Building Integrated Photovoltaics
At the New York City Transit's
Corona Maintenance Shop and Car Wash Facility

Sponsored by:

Christy Herig
National Renewable Energy Laboratory
1617 Cole Blvd., Golden, CO 80401-3393
(303) 384-6546
e-mail: herigc@tcplink.nrel.gov

Prepared for:

Fazla Hassan, Project Manager
New York City Transit
CPM - Capital Planning & Budget
130 Livingston Street, Room 7070c
Brooklyn, NY 11201
(718) 694-5624
e-mail: fahassan@nyct.com

Prepared by:

Thomas E. Hoff
Clean Power Research
10 Glen Ct., Napa, CA 94558

e-mail: tomhoff@clean-power.com
Internet: www.clean-power.com

July 7, 2000

Disclaimer

This preliminary study presents a method to screen for building integrated photovoltaic applications and then applies the method to the New York City Transit's (NYC Transit's) Corona Maintenance Shop and Car Wash Facility. The study was funded by the National Renewable Energy Laboratory. The NYC Transit does not substantiate the data nor does the study reflect the NYC Transit's opinions or conclusions. It is not the final position of the NYC Transit.

Executive Summary

New York City Transit (NYC Transit) is the first public agency to be certified as ISO 14001-compliant. As a result, it has an important role and responsibility in providing environmental stewardship in public sector facilities planning, design, and construction. Accordingly, NYC Transit has chosen to seize the opportunity afforded by construction of the New Corona Maintenance Shop and Car Wash Facility to successfully develop a practical and effective prototype for environmentally-responsible 21st century rail transit maintenance facilities.

The new maintenance facility has the potential to include building integrated photovoltaics (BIPV). As shown in Figure 1, the new 175 foot by 689 foot building could incorporate BIPV in three locations: (1) as a vertical façade on the northwest wall where the administration offices will be housed (40 kW_{AC} of PV); (2) as part of a non-transparent flat roof; and (3) as part of tilted skylights over the maintenance portion of the facility (there is the potential for over 500 kW_{AC} of PV on the whole roof).

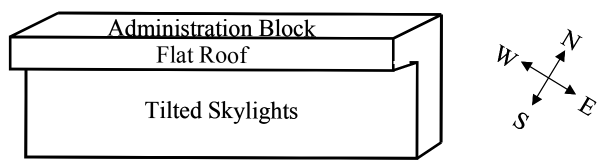


Figure 1. New Corona maintenance facility.

This report provides NYC Transit with information to begin to assess the cost-effectiveness of BIPV systems at this facility.

BIPV system selection and value components

BIPV systems can be broadly categorized as low-efficiency and high-efficiency systems. Low-efficiency systems use low-efficiency thin-film PV or sparsely populated crystalline modules (i.e., a lot of space between the cells in the module). High-efficiency systems typically use standard crystalline modules (i.e., the crystalline cells are placed close together).

BIPV systems are attractive because they have both energy value and area value components. The energy value is based on the PV system power rating (kW) and the area value is based on the PV system size (ft^2).

General conditions that guide system selection

Conditions exist where high-efficiency BIPV systems are more cost-effective than low-efficiency BIPV systems. Assume that: 1) the goal is to maximize net present value; 2) there are no tax effects or economic incentives; 3) different PV systems are compared in the same orientation and application; 4) PV technologies have the same price ($/kW) and technical performance characteristics; and 5) PV technologies have the same positive area-related savings.

Table 1 suggests that high-efficiency systems are more cost-effective than low-efficiency systems only when the system is economically justified without any area savings and the system is area-constrained; low-efficiency systems are preferable under all other conditions. The rationale for this is as follows. Systems ***without*** area constraints have the same energy value and differ only in their area value when they are designed to have the same power rating; the low-efficiency system has higher area value because it covers more area. Systems ***with*** area constraints have the same area value and differ only in their energy value; the high-efficiency system has a higher power rating and is only preferred if the energy value (without area savings) exceeds PV cost.

Table 1. General conditions for BIPV system selection.

	PV is cost-effective without area value (energy value exceeds PV cost)	Area value is required to make PV cost-effective (energy value plus area value exceed PV cost)
Unconstrained Building Area		***Low- Efficiency Systems Preferred***
Constrained Building Area[1]	***High-Efficiency Systems Preferred***	

Screening methodology

The report outlines a screening methodology to identify which systems should be considered for a detailed analysis. The benefit of the methodology is that it provides a way to determine the feasibility of a BIPV system without incurring the cost of a detailed engineering study.

The steps are as follows:

1. calculate the normalized energy value for the selected PV system at the desired orientations ($/kW$_{AC}$ of PV)
2. obtain PV system price estimate from a system vendor ($/kW$_{AC}$)
3. estimate design cost (or assume it is negligible on a per unit basis for large systems)
4. calculate the area value required to make the application cost-effective ($/ft^2)
5. select the most promising options for further analysis

[1] Results for this row have the added assumption that the per unit energy value of two systems with different power ratings is the same.

Application of screening methodology to BIPV at Corona

This methodology was applied to BIPV systems the Corona Maintenance facility.

Step 1

The first step is to calculate the normalized energy value for the selected PV systems at the desired orientations.[2] This was done for twelve scenarios. They include low-efficiency (6% module efficiency) and high-efficiency (12% module efficiency) systems in three applications (southwest skylights, flat roof, and northwest wall) with high energy value (i.e., there is a good match between PV system output and load so that there are high demand savings) and low energy value (i.e., there is no match between PV output and load so that there are no demand savings). The results are presented in Figure 2.

