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Building Integrated Photovoltaic Systems Analysis

Preliminary Report

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Building Integrated Photovoltaic Systems Analysis: Preliminary Report

EXECUTIVE SUMMARY

NREL has estimated that the deployment of photovoltaics (PV) in the commercial buildings sector has the potential to contribute as much as 40 gigawatts peak electrical generation capacity and displace up to 1.1 quads of primary fuel use. A significant portion of this potential exists for smaller buildings under 25,000 square feet (2,300 square meters) in size and two stories or less, providing a strong cross over potential for residential applications as well. To begin to achieve this potential, research is needed to define the appropriate match of PV systems to energy end-uses in the commercial building sector. This report presents preliminary findings for a technical assessment of several alternate paths to integrate PV with building energy systems.

Two preliminary findings currently emerge from this work:

[1] Further research is warranted to investigate the feasibility of tying PV systems to specific building end-use loads. Alternative approaches to transforming PV DC power to AC and feeding general building loads appear promising.

This analysis focused on matching PV power to specific building end-use loads. The reason for this focus is to probe where PV system cost savings may be realized by targeting building end-uses. Particular attention has been directed to building heating, ventilation and air conditioning (HVAC) loads, which generally are a significant component of building peak load profiles and tend to track the daily solar resource. With this focus, it appears to be technically feasible to feed DC power into the DC stage of motor variable speed drive (VSD) control systems, which are finding increased application in building HVAC systems. A similar opportunity exists to feed DC power directly into the DC control circuits of electronically commuted DC motors (ECMs). ECMs represent a rapidly developing technology which overcomes the traditional disadvantages of DC motors (cost, efficiency, and reliability) versus AC motors. Several manufacturers are marketing small commercial and residential scale heat pump systems using ECM/VSD technology. The cost for VSDs and ECMs is coming down with expanding markets. Thus a significant part of the balance of system costs for PVs may be reduced by tying into this trend and exploration of the technical feasibility of direct DC feed to this class of equipment is warranted.

[2] Due to the high, near-term capital cost of PV systems, maximum utilization of the energy produced by the system remains critical and target end-uses should be selected accordingly.

This study explores building enduse targeted PV applications. The objectives were to consider approaches which maximize the value of offset energy use and demand and minimize balance of system costs. The results of the preliminary cost analysis contained in this report show a roughly one for one tradeoff between utilization of system output and the levelized cost of delivered energy. For example, if only 80% of potential PV system energy output is utilized (a 20% reduction), the cost per watt of delivered energy increases by 23%. An example of when this might occur would be if an air conditioning chiller, used only during periods of peak cooling loads, was targeted to be directly fed by a PV system (with minimal battery storage) and the unit was not operating during some portion of the daytime hours when the solar resource was available. A related finding shows that the cost of delivered energy is relatively less sensitive to the value of displaced peak demand. In this analysis, a 20% decrease in the value of reduced demand resulted in only a 1% increase in the cost of PV energy. The driver behind both of these results is the high capital cost for current PV systems. In the first instance, each watt-hour of output is important to amortize the initial system cost. The second result shows the dominance of high capital costs in the levelized cost of energy calculation versus the credit which can be taken for reduced peak demand. Care should therefore be exercised in any design decision which trades off utilization of system output in favor of other objectives such as peak demand reduction.

I. INTRODUCTION

This interim report presents information on the application of building integrated photovoltaics (PV) in small commercial buildings. The primary objective of this effort has been to assess the trade-offs between conventional PV application strategies (which transform DC to AC power to feed general building loads), and applications which eliminate balance of system (BOS) costs by targeting specific building energy end-uses.

If PV technology is to become a viable, large-scale source of power for commercial buildings, a standard approach to PV system design and integration into building end-uses should be developed. One basic question facing the electrical system designer is whether DC PV power can be used directly or should be converted into AC form. The traditional design approach has assumed the conversion of DC power to AC form for most end-uses. However, advances in DC technologies have led us to conclude that solar-assisted DC applications may also play a strong role in future development of PV in the buildings sector.

II. GENERAL DESIGN CONSIDERATIONS

Many factors impact AC and DC system design decisions. Costs are easily assigned to some of these factors, while others are more difficult to quantify, either because costs may be difficult to generalize or because advances in technology are occurring so rapidly that realistic cost figures are difficult to predict. Factors that will impact design decisions include:

- The reason for using a PV source, such as demand reduction or strategic conservation
- The availability and type of storage medium
- The availability and cost of appropriate electrical system components.

Determining whether a PV system is to be used for demand reduction or strategic conservation plays a role in system design considerations. If the primary goal is strategic conservation, then the focus of the design should be the most efficient use of the PV power. If the goal is demand reduction, reliably meeting the demand during peak periods will be the design goal. For peak demand reduction, it may make sense to dedicate certain functions or pieces of equipment to be powered by the PV array.

Commercial building loads generally follow a diurnal profile, peaking during the mid to late afternoon (Figures 1a and 1b). With attention to system design, PV systems can be tuned to provide peak power during a similar period with minimum backup storage in keeping with the strategy to reduce BOS costs. If sized to 10 to 30 percent of the peak building load, full utilization of the PV system is likely during both weekday and weekend periods. By constraining the size of the PV system, both structural and electrical interconnect issues are likely to be simplified.

