 **Sketch of Simulated Building**

The envelope, lighting, and HVAC systems meet minimum Title 24 energy requirements. Occupancy was assumed to be from 8 am to 6 pm weekdays. The building is unoccupied on weekends and holidays. No parking lot or external lighting was assumed as part of the model.

The HVAC plant for the modeled building was assumed to have a water-cooled 120-ton centrifugal chiller and a 500,000 Btu/h boiler. The secondary distribution system was assumed to be a VAV system with hot water reheat.

Building Integrated Photovoltaic Panels

The simulated building has three levels of spandrel panels available for PV installation, each 120 feet long and 7 feet high. The windows are 3.75-feet high with the bottom edge located about 3 feet above the floor. The façade has 1.5-foot overhangs immediately above the windows on each floor. In the optimum orientation, one long side of the building faces directly south and all areas of all three spandrels are unshaded during all daylight hours (labeled “Orientation A” in Figure 2).

The PV panels were assumed to be three-feet in height and were arranged to fill the length of the south-facing side slightly above each window overhang.

An alternative building orientation was selected to explore the influence of self-shading. In this case the building is rotated 180° and the south facing spandrels are divided as shown in Orientation B of Figure 2. One section is in front, and will be unshaded all hours. The other section is "recessed" and will be shaded from direct sun for part of the day. See Figure 2 for the two orientations (the dashed blue line indicates the BIPV surfaces in plan view).

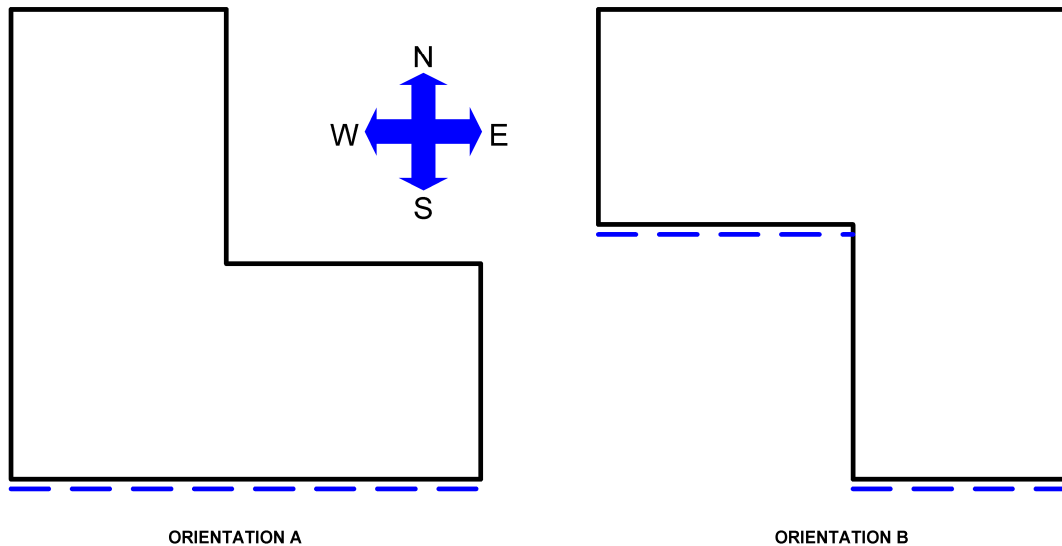


Figure 2 Plan View of Simulated Building Orientations

PV Panels:

The PV panels simulated were assumed to have conversion efficiency characteristics for the uninsulated panels described in the NIST paper titled *Measured Performance of Building Integrated Photovoltaic Panels*. Table 2 shows the assumed panel size, peak power output, total number of panels mounted on the curtain wall, and the power conversion efficiencies of each technology. The panels occupy about 1050 sf, or 21% of the total vertical surface area facing south (about 350 sf of PV panels per floor).