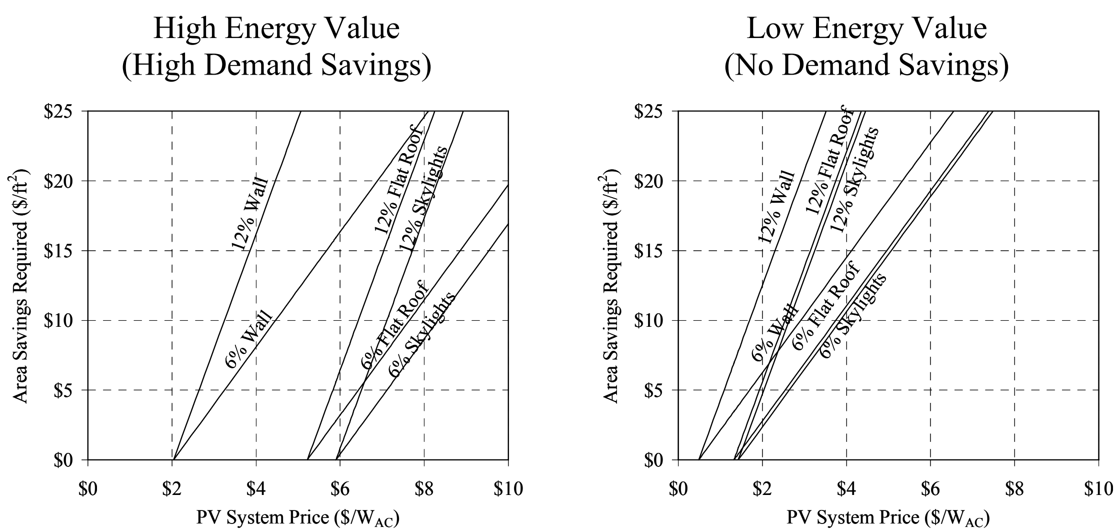


Figure 2. Area savings and PV price required for cost-effective systems.

Step 2

The second step is to obtain a PV system price estimate from a system vendor. Several vendors were contacted. Assuming no special module tailoring for the application, it is estimated that the PV price would be about $\$6.60/W_{AC}$.

Step 3

The third step is to estimate design costs. It is assumed that the design cost is negligible.

[2] This step was accomplished using the Clean Power Estimator tool.

Step 4

The fourth step is to determine the area savings required to make the system cost-effective. Figure 3 shows that from $3/ft^2 to $21/ft^2 (depending upon high or low energy value) are required in material savings at a PV price of $6.60/$W_{AC}$ for 6% efficient skylight systems. Table 2 summarizes the results for each of the twelve scenarios.

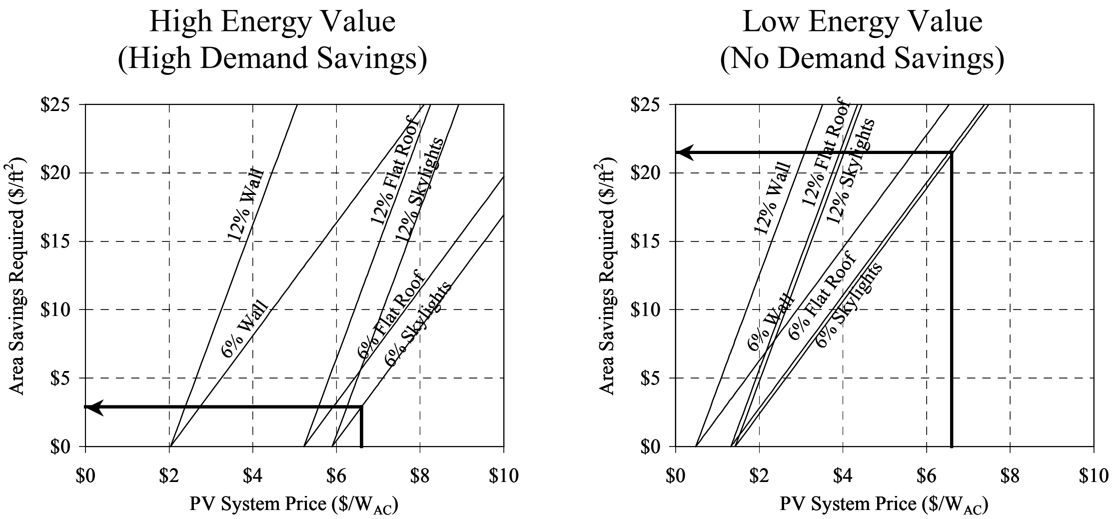


Figure 3. Area savings required for cost-effective skylights system.

Table 2. Area savings required for cost-effective systems at $6.60/$W_{AC}$ PV price.

	High Energy Value	Low Energy Value
Low-Efficiency Systems		
Skylights	$3	$21
Flat Roof	$6	$22
Admin. Wall	$19	$25
High-Efficiency Systems		
Skylights	$6	$43
Flat Roof	$11	$44
Admin. Wall	$38	$50

Step 5

Low-efficiency skylight and flat roof systems require area savings from $3/ft^2 to $6/ft^2, respectively given high energy value. These savings are within the range of estimated material savings associated with these applications. The conclusion is that roof applications may be economically justifiable if the energy value is high.

Next steps in this work are to verify the assumption that the energy value will be high (accomplished by obtaining Corona Maintenance building load profile and performing the analysis again) and to perform a more detailed study to determine the area savings for the skylight and flat roof systems.

Introduction

New York City Transit (NYC Transit) is the first public agency to be certified with the environmental compliance to ISO 14001. As a result, it has an important role and responsibility in providing environmental stewardship in public sector facilities planning, design, and construction. Accordingly, NYC Transit has chosen to seize the opportunity afforded by the construction of the New Corona Maintenance Shop and Car Wash Facility to successfully develop a practical and effective prototype for environmentally-responsible 21st century rail transit maintenance facilities.

The existing Corona Yard is presented in Figure 4. The new maintenance building will be located near the number 6 and will have a footprint of 175 feet by 689 feet. It will be oriented along a southwest/northeast axis. The administrative offices will be located along the northwest side of the building. Part of the roof structure will include overhead skylights to provide lighting for the maintenance area.