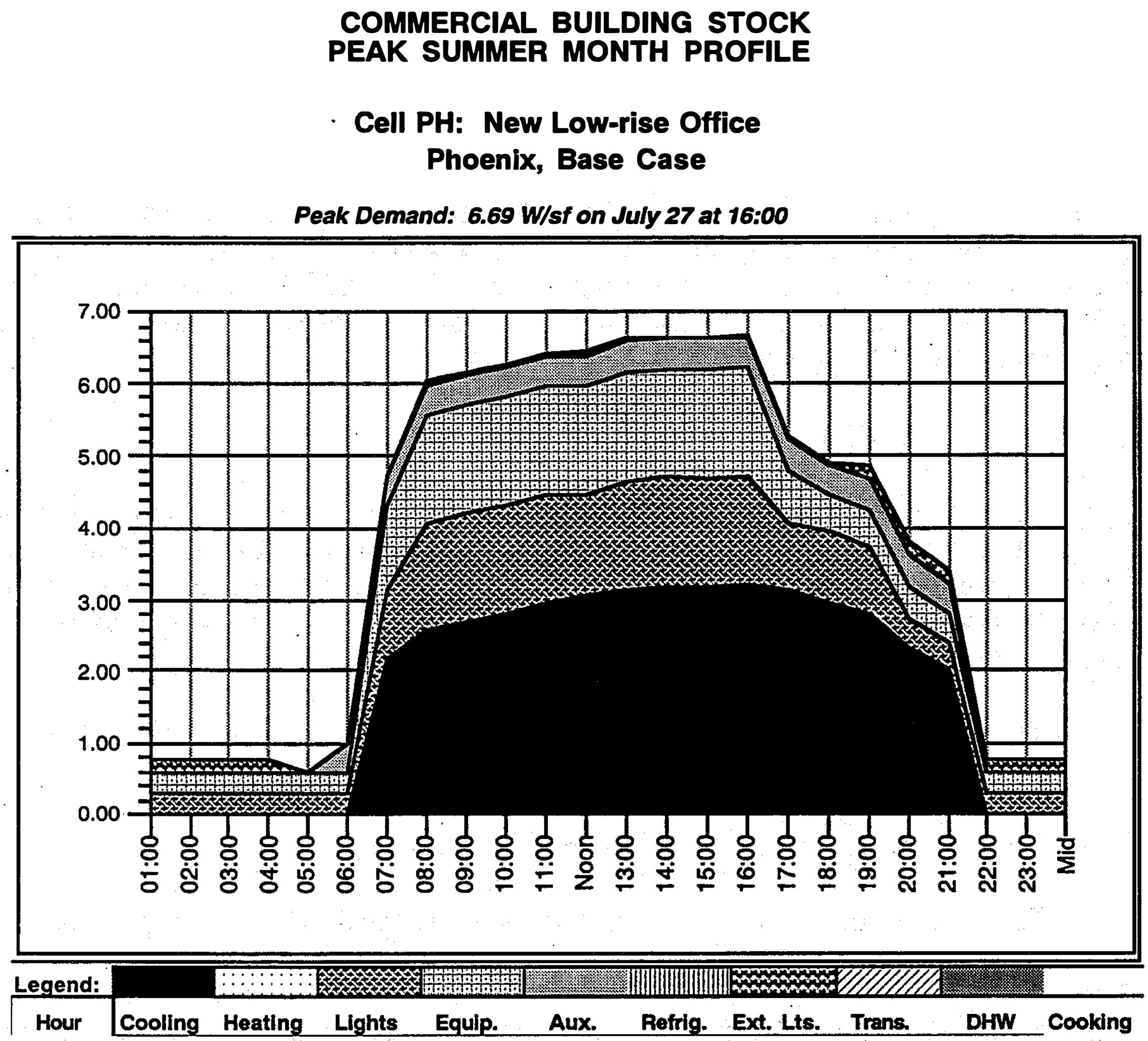

Figure 1a: Sample Commercial Building Summer Load Profile

COMMERCIAL BUILDING STOCK
PEAK WINTER MONTH PROFILE

Cell PH: New Low-rise Office
Phoenix, Base Case

Peak Demand: 5.81 W/sf on October 13 at 16:00

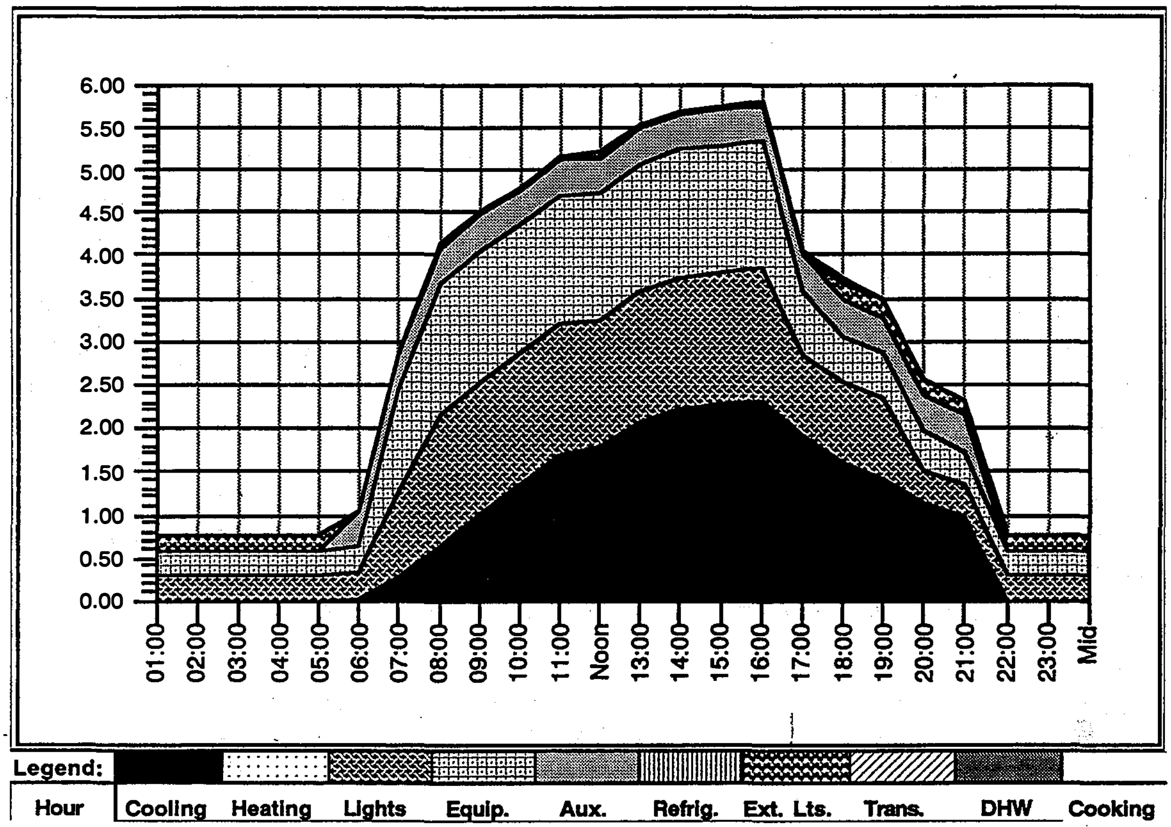

Figure 1b: Sample Commercial Building Winter Load Profile

Energy storage is required if firm peak capacity savings is a prime objective for PV systems due to the intermittent nature of the solar resource. This requirement might be relaxed if active demand limiting within the building is coordinated with PV system performance. If the PV system is scaled to the cooling load, electrical storage capacity might be minimized due to strong coincidence between the solar resource and this end-use load in most commercial buildings. As a peak reduction strategy, the interaction of building integrated PV systems and cool storage deserves further research.

The type of energy storage system selected is related to the avoided electric utility cost. This cost is quite dependent upon the rate structure, particularly on the structure of demand charges. From a customer perspective, if rates are sufficiently high, the additional cost of storage may be justified. Battery systems and their accompanying electrical conversion and conditioning equipment have become more affordable in recent years due to the growing popularity of building uninterruptible power supply (UPS) systems. However, if demand charges are low, the utility grid may be the least cost source of back-up power.

Sections III and IV below further discuss some of the issues and tradeoffs between AC and DC approaches to integrate PV power in buildings.