Table 1 Simulated Panel and PV Cell Characteristics

BIPV Type	Panel			Cell Conversion Efficiency %	
	Area (sf)	Rating (W)	Count	Uninsulated Backing	Insulated Backing
MonoC	17.5	133.4	20	10.3	9.9
PolyC	17.5	125.8	20	9.7	9.4
SiFilm	17.5	104.0	20	6.0	5.8
TripleJ	21.8	57.0	16	5.9	6.0

Inverters:

No specific inverter size, type, or electrical characteristics were specified. In a real installation, the size and voltage of panels, the fill factor, number of panels in series, and inverter characteristics will need to be coordinated to achieve reasonable performance. In order to minimize the effect of inverter and string variations on the results presented here, each PV system was modeled with *all panels in parallel*. A different virtual inverter was assumed for each PV panel type, with characteristics listed in Table

Table 2 General Inverter Characteristics for DOE 2.2 Simulations

Power	1.2 x sum of peak power
Max-track volts	1.0 x open circuit volts
Min-track volts	0.5 x max-track volts
Min operating volts	0.3 x open circuit volts

Climate Zones

Four climate zones representing large population centers in coastal and inland areas were selected for the parametric simulations. See Table 3.

Table 3 Climate Zones and Representative Cities

Climate Zone	Representative City
CZ-03c	Oakland
CZ-06c	Long Beach
CZ-10c	Riverside
CZ-12c	Sacramento

Simulation Results

Baseline

A set of simulations was run to create a baseline in each climate zone. The simulated building has 100 - 180 kW monthly peak demand, depending on location and time of year, with the peak set during the summer in all locations. The cost calculations were based on Pacific Gas & Electric Company's A10a rate schedule for all locations. This rate schedule was used to show representative costs, not predicted costs based on prevailing utility rates in each location since other utilities serve the selected cities. The value of saved energy using the PGE A10a rate is about \$0.145/kWh.

Table 4 Baseline Building Energy Simulation Results

Climate Zone	Representative City	Total kWh	Peak Demand	Energy \$	Demand \$	Total \$	kWh/sf-yr
CZ-03c	Oakland	385,497	139	\$53,082	\$ 6,612	\$60,594	12.85
CZ-06c	Long Beach	423,554	157	\$58,384	\$ 7,453	\$66,737	14.12
CZ-10c	Riverside	427,310	169	\$58,950	\$7,735	\$67,586	14.24
CZ-12c	Sacramento	413,247	176	\$57,387	\$7,807	\$66,094	13.77
	Averages	412,402	160	\$56,951	\$7,402	\$65,253	13.75

Unshaded (Orientation A)

Table 5 shows the results for each panel type by climate zone. As might be expected, higher conversion efficiency yields greater energy production. Also, climate zones with higher overall solar radiation (less cloudy) yield greater energy production, although the differences among the four selected climate zones is relatively small.

The overall energy savings range from 0.8% to 2.0% and the cost savings range from 0.7% to 1.8% annually. Demand savings for the south orientation are greatest in winter when the sun angle is low, due to higher direct radiation to the panels. The effect on peak demand is almost zero, since the sun angle is very high in summer when the peak is set and the south orientation with the vertical mounting produces the least amount of electricity. Roof-mounted panels that are horizontal or mounted at low angles have the greatest production during the summer, coincident with peak demand.

Table 5 Economic Assessment Simulation Results

Climate Zone	BIPV Type	Module			Array		Annual Savings		Normalized Annual Savings		
		Area (sf)	Rating (W)	Count	Area (sf)	Rating (kW)	Net Energy (kWh)	Value (\$)	kWh/sf	kWh/kW	\$/kWh
Ctz03 - Bay Area	MonoC	17.5	133.4	20	1051.1	8.0	7,290	1,052	6.9	911	0.144
	PolyC	17.5	125.8	20	1051.1	7.5	7,304	1,059	6.9	968	0.145
	SiFilm	17.5	104.0	20	1051.1	6.2	5,285	760	5.0	847	0.144
	TripleJ	21.8	57.0	16	1047.1	2.7	3,124	464	3.0	1,141	0.149
Ctz06 - South Coast	MonoC	17.5	133.4	20	1051.1	8.0	8,310	1,176	7.9	1,038	0.142
	PolyC	17.5	125.8	20	1051.1	7.5	8,356	1,188	7.9	1,107	0.142
	SiFilm	17.5	104.0	20	1051.1	6.2	6,213	876	5.9	996	0.141
	TripleJ	21.8	57.0	16	1047.1	2.7	3,786	556	3.6	1,383	0.147
Ctz10 - Riverside	MonoC	17.5	133.4	20	1051.1	8.0	8,607	1,174	8.2	1,075	0.136
	PolyC	17.5	125.8	20	1051.1	7.5	8,745	1,202	8.3	1,159	0.137
	SiFilm	17.5	104.0	20	1051.1	6.2	6,579	892	6.3	1,055	0.136
	TripleJ	21.8	57.0	16	1047.1	2.7	4,136	576	4.0	1,511	0.139
Ctz12 - Sacramento	MonoC	17.5	133.4	20	1051.1	8.0	7,189	1,023	6.8	898	0.142
	PolyC	17.5	125.8	20	1051.1	7.5	7,336	1,049	7.0	972	0.143
	SiFilm	17.5	104.0	20	1051.1	6.2	5,256	745	5.0	843	0.142
	TripleJ	21.8	57.0	16	1047.1	2.7	3,309	485	3.2	1,209	0.147