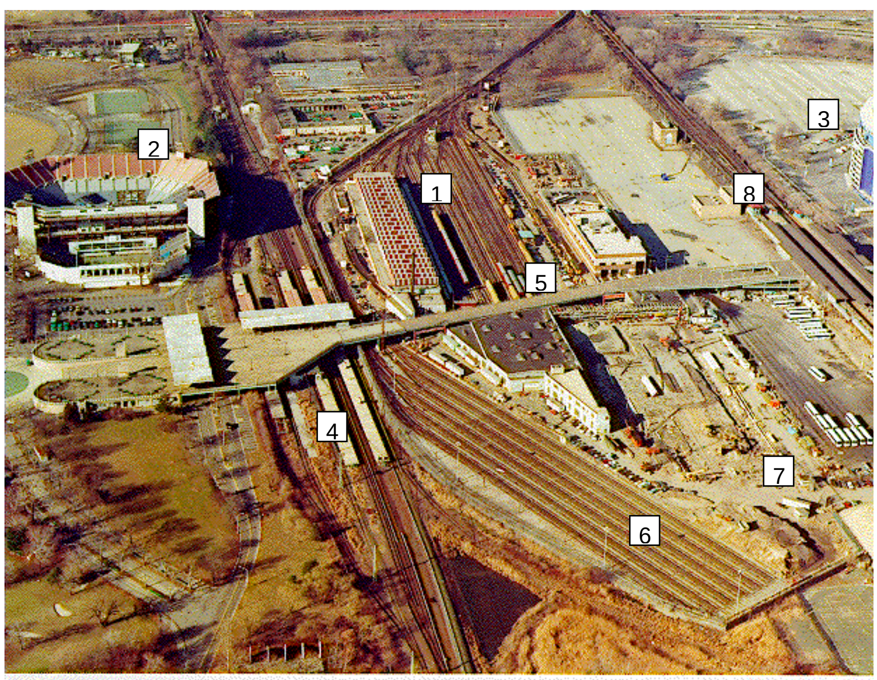


Figure 4. Existing Corona Shop and Yard with General Surroundings.

Building integrated photovoltaic (BIPV) systems could be incorporated in the following locations:

- Wall: northwest wall where the administration offices will be housed (689 feet long by 30 feet high)[3]
- Flat Roof: flat roof over administration building (689 feet long by 20 feet wide)
- Skylights: sawtooth skylight where the vertical portion of the skylight faces northeast and PV is on a 30° tilted southwest portion (689 feet long by 155 feet wide).

To illustrate the size of these systems, assume that half of the administration wall and half of the roof is covered with PV. The wall would have a power rating of 40 kW_{AC} (low-efficiency system) and the roof (both skylights and flat roof systems) would have a power rating between 250 kW_{AC} (low-efficiency system) and 500 kW_{AC} (high-efficiency system).

Objective

The objective of this report is to provide the NYC Transit with information that will help it to assess the cost-effectiveness of BIPV systems at the Corona Maintenance facility. The ideal way to perform such an analysis is to obtain the data and perform the calculations. Unfortunately, some of the required data are not available. First, the building's load profile is unknown; this results in uncertainty about the energy value. Second, the value of the material saved by using the BIPV is unknown.

In order to deal with the lack of load information, scenarios of high and low energy value are considered. In order to deal with the unknown material savings, a screening methodology is developed to determine how high the area savings need to be in order to make the systems cost-effective.

The first section of the report presents an economic model to evaluate the economic feasibility of the BIPV systems; general insights about BIPV systems are drawn using this model. The second section presents results specific to the Corona Maintenance facility. Conclusions are drawn in the third section. The appendix provides background information on BIPV systems including the type of BIPV systems and design issues associated with the various types of systems as well as some parameters used in the analysis. It also includes input and output screens of the Clean Power Estimator tool.

---

[3] A sunshade, or awning system, could be used in place of the vertical façade.

BIPV Cost-effectiveness Model

This section presents the cost-effectiveness model used to evaluate the BIPV systems. The model is presented and described and then manipulated in several ways to generate some fundamental observations about BIPV systems.

Overview

BIPV systems are attractive because they have energy value and area value components. The energy value is based on the PV system rating (kW) and the area value is based on the PV system size (ft^2). The net present value of a BIPV system is found by adding the energy value plus the area value and then subtracting the cost of the PV system.

$$NPV(\$) = \overbrace{\underbrace{\hat{E}}_{\substack{\text{Norm. Energy Value} \\ (\$/\text{kW}_{\text{AC}}\text{ of PV})}} \underbrace{0.0929\eta\varepsilon}_{\substack{\text{Power Density} \\ (\text{kW}_{\text{AC}}/\text{ft}^2)}} \underbrace{A}_{\substack{\text{BIPV} \\ \text{Area }(\text{ft}^2)}}}^{\text{Energy Value}} + \overbrace{\underbrace{O}_{\substack{\text{Area Savings} \\ (\$/\text{ft}^2)}} \underbrace{A}_{\substack{\text{BIPV} \\ \text{Area}(\text{ft}^2)}}}^{\text{Area Value}} - \overbrace{\underbrace{\hat{P}}_{\substack{\text{PV System} \\ \text{Price }(\$/\text{kW}_{\text{AC}})}} \underbrace{0.0929\eta\varepsilon}_{\substack{\text{Power Density} \\ (\text{kW}_{\text{AC}}/\text{ft}^2)}} \underbrace{A}_{\substack{\text{BIPV} \\ \text{Area }(\text{ft}^2)}} + \underbrace{D}_{\substack{\text{Design \& Other} \\ \text{Cost }(\$)}}}^{\text{PV System Cost}}$$

where 0.0929 (kW/ft^2) corresponds to the insolation at rated conditions, η is the DC-to-AC system efficiency, ε is the DC module efficiency under Standard Test Conditions, the normalized energy value is the summation over year (t) and hour (h) of the PV output times the energy value, discounted to the present (note that this average energy value is for a particular PV system size in a particular orientation)

$$\underbrace{\hat{E}}_{\substack{\text{Normalized Energy Value} \\ (\$/\text{kW}_{\text{AC}}\text{ of PV})}} = \sum_t \sum_h \underbrace{P_t^h}_{\substack{\text{PVOutput} \\ (\text{kWh}/\text{kW}_{\text{AC}}\text{ of PV})}} \underbrace{E_t^h}_{\substack{\text{Energy Price} \\ (\$/\text{kWh}/\text{kW}_{\text{AC}}\text{ of PV})}} \underbrace{\frac{1}{(1+r)^t}}_{\text{Present Value Factor}}$$

and PV price equals

$$\underbrace{\hat{P}}_{\substack{\text{PV Sytem Price} \\ (\$/\text{kW}_{\text{AC}})}} = \underbrace{P}_{\substack{\text{PV Module} \\ \text{Cost }(\$/\text{kW}_{\text{DC}})}} / \underbrace{\eta}_{\substack{\text{DC-to-AC} \\ \text{Efficiency}}} + \underbrace{I}_{\substack{\text{Inverter \&} \\ \text{Access. Cost} \\ (\$/\text{kW}_{\text{AC}})}} + \underbrace{B}_{\substack{\text{Area Cost} \\ (\$/\text{ft}^2)}} / \underbrace{0.0929\eta\varepsilon}_{\text{Power Density}}$$