III. AC POWER SYSTEMS

AC power systems are the standard design, and most commercial buildings are designed with a 230 V feed. AC systems have been the design choice in the past for several reasons. The system design requirements are well developed and documented in standards such as the National Electric Code. AC equipment is fairly well understood and reasonably priced. The greatest problems now experienced with AC power systems are those associated with harmonics, caused by the increasingly common use of electronics in various controls and computer applications.

The addition of a PV system to this type of power system is fairly simple. The PV power is converted to an AC form through an inverter or so-called power conditioning system (PCS), as indicated in Figure 2. Once this conversion takes place, the power is part of the building's power grid.

Figure 2: Conventional PV AC installation

The equipment used with this type of system is standard equipment that is readily available. The inverter is the most complicated component, and this type of equipment is rapidly coming down in cost. The growing popularity of UPS systems is making this type of DC-AC conversion system more affordable than in the recent past. Current costs are between 1 to 2 $/kVA [6].

The utility grid normally provides the storage and back-up capability for this type of system. For this reason, the system is not desirable if firm demand reduction is the goal, unless other arrangements are made for energy storage or coordination with other building automation controls. Low cost power conditioning systems should be avoided. The squared-wave output typical of low-end inverters may inject undesirable harmonic distortion into the building power system with detrimental impact particularly on motors and transformers.

A PV system which simply feeds into the building AC circuits is attractive for several reasons. There is no need to associate the PV system with any particular load. There are few risks associated with this type of design; the component design is well established. The greatest risks are that the system may cause some harmonics problems, originating with the switching system associated with the power conversion, and that the system may not be as cost effective or efficient as a DC power system.

AC power systems are not inherently efficient where variable speed drive applications are needed. Squirrel cage motors may be built with two-speed capabilities, but they are not capable of stepless variation in speed without the use of a variable speed drive unit. This additional cost is a factor that should be evaluated when comparing AC and DC-powered systems.

As an indication of trends in the PV industry, in December 1992, Mobile Solar Energy Corp. announced pre-engineered/modular 4-kW PV power systems with the AC inverter integrated into the design [10].

IV. DC POWER SYSTEMS

DC power systems in buildings have traditionally been rare, generally used only in cases where AC power is not available. Reasons for this include the lack of DC components, the cost and efficiency premiums generally associated with DC components, and the lack of established design standards.

DC-driven components have generally not been attractive for a number of reasons. A natural use for DC power would be for motors; DC motors are inherently variable speed machines. However, traditional DC motors also have a significantly higher first cost than their AC squirrel cage counterparts. These DC designs are also less efficient than squirrel cage motors. Finally, the commutator brushes on DC motors require additional maintenance that is not needed on AC motors. It can be very difficult to justify the variable speed capability based on the economics.

Recent advances in motor technology are making the use of DC motors much more attractive. Electronically commutated, brushless DC motors are now available in 5-hp and smaller sizes. These motors are comparable in efficiency and first cost to traditional squirrel cage designs [3].

Three DC system configurations are discussed in the balance of this section. These include:

- Direct-coupled DC motor package
- Hybrid AC/DC design
- Dedicated DC bus.

Back-up power requirements must be considered for each of these approaches. Options include providing redundant AC-powered equipment, DC power storage devices (or other form of energy storage, e.g., cool storage), and additional AC to DC switching and conversion capabilities.

DIRECT COUPLED CONVENTIONAL DC MOTOR PACKAGE

The direct coupled DC motor application is one in which a DC motor is driven by DC power from the PV array, as indicated in Figure 3. In a commercial building, it is most likely that this motor would be associated with a compressor or fan as part of a building air conditioning system.

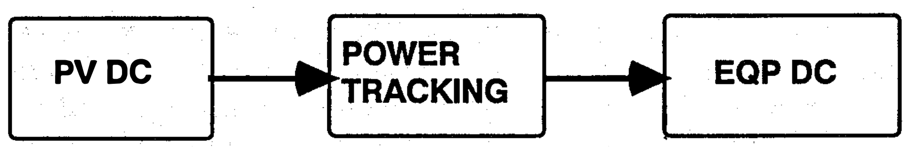

Figure 3: **Direct DC Coupled Installation**

A direct PV-driven conventional DC motor has not been an attractive option for the following reasons:

- Conventional DC (brush commutated) motors are less efficient than their AC counterparts and historically require more maintenance.

- Conventional DC motors are three to five times more expensive for a given size, due to lower sales volume and higher manufacturing costs. At the present time, inverter costs are comparable to the cost premium for DC motors.

- Direct feed of PV-generated DC to a motor load is not recommended. A directly connected DC motor will tend to force a PV array to operate at a point significantly below maximum efficiency. Battery storage can act to buffer the PV array from the load fluctuations imposed by the motor, or control circuitry ("maximum power point trackers") can be added to keep circuit impedance at levels which optimize PV performance (with added cost).

Electronically commutated brushless DC motors (ECMs) are a promising new technology currently used with variable speed drive (VSD) control systems. By combining these technologies, problems associated with a direct PV-driven conventional DC motor may be avoided as discussed in the next section.

HYBRID AC/DC SYSTEM

Variable speed drive (VSD) control systems are gaining popularity in applications in which different motor speeds are required or advantageous. The typical VSD controller is fed AC power, converts it to a DC form to gain the speed control characteristics, and converts it back into a pseudo-AC form to drive a squirrel cage motor.

ECMs essentially combine VSD control technology with innovations in DC motor design. ECMs offer the promise of both higher efficiency and low maintenance. A power conversion stage is built into ECMs which converts AC to high frequency switched DC, delivering the commutated power to drive the motor. Several sources (Ward Bower, Sandia Laboratory, Albuquerque, and SR Drives Ltd., U.K.) have indicated that it is technically feasible to supply DC power directly to the "DC bus" portion of the control system typical of an ECM motor [4][5]. By the nature of the tie into the "DC bus" (250 volt) of the ECM control circuitry, PV maximum power point operation should be easier (less costly) to achieve. The first cost of ECMs now manufactured by General Electric is comparable to the cost of similarly sized squirrel cage motors.

It is possible to skip the initial AC to DC conversion step by injecting DC power after the point in the control circuitry when the conversion normally occurs. If the PV assisted end-use application is completely decoupled from the building AC system, speed control may become an issue. A VSD needs some kind of reference point to establish speed, and many of the systems in existence use the 60 Hz inherent in AC power systems to set the reference point. This is not an insurmountable challenge.