Shaded (Orientation B)

The current version of the DOE 2.2 program does not integrate the effect of shading on BIPV arrays by other building surfaces. The effect of modest shading fractions is highly dependent on panel type and array wiring layout and these characteristics are not defined in the program inputs at this time. For example, the power output of a group of panels wired in series will be diminished to a greater extent by the shading of one panel, than the power output from a group of panels in parallel (or with independent inverters). However, it is possible to bound the shading degradation effect from the simulation reports.

The lower spandrel panels will be shaded to a greater degree than the upper ones. See Table 1 for degradation limits. The minimum degradation is listed in the column titled “% of Unshaded Radiation, Total.” The maximum degradation is listed in the column titled “% of Mostly Unshaded (> 90% Direct Sun) Sunny Hours.”

For example, the PV panels located above the first floor windows will receive a maximum of 82% of the total available annual solar radiation. The reason for this 18% decrease is self-shading due to the angle of the sun during certain parts of the year and the building layout. The worst case for the first floor BIPV would be a design with all

panels wired in series and with 10% of the PV panel area shaded. In this case it is likely that there would be no electric power output during this condition. The first floor BIPV, due to its location and wiring arrangement, would be able to use only about 50% of the available solar radiation. This results in overall lower electrical output and has a significant adverse affect on the economics of installing BIPV.

Table 6 Self-shading Degradation Limits for Orientation B

	% of Unshaded Radiation		% of Mostly Unshaded (>90% direct sun) Sunny hours
	Direct	Total	Direct
1st Floor	85%	82%	50%
2nd Floor	92%	87%	65%
3rd Floor	99%	95%	80%

First Cost Estimates

We were able to obtain reliable total-cost installation estimates for large roof-mounted PV arrays. For rooftop systems with rated peak output of 30 kW and greater, the estimated cost ranges from \$7 to \$10 per peak watt. It is our opinion that smaller systems such as the ones simulated will be slightly more expensive, probably in the range of \$8 to \$12 per peak watt.

The range in installed costs for a 2.7 to 8.0 kW installed system with 1050 sf of surface area would be \$22,000 to \$96,000, assuming that the nominal cost per peak watt applies to all four of the simulated PV panel types. The nominal cost per square foot of installed PV surface would range between \$21 – 91/sf.

Conclusions

A vertical south-facing panel has a small effect on building or system peak demand. Maximum building peak demand reductions were in Riverside and were about 20% of the rated panel output. Other sites and systems were as low as 5%. Peak demand was set during the summer due to air conditioning loads. Rooftop and/or parking lot shading structures provide a better match for reducing peak demand.

Simple payback periods for all locations are from about 20 to 90 years. The cost of BIPV may be offset in California by utility or government rebate programs, but it is clear that vertically mounted curtain wall BIPV is expensive relative to other distributed power generation options. Rooftop and parking structure PV systems have better payback periods due to higher power production and coincidence in peak power production with peak cooling loads.

Recommendations

For new construction, vertical BIPV should be considered when the cost of the installed BIPV is less than the initially specified curtain wall material. This may be the situation for show case office buildings.

For new construction and retrofit, BIPV in vertical curtain-walls may have public relations value. Although this may be an intangible benefit, it directly demonstrates the building owner's commitment to sustainable design.

Curtain-wall mounted BIPV should be considered when installing a rooftop or parking lot system to take advantage of its public visibility. A rooftop system is usually hidden from public view. Adding curtain-wall mounted BIPV to a rooftop system project would likely lower the marginal installed costs and provide a public relations benefit.