The most important thing to notice is that the normalized energy value ($\hat{E}$) depends upon PV system rating and orientation and its interaction with building load (the effect of the interaction is included in the Energy Price variable) but it does not depend on PV system efficiency. That is, the energy value for a BIPV system with a given orientation and power rating is the same whether the system is a low-efficiency thin-film system or a high-efficiency crystalline system; the two differ only in their area requirements.

Comparative Analysis

This equation is particularly useful in performing comparative analyses. The following subsections use this equation to draw general conclusions for systems with the same power rating (but different areas) and systems with the same area (but different power ratings).

Assume that the per unit area savings and design cost do not depend upon the type of system. In this case, the net present value for system *type* with a given *rating* equals:

$$NPV_{type} = \hat{E}_{rating} 0.0929 \eta \varepsilon_{type} A_{type} + OA_{type} - \hat{P}_{type} 0.0929 \eta \varepsilon_{type} A_{type} + D$$

Systems With Same Power Rating

Systems with different module efficiencies can be sized to have the same power rating. This is accomplished by requiring that the area for the system with the lower efficiency equal $A_{low} = A_{high}\varepsilon_{high}/\varepsilon_{low}$. Systems with the same power rating in the same orientation have the same energy value. The low-efficiency system covers more area, however, and thus has higher area-related value (e.g., the reduction in other building materials due to the use of PV). The result is as follows.

Low-efficiency systems are preferred over high-efficiency system when they have the same power rating and PV system price ($/kW), when area savings ($/ft^2) is positive, and there are no area constraints.

This means a low-efficiency system that has the same cost ($/kW) as a high-efficiency system should be selected if area savings is positive and there are no area constraints.

Systems With Same Area

Next, assume that the building space is constrained so that the BIPV systems have the same area. Systems with the same area in the same application have the same area value but differ in their energy value. Assuming that the normalized energy value is the same for both systems (i.e., the per unit value does not change with system size), the result is as follows.

High-efficiency systems are preferred over low-efficiency systems only when PV system price is less than normalized energy value.

Systems with high power ratings are desired if the energy value is greater than the PV system price because each additional kW of PV results in a higher net present value. Systems with low power ratings are desired if the energy value is less than the PV system price because each additional kW of PV results in a lower net present value.

Screening Methodology

One of the difficult parameters to estimate in this equation is the area-related savings. That is, without performing a detailed engineering study, what is the value of the material savings associated with the BIPV system?

Rather than answering this question directly, this equation can be used to develop a screening methodology to determine how much area savings are required in order to justify BIPV without performing a detailed material savings study. This is accomplished by setting the design cost equal to zero and assuming that the NPV is greater or equal to zero. The result is that the BIPV is cost-effective when:

$$\underbrace{O}_{\substack{\text{Other Savings}\\ \left(\$/\text{ft}^2\right)}} \geq \left(\underbrace{\hat{P}}_{\substack{\text{PV Price}\\ (\$/\text{kW}_{\text{AC}})}} - \underbrace{\hat{E}}_{\substack{\text{Energy Value}\\ (\$/\text{kW}_{\text{AC}})}} \right) \underbrace{0.0929\eta\varepsilon}_{\substack{\text{Power Density}\\ \left(\text{kW}_{\text{AC}}/\text{ft}^2\right)}}$$

All of the terms on the right hand side of the equation can be estimated using existing tools or information from the PV industry. This allows one to determine if the project has the potential to be economically justifiable without going through a detailed costing study to determine the area savings.

The resulting screening methodology is as follows:

1. calculate the normalized energy value for the selected PV system at the desired orientations ($/kW$_{AC}$ of PV)[4]
2. obtain PV system price estimate from a system vendor ($/kW$_{AC}$)
3. estimate design cost (or assume it is negligible on a per unit basis for large systems)
4. calculate the area value required to make the application cost-effective ($/ft^2)
5. select the most promising options for further analysis

Results

This section applies the screening methodology to BIPV at the Corona Maintenance shop.

Step 1: Energy Value (Three System Configurations)

The first step is to compute the normalized energy value. One option is to assume that electricity prices are constant over time.[5] Another option is to use a tool devoted to the purpose of calculating the value of PV systems. The Clean Power Estimator tool is one such tool that is used by PV system manufacturers/integrators, state agencies, and electric utilities throughout the U.S. This tool can determine the value of a PV system at any orientation for rate structures throughout the U.S.

The tool is used to calculate the energy value for the following three systems:

- BIPV skylights tilted at 30 degrees facing southwest (Skylights)[6]
- PV panels tiled on a flat roof (Flat Roof)
- BIPV vertical exterior wall facing northwest (Wall)

[4] This step was accomplished in this report using the Clean Power Estimator tool.

[5] When this is true ($E = E_t^h$), Energy Value equals:

$$\underbrace{\hat{E}}_{\substack{\text{Energy Value}\\ (\$/\text{kW}_{\text{AC}})}} = \underbrace{\underbrace{C}_{\substack{\text{Capacity}\\ \text{Factor}}} \underbrace{8760}_{\substack{\text{Hours per}\\ \text{year}}}}_{\text{Annual Energy Output}} \underbrace{E}_{\substack{\text{Avg. Electricity}\\ \text{Price}}} \underbrace{\left\{ \left[(1+r)^L - 1 \right] / r(1+r)^L \right\}}_{\text{Present Value Factor}}$$

[6] While this system is referred to skylights, the same analysis applies to a tilted system that is not part of the skylights.