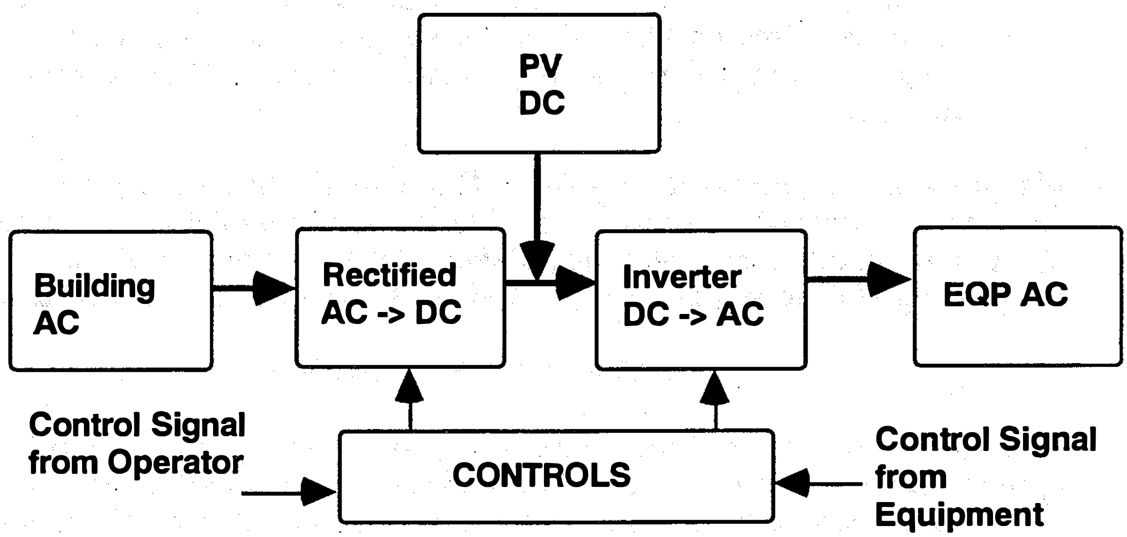

Figure 4: PV DC Assisted Installation

Several heat pump systems are currently on the market which use the ECM technology either for the compressor motor, the air handler fan, or both. The Lennox HP21 heat pump (5 ton max) uses variable speed ECM fan features. The Carrier Hydrotech 2000 unit (3 ton max) uses ECMs for both the fan and compressor motor. (The Carrier unit is priced at roughly $2800, which is double the cost of a comparable non-ECM 3-ton unit.) In larger packaged systems (5 ton and up), standard electronic VSDs are combined with AC induction drive motors [8],[9].

Trane experimented with DC chiller packages in larger capacities but has abandoned the project due to lack of market and competition for in-house development dollars[7].

DEDICATED DC BUS

One approach that should be considered for new construction is a design that involves the use of a dedicated DC bus. This approach assumes that certain DC equipment, such as lighting or variable speed motors and charging for UPS equipment, will be fed from the bus. This design alternative requires further investigation.

BACK-UP SYSTEMS

Several options have already been mentioned as potential back-up systems. These include redundant AC-driven equipment, energy storage systems, and AC conversion systems. Of these options, AC conversion systems may be the most cost effective. Converting AC to DC is not as expensive as converting DC to AC. UPS equipment is in place in many office environments, so the basic AC to DC switching and conversion equipment is already available.

Adding circuitry to allow AC power to act as the back-up for DC equipment may be relatively simple. If peak demand reduction is an issue, battery or thermal storage would need to be considered.

V. SENSITIVITY ASSESSMENT: COST OF SAVED ENERGY

The previous sections have presented a preliminary survey of technical issues bearing on the choice of AC versus DC applications for PV power in commercial buildings. The cost of delivered energy and the factors that drive that cost provide a further basis to focus design decisions for building integrated PV systems. This section presents the results of "cost of saved energy" (CSE) calculations. CSE provides a simple life cycle cost measure of the cost of PV energy [11]. The formulation of the simple cost model used in this analysis appears in the Appendix to this report. As defined, CSE includes the effect of both energy and demand savings.

The CSE model is simple while allowing treatment of key factors which effect the delivered cost of energy for PV systems. Most importantly, it includes a credit taken for displaced peak demand and the impact of changes to balance of system components and end-use costs and efficiency. The thrust of this preliminary analysis is to probe the sensitivity of PV energy cost to several key factors. These factors include balance of system costs, value of demand versus energy savings, and system efficiency improvements. In general, the range of values used in the cases defined below attempt to push values to their credible extreme to show worst/best case impact on CSE. No attempt has been made in this first order analysis to treat more intricate ratchet utility rate structures. Note that by including a demand credit in the formulation, CSE should be compared to blended (demand and energy charges combined on a $/kWh basis) utility rates.

For this preliminary analysis, a PV system size was selected at 6500 W_{peak} capacity which is comparable to the capacity needed to power a typical HVAC supply fan or the compressor in a 5-ton package chiller system. Recent PV system bids submitted to the Sacramento Municipal Utility District (SMUD) for commercial PV system costs ranged from $7 to $10 per W_{peak} capacity. A figure of $9.50/$W_{peak}$ was selected as the base case value for this analysis (including power conditioning subsystem, array wiring, and end-use interconnect costs). Other parameters used in the analysis are defined in the Appendix [1],[2].

CSE calculations were performed for three locations; Phoenix, San Francisco, and New York. Phoenix was selected as a site with high solar resource coincident with peak commercial building (cooling) loads. San Francisco and New York were analyzed due to the coincidence of commercial sector loads with the utility system peak.

Nine cases were defined to test the sensitivity of CSE to varying assumptions about capital cost, demand charges, and energy utilization. Simple energy and demand rates were used with no ratchet features and full demand credit for the PV systems equal to its design capacity.

The nine cases are summarized as:

(1) **Base Case**

(2) **High Demand Rate** - increase demand rate by a factor of ten from $2/kW to $20/kW

(3) **Low PCS Cost** - reduce power conditioning subsystem (PCS) cost from $2.00/peak watt to $0.00/peak watt

(4) **High PCS Efficiency** - increase PCS efficiency from 95 to 100 percent

(5) **80% Peak Capacity Credit** - reduce demand charge credit by 20%

(6) **80% Energy Credit** - reduce energy utilization by 20%

(7) **Low PV Module Cost** - reduce module cost from $6.40/peak watt to $2.00/peak watt

(8) **Low Module and PCS Cost** - reduce module cost to $2.00/peak watt and PCS cost to $0.20/peak watt

(9) **Low Module/PCS Cost and High Demand Charge** - case 8 with demand charge increased from $2 to $10/kW/month

Figure 5 summarizes the computed CSE values for the base and eight alternate cases for Phoenix. A more detailed presentation of these calculations appears in the Appendix, including the results for San Francisco and New York.

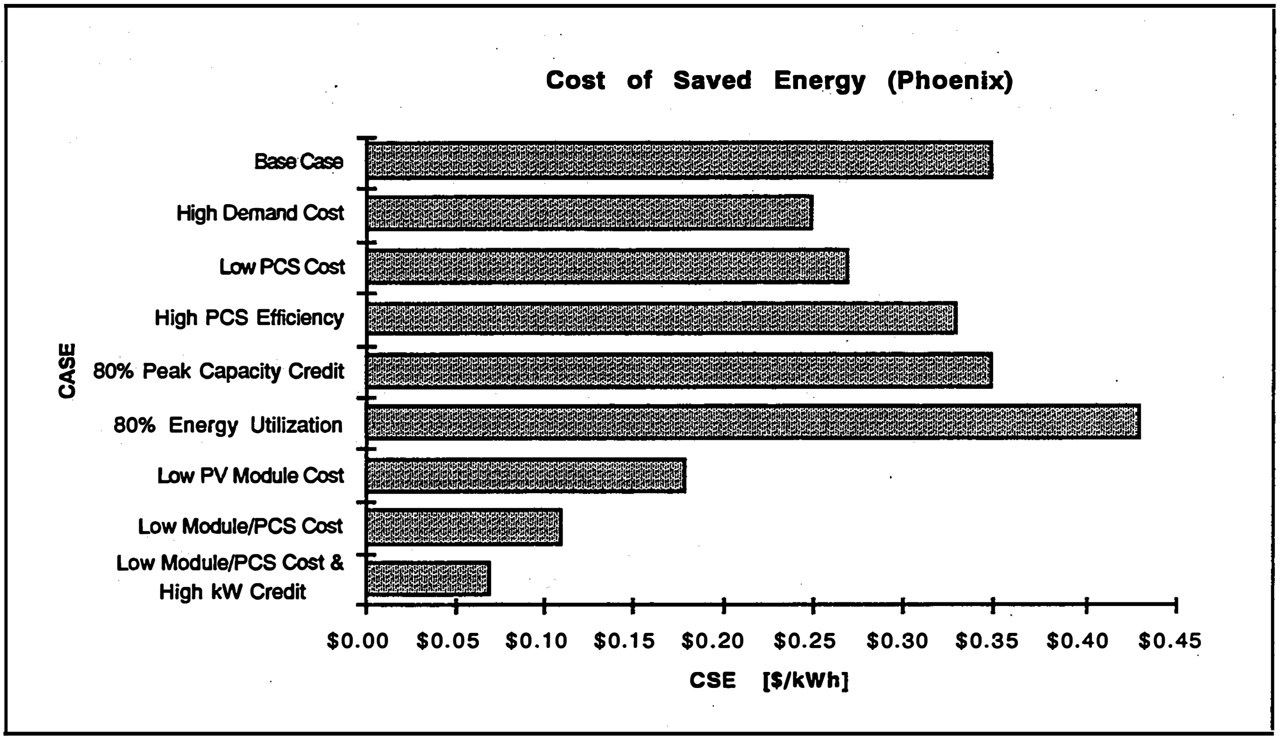

Figure 5: **Summary of Cost of Saved Energy Sensitivity Analysis**

Key findings from this analysis are:

- The base line CSE at $0.35/kWh is high compared to utility-provided power. As a point of comparison, the California Energy Commission's Energy Technology Status Report (ETSR) cites a levelized cost for near-term distributed PV systems in the range of 44 to 56 cents/kWh (1987 dollars) [15]. ETSR cites 12.5 to 15 cents/kWh as an accepted target range for peak duty technologies.

- With the capital cost of PV systems currently dominated by the PV modules themselves, the relative impact on CSE by other BOS components is reduced. Comparing the base case and Case 3, CSE is reduced by 23% for the total system. This assumes totally eliminating the $2/peak watt cost of the power conditioning system (PCS). Reducing the cost of PV modules from $6.40 to $2.00 per peak watt reduced CSE by 49% (Case 7). In either case, the cost of PV energy remains high relative to power from the utility grid. **Note:** Part of the cost differential can be immediately achieved in commercial building applications by using a "dual use" approach where the building PV is incorporated into the building shell. (See reference 14 which describes a variety of dual use strategies.)

- More value is realized in maximizing PV energy utilization, rather than displacing demand charges. A 20% reduction in utilization of the energy produced by the array increases CSE by 23% to $0.43/kWh (Case 6). If the peak demand credit is reduced by 20%, the increase in CSE is less than 1% (Case 5). Peak demand charges must be increased tenfold to reduce CSE by 29% (Case 2).

- With the combination of reduced module and BOS costs, CSE approaches the cost of grid power (Case 8). When the capital cost component of delivered energy cost is reduced, the credit for peak demand becomes more significant. CSE is reduced from 0.11 to 0.07 $/kWh by increasing the demand credit from 2 to 10 $/kW/month (Case 9).

Qualitatively similar results were generated for San Francisco and New York. The base case CSE is $0.46/kWh and $0.58/kWh for each location, respectively.

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July 12, 1993

Appendices

- References
- Outline of Cost of Saved Energy (CSE) Calculations
- Base Case and Sensitivity CSE Results for Phoenix, New York, and San Francisco

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[15] "Energy Technology Status Report - Summary, California Energy Commission, June 1991, p. 65.

Outline of Cost of Energy Calculations

PV Modules

Given:

Area/Module	0.5 m^2	A_M
Efficiency	12 %	η_M

Rated module output = (1000 $^W/M^2$ (A) (η) = Q_R = 60W_{pk}

Given:

Cost/module	$384	C_M

Normalized Module Cost = $C_M/Q_R = C_N$ = $6.40/$W_{pk}$

Given:

Required Peak Output (1) = 6500 W = Q_{pk}

Array Size =$Q_{pk}/Q_R * A_M = A_A$ = 54.2 m^2

System Efficiency

Given:

Array Eff.	= η_M = 12%
Field/wiring Eff.	= η_F = 98%
Power conditioning Eff.	= η_P = 95%
End-use Eff.	= η_E = 100%

Combined system Eff. = $\eta_M \eta_F \eta_P \eta_E$ = 11.2% = η_{sys}

Solar Resource Estimate

Given:

Annual Avg. Beam Irradiance = I_b kw/m_2

Annual Irradiation = Q_o GJ/m_2

(Based on Figure 3.2 by Rabl, Ref 13)

Annual Irradiation = Q_o * 277.78 = kwh/m^2

For Phoenix Q_o = 2417 kwh/m^2

(1) Sized based on 5 ton RTU w/ 8.7 HP motor

Outline of Cost of Saved Energy Calculations **2 of 2**

Total capital cost = $Q_{pk} * (C_N+C_F+C_P+C_E)$ = TCC [$]

where C_N etc. are costs in $/Wpk
for array, field, power conditioning, and end-use equipment

Annualized capital cost = TCC * CRF = ACC [$/Yr, present value]

where CRF is the capital recovery factor
based nominally on 5% discount rate and 20-year lifetime

Annual Demand Credit = $Q_{pk}/1000 * CF_{pk} * 12 * R_{pk}$ = ADC [$/Yr]

where
CF_{pk} = Coincidence factor for peak demand
R_{pk} = Monthly utility demand charge

Annual O&M Cost = ACC * Ro&m = AOM [$/Yr]

where
$R_{o\&m}$ = Annual O&M cost as a percent of annual capital cost

Annual Energy Saved = $Q_o * A_a * \eta_{sys} * CF_E$ = AES [kWh/Yr]

where
CF_E = coincidence/utilization factor for energy

Cost of Saved Energy = CSE = (ACC - ADC + AOM)/AES [$/kWh]

NOTE: Costs, utility rates, and PV characteristics were defined by ERG as representative for this first order analysis.