It is assumed that the Corona Maintenance shop is on NYPA's Rate 14-3, with delivery charges paid to Consolidated Edison.[7] The total rate structure is:

Demand Charge: $24.57 per month per kilowatt of billing demand
Energy Charge: $0.03825 per kilowatt hour

A comment is in order about this rate schedule. This rate schedule has a high demand charge relative to the energy charge. A demand charge is a power related cost and is based on the maximum power (kW) demand at any time during the month. Suppose that the building had a 25-kW demand at all times during the month except for a 15-minute period where the demand reached 100 kW; the demand charge is based on the 100 kW demand even though it only occurred once during the month. This makes it important both how much energy is produced by a BIPV system (and thus its energy savings) and the timing of the output (and thus its demand savings).

Due to the lack of load profile information, two load profiles are used in the calculation. The first load profile is where there is a perfect match between the PV system output and the load; this results in a maximum demand reduction. The second load profile is where there is no match between the PV system output and the load; this eliminates any reduction in the building's peak demand and thus there are no demand charge savings.

The analysis utilized a discount rate of 2.65 percent (a value that is chosen to represent MTA-NYC Transit's long-term average cost of capital) and a 35-year life-cycle of each system.[8] The results are presented in Table 3. The "Total" line is the annual utility bill savings and the bottom line is the 35-year net present value of the utility bill savings. As shown in the bottom of the table, the energy value ranges from a high of $5,898/kW$_{AC}$ (High Energy Value for Skylights) to a low of $482 (Low Energy Value for Wall). See the Appendix for a presentation of the model used to perform these calculations.

The exact load match will determine the actual reduction in the building's peak load and thus the value of the system.

[7] This is the rate structure that the Stillwell Avenue terminal is on.
[8] While a maintenance shop rehabilitation is planned at 50 years, it is assumed that the PV system will continue producing electricity for 35 years.

Table 3. Normalized energy value ($\$/kW_{AC}$) for three systems.

	High Energy Value			*Low Energy Value*		
	Skylights	Flat Roof	Wall	Skylights	Flat Roof	Wall
January	$16	$11	$3	$3	$2	$1
February	$20	$16	$4	$5	$4	$1
March	$22	$19	$7	$5	$5	$2
April	$26	$24	$9	$6	$6	$2
May	$25	$25	$11	$7	$7	$3
June	$27	$27	$13	$7	$8	$3
July	$26	$26	$13	$7	$7	$3
August	$25	$24	$10	$6	$6	$2
September	$23	$20	$8	$6	$5	$2
October	$22	$17	$5	$5	$4	$1
November	$14	$11	$3	$3	$2	$1
December	$15	$10	$3	$3	$2	$1
Total	$261	$231	$90	$63	$58	$21
35-yr Present Value	**$5,898**	**$5,218**	**$2,034**	**$1,425**	**$1,322**	**$482**

Figure 5 and Table 4 present peak PV system output throughout the year. The output from the Skylights and Flat Roof systems is similar throughout the year. Figure 6 presents the average daily output in June for the three systems. The output of the Skylights and Flat Roof systems is similar but the output from the northwest Wall is substantially less at almost all times and peaks late in the afternoon.

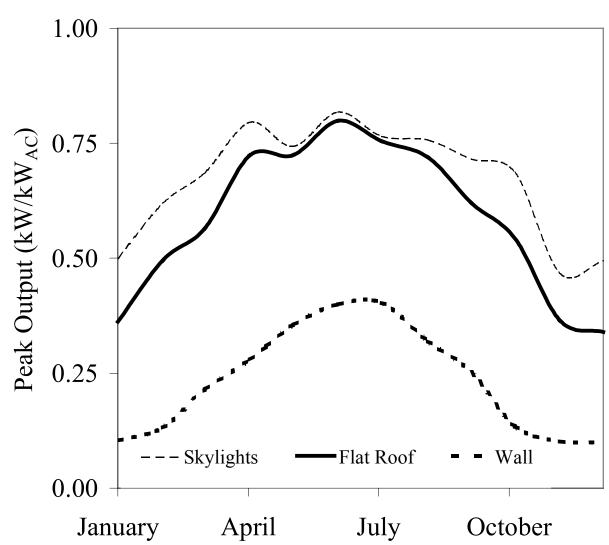


Figure 5. Peak PV system output.

Table 4. BIPV system performance.

	Peak Output (kW/kW_{AC})			Energy Production (kWh/kW_{AC}-month)		
	Skylights	Flat Roof	Wall	Skylights	Flat Roof	Wall
January	0.50	0.36	0.10	86	63	20
February	0.62	0.50	0.13	118	95	30
March	0.69	0.56	0.21	138	121	41
April	0.80	0.72	0.28	165	160	56
May	0.74	0.72	0.36	173	178	70
June	0.82	0.80	0.40	189	199	83
July	0.76	0.75	0.40	180	189	78
August	0.76	0.72	0.32	168	168	63
September	0.72	0.62	0.25	149	136	47
October	0.69	0.54	0.13	125	104	32
November	0.47	0.36	0.10	78	59	18
December	0.49	0.34	0.10	77	54	17

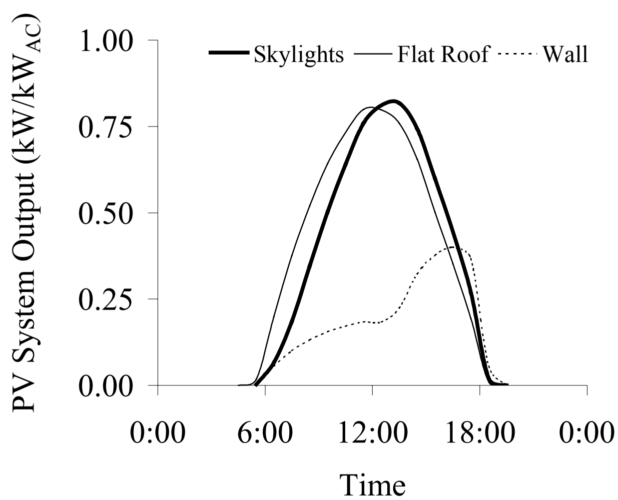


Figure 6. Average PV system output in June.