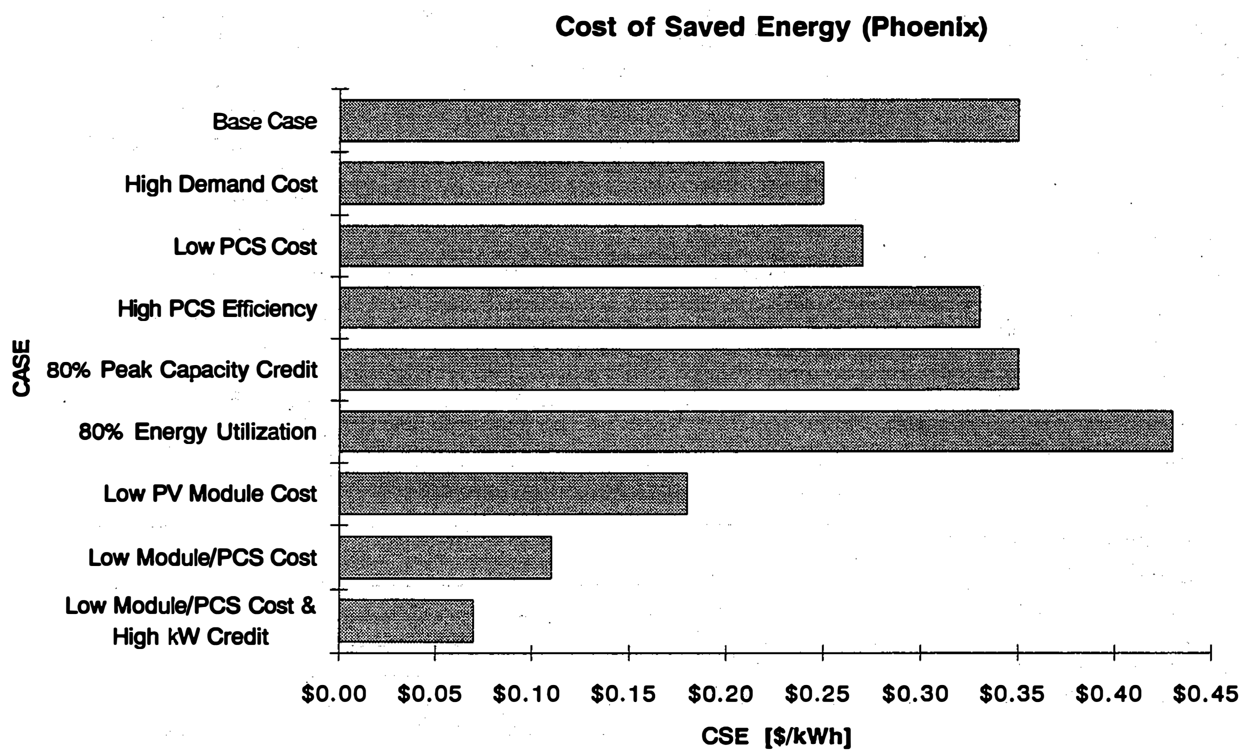
Phoenix Base Case

PV Commercial Buildings Assessment			ERG Project 591		
Cost of Saved Energy Calculations					
4/8/93, NW	**Case:**	Base Case - Phoenix			
Cost Data					
PV Array Cost ($/Wpk)	$6.40	**Capital Recovery Factor**			
Field Costs ($/Wpk)	$1.00	Discount Rate	0.05		
Power Conditioning Costs ($/Wpk)	$2.00	Period	20		
End-Use Costs ($/Wpk)	$0.10	CRF	0.0802		
O&M Cost (Percent of Ann. Capital Cost)	2%				
PV Module Characteristics		**Modified Cost of Saved Energy Calculation ****			
Target System Size (W)	6500	Total Capital Cost		$61,750	
Module Area (sq. meters)	0.5	Annualized Capital Cost ($/Yr)		$4,955	ACC
Module Rated Output (Wpk)	60	Annual Demand Credit ($/Yr)		$156	ADC
Module Cost ($/module)	$384.00	Annual O&M Cost ($/Yr)		$99	AOM
Normalized Module Cost ($/Wpk)	$6.40	Annual Energy Savings (kWh)		14177	AES
Required Array Size (m2)	54.17	Value of Saved Energy ($/Yr)		$1,418	
Efficiencies		Cost of Saved Energy ($/kWh)		$0.35	CSE
array	12.00%				
field	95.00%				
power conditioning	95.00%				
end-use	100.00%		** Cost of Saved Energy modified to include		
			demand credit and O&M Cost		
Combined System Efficiency	10.83%				
			Definition:		
Utility Data			Cost of Saved Energy = CSE		
Energy charges ($/kWh)	$0.10		= (ACC - ADC + AOM) / AES		
Demand Charges ($/kW)	$2.00				
Solar Resource Data					
Annual Avg. Beam Irradiance (kW/m2)	0.60				
Annual Irradiation (GJ/m2)	8.70				
Annual Irradiation (kWh/m2)	2416.7				
PV Peak Coincidence Factor	100%				
PV Energy Coincidence Factor	100%				
			ERG Intl, Inc.		

Summary of Cost of Saved Energy Sensitivity Analysis (Phoenix)

Case	Cost of Saved Energy		Changes From Base Case
	[$/kWh]	% of Base Case	
Base Case	$0.35	100%	
High Demand Cost	$0.25	71%	2.00 to 20.00 $/kW/month
Low PCS Cost	$0.27	77%	2.00 to 0.00 $/Wpk
High PCS Efficiency	$0.33	94%	95% to 100%
80% Peak Capacity Credit	$0.35	100%	100% to 80% utilization
80% Energy Utilization	$0.43	123%	100% to 80% demand credit
Low PV Module Cost	$0.18	51%	$6.40 to $2.00/Wpk
Low Module/PCS Cost	$0.11	31%	$2/Wpk-PV, $0.20/Wpk-PCS
Low Module/PCS Cost & High kW Credit	$0.07	20%	Low Module/PCS Cost & $10/kW Demand Charge

W_{pk} = Watts peak i.e. Watt capacity at peak conditions

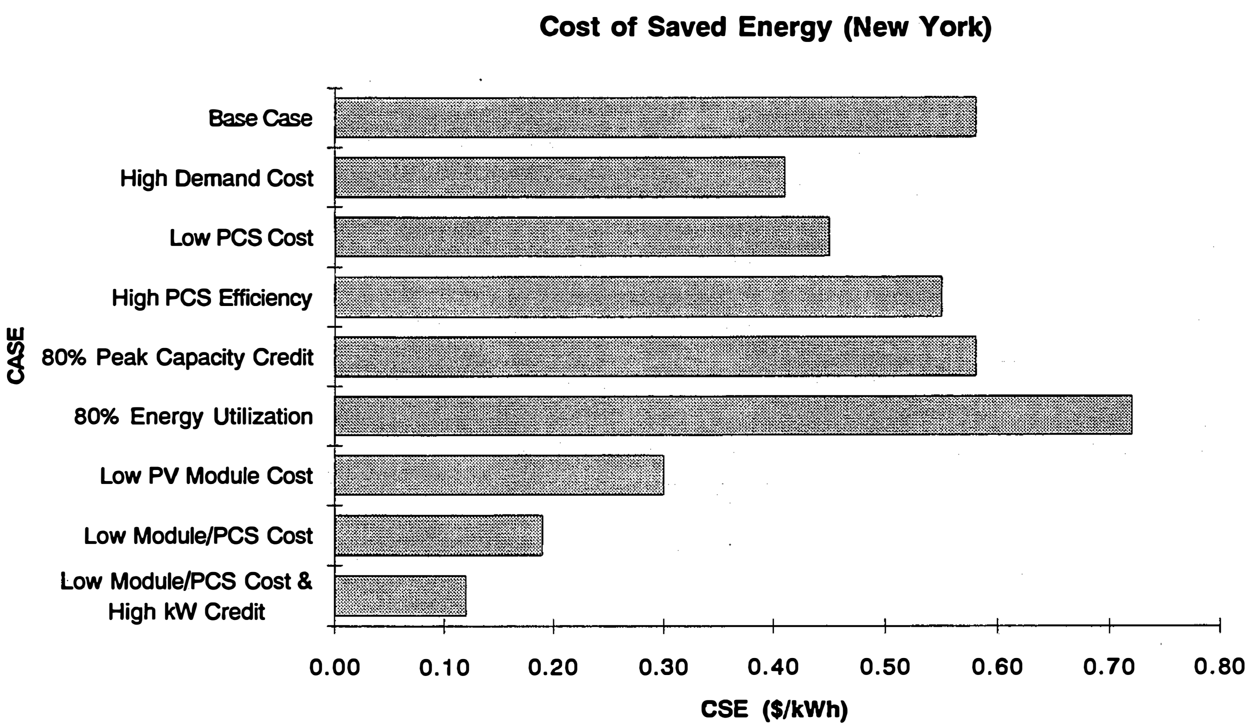

Cost of Saved Energy (Phoenix)
CASE
Base Case
High Demand Cost
Low PCS Cost
High PCS Efficiency
80% Peak Capacity Credit
80% Energy Utilization
Low PV Module Cost
Low Module/PCS Cost
Low Module/PCS Cost & High kW Credit
$0.00
$0.05
$0.10
$0.15
$0.20
$0.25
$0.30
$0.35
$0.40
$0.45
CSE [$/kWh]

New York Base Case

PV Commercial Buildings Assessment			ERG Project 591		
Cost of Saved Energy Calculations					
4/8/93, NW	**Case:**	Base Case - New York			
Cost Data					
PV Array Cost ($/Wpk)	$6.40	**Capital Recovery Factor**			
Field Costs ($/Wpk)	$1.00	Discount Rate	0.05		
Power Conditioning Costs ($/Wpk)	$2.00	Period	20		
End-Use Costs ($/Wpk)	$0.10	CRF	0.0802		
O&M Cost (Percent of Ann. Capital Cost)	2%				
PV Module Characteristics		**Modified Cost of Saved Energy Calculation ****			
Target System Size (W)	6500	Total Capital Cost		$61,750	
Module Area (sq. meters)	0.5	Annualized Capital Cost ($/Yr)		$4,955	ACC
Module Rated Output (Wpk)	60	Annual Demand Credit ($/Yr)		$156	ADC
Module Cost ($/module)	$384.00	Annual O&M Cost ($/Yr)		$99	AOM
Normalized Module Cost ($/Wpk)	$6.40	Annual Energy Savings (kWh)		8474	AES
Required Array Size (m2)	54.17	Value of Saved Energy ($/Yr)		$847	
Efficiencies		Cost of Saved Energy ($/kWh)		$0.58	CSE
array	12.00%				
field	95.00%				
power conditioning	95.00%				
end-use	100.00%		** Cost of Saved Energy modified to include		
			demand credit and O&M Cost		
Combined System Efficiency	10.83%				
			Definition:		
Utility Data			Cost of Saved Energy = CSE		
Energy charges ($/kWh)	$0.10		= (ACC - ADC + AOM) / AES		
Demand Charges ($/kW)	$2.00				
Solar Resource Data					
Annual Avg. Beam Irradiance (kW/m2)	0.30				
Annual Irradiation (GJ/m2)	5.20				
Annual Irradiation (kWh/m2)	1444.5				
PV Peak Coincidence Factor	100%				
PV Energy Coincidence Factor	100%				
			ERG Intl, Inc.		

Summary of Cost of Saved Energy Sensitivity Analysis (New York)

Case	Cost of Saved Energy		Changes From Base Case
	[$/kWh]	% of Base Case	
Base Case	$0.58	100%	
High Demand Cost	$0.41	71%	2.00 to 20.00 $/kW/month
Low PCS Cost	$0.45	78%	2.00 to 0.00 $/Wpk
High PCS Efficiency	$0.55	95%	95% to 100%
80% Peak Capacity Credit	$0.58	100%	100% to 80% utilization
80% Energy Utilization	$0.72	124%	100% to 80% demand credit
Low PV Module Cost	$0.30	52%	$6.40 to $2.00/Wpk
Low Module/PCS Cost	$0.19	33%	$2/Wpk-PV, $0.20/Wpk-PCS
Low Module/PCS Cost & High kW Credit	$0.12	21%	Low Module/PCS Cost & $10/kW Demand Charge