Step 2: PV System Cost

PV system cost estimates were obtained from two PV system vendors. The vendors were told that the application was for a 100 kW PV system. PowerLight estimated that the installed cost of a PowerGuard system (a horizontal PV system mounted on foam insulation) would be about $\$7,150/kW_{AC}$.[9] Atlantis estimated that the installed cost of a tilted PV system would be about $\$6,600/kW_{AC}$.[10] ***It is important to emphasize that these***

[9] The $\$7,150/kW_{AC}$ is based on a PV Module cost of $\$4,650/kW_{AC}$, Inverter & Accessories cost of $\$2,000/kW_{AC}$, and a balance of system cost of $\$4.13/ft^2$ ($\$500/kW_{AC}$). Phone conversation with Dan Shugar, Executive Vice President, PowerLight Corp., May 18, 2000.

[10] Cost estimate is based on a discussion with Steve Coonen, Vice President at Atlantis Energy Systems on June 8, 2000.

are not quotes and are not necessarily directly comparable. The application was described to both manufacturers but no other information was given.

In order to state results in comparable terms, it is assumed that PV system cost is $\$6{,}600/kW_{AC}$ for all types of PV systems.

Step 3: Design Cost

It is assumed that the design costs are negligible because the system is large.

Step 4: Area Savings

Results will be determined for zero area savings as well as area savings that result in a zero net present value (i.e., they will be calculated to determine what they need to be to result in a zero net present value).

Example 1: High-Efficiency Flat Roof

The first example is a high-efficiency Flat Roof system. In order to have a system with a power rating of 250 kW_{AC} for Examples 1 and 2, the system will consist of 30,000 ft^2 of 12% efficient DC modules.[11] A high estimate of the energy value for a Flat Roof system is $\$5{,}218/kW_{AC}$. Assuming that area savings and design cost equal zero and PV system cost is \$6,600 kW_{AC}, the net present value is negative \$345,000.

This system would be cost-effective if the area savings are greater than $\$12/ft^2$. These results were verified using the Clean Power Estimator tool.

Example 2: Low-Efficiency Skylights

The second example is a low-efficiency Skylight system. In order to have a system with a power rating of 250 kW_{AC}, the system will consist of 60,000 ft^2 of 6% efficient DC modules. A high estimate of the energy value for a Skylight system is $\$5{,}898/kW_{AC}$. Assuming that area savings and design cost are zero and PV system cost is \$6,600 kW_{AC}, the net present value is negative \$176,000.

This system would be cost-effective if the Area savings is greater than about $\$3/ft^2$. These results were verified using the Clean Power Estimator tool.

[11] There is a DC-to-AC efficiency of 75 percent.

General Results

The equations developed above enable us to go beyond specific examples and to state general results. Figure 7 presents the area savings required for the three system configurations (Wall, Flat Roof, and Skylight systems) and two technology types (12% efficient corresponds to crystalline and 6% efficient corresponds to thin-film or widely spaced crystalline cells) for scenarios of high energy value (left side of figure) and low energy value (right side of figure) as a function of PV System Price. The required area savings can be determined for any of these twelve configurations.

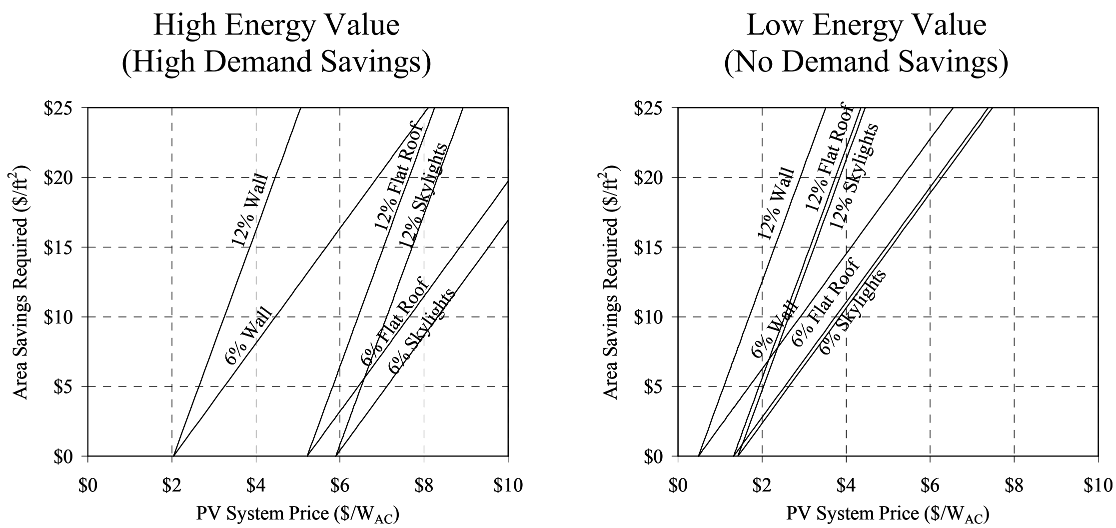


Figure 7. Area savings ($/ft^2) required for cost-effective systems.

The figure summarizes a lot of information. The following example illustrates how to use it. Suppose that NYC Transit is considering using semi-transparent 6 percent efficient PV modules in place of the northwest wall of the administration building. Suppose that the system costs $6.60/Watt$_{AC}$. In addition, assume that energy value is high. The left side of Figure 7 indicates that area savings of $19/ft^2 are needed to justify the PV system.

That is, this system is cost-effective if: (1) the NYC Transit can purchase the PV system at $6.60/Watt$_{AC}$; (2) there is a very good match to building load; and (3) more than $19/ft^2 can be saved in material (e.g., due to the reduction in spandrel glass).