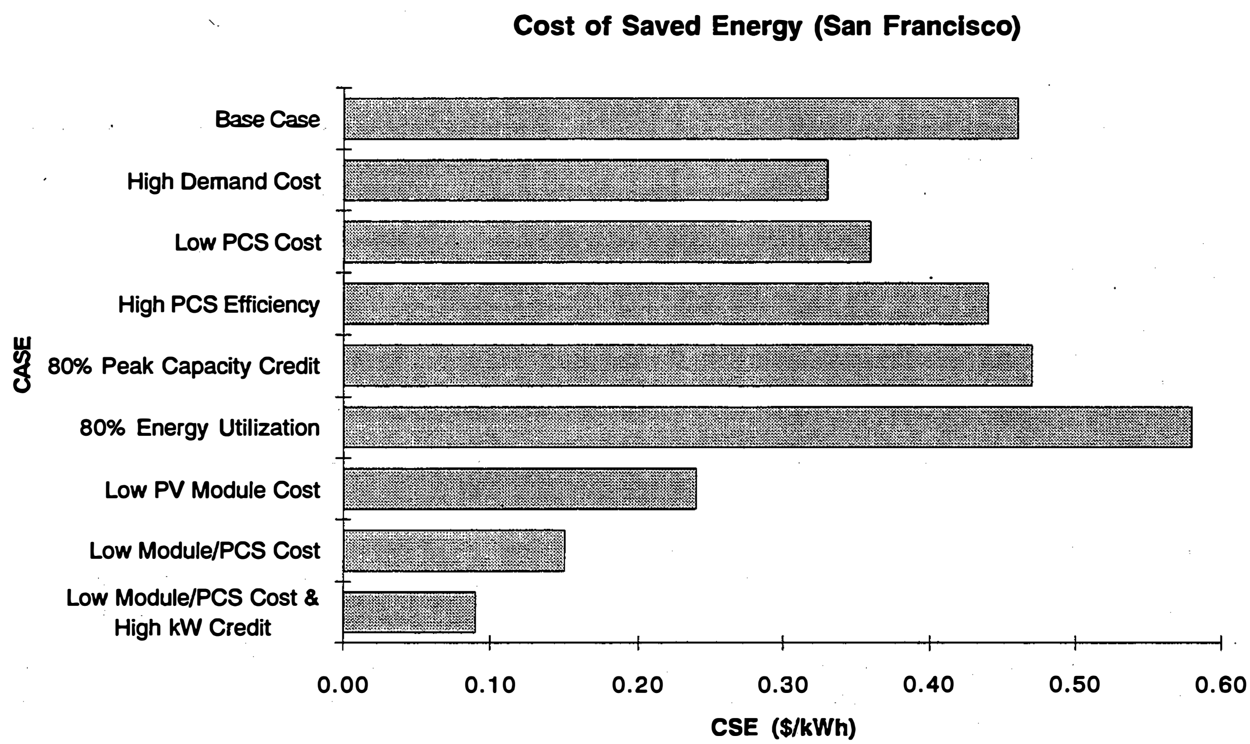

Cost of Saved Energy (New York)
CASE
Base Case
High Demand Cost
Low PCS Cost
High PCS Efficiency
80% Peak Capacity Credit
80% Energy Utilization
Low PV Module Cost
Low Module/PCS Cost
Low Module/PCS Cost &
High kW Credit
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
CSE ($/kWh)

San Francisco Base Case

PV Commercial Buildings Assessment			ERG Project 591		
Cost of Saved Energy Calculations					
4/8/93, NW	**Case:**	Base Case - San Francisco			
Cost Data					
PV Array Cost ($/Wpk)	$6.40	**Capital Recovery Factor**			
Field Costs ($/Wpk)	$1.00	Discount Rate	0.05		
Power Conditioning Costs ($/Wpk)	$2.00	Period	20		
End-Use Costs ($/Wpk)	$0.10	CRF	0.0802		
O&M Cost (Percent of Ann. Capital Cost)	2%				
PV Module Characteristics		**Modified Cost of Saved Energy Calculation ****			
Target System Size (W)	6500	Total Capital Cost		$61,750	
Module Area (sq. meters)	0.5	Annualized Capital Cost ($/Yr)		$4,955	ACC
Module Rated Output (Wpk)	60	Annual Demand Credit ($/Yr)		$156	ADC
Module Cost ($/module)	$384.00	Annual O&M Cost ($/Yr)		$99	AOM
Normalized Module Cost ($/Wpk)	$6.40	Annual Energy Savings (kWh)		10592	AES
Required Array Size (m2)	54.17	Value of Saved Energy ($/Yr)		$1,059	
Efficiencies		Cost of Saved Energy ($/kWh)		$0.46	CSE
array	12.00%				
field	95.00%				
power conditioning	95.00%				
end-use	100.00%		** Cost of Saved Energy modified to include		
			demand credit and O&M Cost		
Combined System Efficiency	10.83%				
			Definition:		
Utility Data			Cost of Saved Energy = CSE		
Energy charges ($/kWh)	$0.10		= (ACC - ADC + AOM) / AES		
Demand Charges ($/kW)	$2.00				
Solar Resource Data					
Annual Avg. Beam Irradiance (kW/m2)	0.42				
Annual Irradiation (GJ/m2)	6.50				
Annual Irradiation (kWh/m2)	1805.6				
PV Peak Coincidence Factor	100%				
PV Energy Coincidence Factor	100%				
			ERG Intl, Inc.		

Summary of Cost of Saved Energy Sensitivity Analysis (San Francisco)

Case	Cost of Saved Energy		Changes From Base Case
	[$/kWh]	% of Base Case	
Base Case	$0.46	100%	
High Demand Cost	$0.33	72%	2.00 to 20.00 $/kW/month
Low PCS Cost	$0.36	78%	2.00 to 0.00 $/Wpk
High PCS Efficiency	$0.44	96%	95% to 100%
80% Peak Capacity Credit	$0.47	102%	100% to 80% utilization
80% Energy Utilization	$0.58	126%	100% to 80% demand credit
Low PV Module Cost	$0.24	52%	$6.40 to $2.00/Wpk
Low Module/PCS Cost	$0.15	33%	$2/Wpk-PV, $0.20/Wpk-PCS
Low Module/PCS Cost & High kW Credit	$0.09	20%	Low Module/PCS Cost & $10/kW Demand Charge


Cost of Saved Energy (San Francisco)
CASE
Base Case
High Demand Cost
Low PCS Cost
High PCS Efficiency
80% Peak Capacity Credit
80% Energy Utilization
Low PV Module Cost
Low Module/PCS Cost
Low Module/PCS Cost & High kW Credit
0.00
0.10
0.20
0.30
0.40
0.50
0.60
CSE ($/kWh)

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15. Supplementary Notes

NREL Technical Monitor: Douglas E. Dahle

16. Abstract (Limit: 200 words)

The National Renewable Energy Laboratory (NREL) has estimated that the deployment of photovoltaics (PV) in the commercial buildings sector has the potential to contribute as much as 40 gigawatts peak electrical generation capacity and displace up to 1.1 quads of primary fuel use. A significant portion of this potential exists for smaller buildings under 25,000 square feet (2,300 square meters) in size or two stories or less, providing a strong cross over potential for residential applications as well. To begin to achieve this potential, research is needed to define the appropriate match of PV systems to energy end-uses in the commercial building sector. This report presents preliminary findings for a technical assessment of several alternative paths to integrate PV with building energy systems.

17. Document Analysis

a. Descriptors

photovoltaics; buildings; systems integration; sensitivity analysis

b. Identifiers/Open-Ended Terms

c. UC Categories

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