Conclusions

This report was designed to provide NYC Transit with information that will help it to assess the cost-effectiveness of BIPV systems at the Corona Maintenance facility. Background information on BIPV systems was presented, an economic model was developed, and the model was used to obtain results specific to the Corona Maintenance facility.

System selection (low-efficiency vs. high efficiency)

BIPV systems can be broadly categorized as low-efficiency and high-efficiency systems. Low-efficiency systems use low-efficiency thin-film PV or sparsely populated crystalline modules (i.e., a lot of space between the cells in the module). High-efficiency systems typically use standard crystalline modules.

BIPV systems are attractive because they have both energy value and area value components. The energy value is based on the PV system power rating (kW) and the area value is based on the PV system size (ft^2).

Conditions exist where low-efficiency BIPV systems are preferred over high-efficiency BIPV systems. Assume that: 1) the goal is to maximize net present value; 2) tax effects or economic incentives are not available; 3) different PV systems are compared in the same orientation and application; 4) PV technologies have the same price ($/kW) and technical performance characteristics; and 5) PV technologies have the same positive area-related savings. As shown in Table 5, high-efficiency systems are more cost-effective than low-efficiency systems only when the system is cost-effective without any area savings (i.e., energy value exceeds PV cost and area savings are not required to make the PV cost-effective) and the system is area-constrained. Low-efficiency systems are preferable under all other conditions.

Table 5. General conditions for BIPV system (efficiency) selection.

	PV is cost-effective without area savings (energy value exceeds PV cost)	Area savings are required to make PV cost-effective (energy value plus area savings exceed PV cost)
Unconstrained Building Area	***Low- Efficiency Systems Preferred***	***Low- Efficiency Systems Preferred***
Constrained Building Area[12]	***High-Efficiency Systems Preferred***	***Low- Efficiency Systems Preferred***

[12] Results for this row have the added assumption that the per unit energy value of two systems with different power ratings is the same.

Screening methodology

The report outlines a screening methodology to identify which systems should be considered for a detailed analysis. The steps are as follows:

1. calculate the normalized energy value for the selected PV system at the desired orientations using a tool such as the Clean Power Estimator ($/kW$_{AC}$ of PV)
2. obtain PV system price estimate from a system vendor ($/kW$_{AC}$)
3. estimate design cost (or assume it is negligible on a per unit basis for large systems)
4. calculate the area value required to make the application cost-effective ($/ft^2)
5. select the most promising options for further analysis

Corona results

This methodology was applied to the Corona Maintenance facility. Table 6 presents the required area savings that will make the system cost-effective for the various system configurations for both High Energy Value and Low Energy Value scenarios. Results suggest that low-efficiency skylight and flat roof systems require material savings from $3/ft^2 to $6/ft^2, respectively when there is High Energy Value (i.e., there is a good match between PV output and building load). These savings are within the range of estimated material savings associated with these applications. That is, roof applications should be economically justifiable if the energy value is high. These results may not be true if the energy value is very low.

Table 6. Area savings ($/ft^2) required for cost-effective systems at $6.60/W$_{AC}$ PV price.

	High Energy Value	**Low Energy Value**
Low-Efficiency Systems		
Skylights	$3	$21
Flat Roof	$6	$22
Admin. Wall	$19	$25
High-Efficiency Systems		
Skylights	$6	$43
Flat Roof	$11	$44
Admin. Wall	$38	$50

Next Steps

Next steps in this work are to verify the assumption that the energy value will be high (accomplished by obtaining Corona Maintenance building load profile and performing the analysis again) and to perform a more detailed study to verify the required area value for either the flat roof and/or tilted roof systems.

Appendix

This appendix includes the following information: discussion about the types of BIPV systems; issues to consider when designing these systems; information about some of the parameters in the economic analysis; material savings associated with BIPV systems; and sample input and output screens for the Clean Power Estimator tool.

Types of BIPV Systems[13]

Photovoltaic systems can be integrated into buildings in four basic ways. These include vision, spandrel, sunshades, and rooftop systems.

Vision

Vision systems are ones in which the PV panels allow light to shine through. The panels can be added to a window so as to create an insulated window that produces electricity. They can be either crystalline or thin-film (the crystalline panels project a pattern on the workspace). PV used in an atrium or skylight application could also be classified as a vision system.

Spandrel

Spandrel glass is the opaque material used on the outside of the buildings between windows. This is the part of the building façade through which light does not shine. The PV panels replace these non-insulating glass components. The PV can also replace non-glass building façade material, such as granite and other stone products.

Sunshades

In this system, the PV panels are attached to an awning that protrudes from the building. The shade provided by the awnings can reduce heating and cooling requirements.

Rooftop

PV panels are placed on top of the roof. Available products include custom-designed PV systems (e.g., Atlantis Energy Systems), ballasted systems (e.g., Applied Power), and PV panels that are attached to insulation and laid directly on the roof (e.g., PowerLight).

Design Issues

Vision

An important issue for vision systems is whether or not PV transmits a sufficient amount of light to be used in windows. Windows are designed to allow light into a building. The table at the end of the Appendix presents the visible transmittance for a variety of glass surfaces. Clear and gray glass substrates are included because they represent the low and

---

[13] This section is based on discussions with Paul Wormser, Bill Reever, and Dan Shugar. Paul Wormser is Director of Technology, Solar Design Associates, Solar Design Associates, (978) 456-6855, wormser@solardesign.com. Bill Reever is Marketing Manager with BP Solarex, (301) 698-4208, reverbb@bpsolarex.com. Dan Shugar is Executive Vice President, PowerLight Corp., (510) 540-0550 x 224, shugar@powerlight.com.

high ends of how much light is transmitted through the window. The visible transmittance for those windows ranges from 3 to 18 percent for gray windows with a reflective surface of 7 to 36 percent for clear windows with a reflective surface of almost 80 percent for clear, uncoated windows.

The visible transmittance of windows with PV depends upon several factors. First, one could space the crystalline silicon in the windows so as to create the desired amount of light in between the cells. Second, thin-film PV currently has a visible transmittance of about 10 percent; it is estimated that this could be increased up to about 30 percent.

Another issue for any vertical surface is the problem of shading due to other buildings.

Spandrel

Spandrel applications of BIPV systems do not face the same constraint as vision systems because they are opaque and do not require any light to be transmitted. One current difficulty with these systems (as well as thin-film modules used in vision systems), is that the size of the modules is limited.

It is feasible to manufacture crystalline silicon modules in all sizes. The current size of thin-film PV modules presents one problem for BIPV systems. Their maximum size[14] is currently 8 ft^2 while the normal size of window glass for buildings is 25 ft^2.

There are several ways to address this issue. One option is to leave the module sizes as they are and to increase the aluminum framing that supports the PV. The result is that the saving in glass cost can be lost in the added aluminum cost.[15] A second option is to encapsulate the thin-film modules between two pieces of glass so as to effectively make a larger module. This approach, which is what was done for the Times Square building, loses the benefit of reducing the amount of glass. A third option is to design the building such that the spandrel glass is split above and below the visible windows. For example, suppose there is a 12-foot span between floors. There could be 7 feet of windows and 5 feet of spandrel glass.

Sunshades

There are several design issues associated with sunshade systems. First, in many cases, the wiring for these systems will need to penetrate the building envelope, and thus introduce the possibility of leakage. Second, if an awning system was not initially planned, there will be substantial added structural costs to hold the PV modules.

Rooftop

There are three ways to place BIPV on rooftops. First, they can be physically attached to the roof. Second, they can be laid horizontally on the roof with no physical attachment

---

[14] BP Solarex manufacturers 5'x16" modules in its Fairfield plant and 2'x 4' modules in its Virginia plant. First Solar will make 2'x4' modules.

[15] Assuming that aluminum framing costs $2.50/linear foot (this translates to $25/ft^2 for a large number of 5 ft square windows), and that the same framing is used for the smaller windows, the aluminum cost for 2'x4' windows is increased by 87.5% for a total cost of almost $47/ft^2.

(e.g., PowerGuard® product) or they can be set on the roof with a ballast to hold them down. Products that are laid on the roof without physical attachment may not work in areas with high wind loads. BIPV systems using ballast may require additional support in the roof to hold the extra weight of the systems. Third, they can be integrated into the roof structure (e.g., atrium, or skylights).

DC Module Efficiency

Table 7 presents the DC module efficiency for a variety of modules. In general, the efficiency for thin-film modules is about 6 percent while the efficiency for crystalline modules is about 12 percent. While not shown in the table, crystalline modules can be constructed to have lower efficiencies by leaving a greater spacing between the cells in the modules.

Table 7. Module efficiency (DC Nameplate Rating).

Module	DC Efficiency (Nameplate) [16]
Single crystal	
ASE-300-DG/50-285	11.7%
AstroPower AP1206	12.3%
BP Solarex's Saturn	13.5%
Siemens SP75	11.8%
Multi-crystal	
Kyocera KC 120-1	12.9%
Solarex MSX-60	10.8%
Thin-film	
Solarex Millennia MST-43	5.2%
Uni-Solar 64-Watt	6.3%

[16] Nameplate module efficiency equals the module's nameplate power density (nameplate rating in Watts divided by module area in ft^2) divided by the rating conditions of 92.9 W/ft^2 (1,000 W/m^2).

DC-to-AC System Efficiency

Losses occur when converting sunlight to DC electricity due to the module efficiency. There are other losses in addition to module losses. While these losses are system dependent (Figure 8 presents the DC-to-AC efficiency for 83 systems throughout the U.S.) a good estimate of the losses include:

- 10 percent losses when the module is rated under real world test conditions of 1,000 Watts/m^2 and 20° C ambient temperature versus its rating under laboratory conditions;
- 5 percent inverter losses; and
- 12 percent wiring and other losses.

This translates to a DC-to-AC efficiency of about 75 percent (0.90*0.95*0.88=0.75).

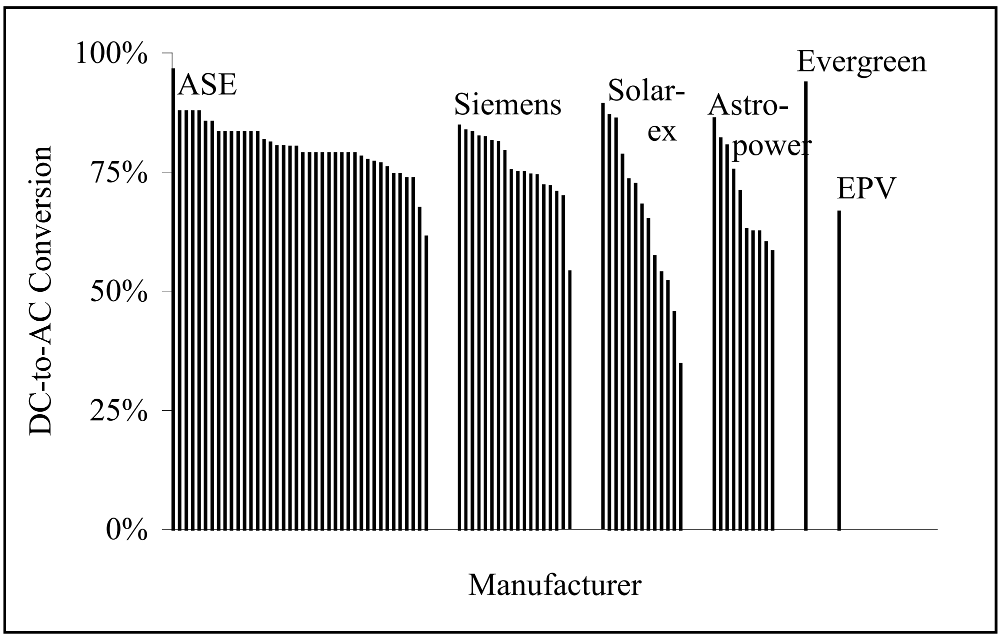


Figure 8. DC to AC conversion efficiency (source: UPVG sponsored systems).[17]

[17] Data for these systems can be viewed at http://www.upvg.org/upvg/sindex.htm.

Area savings

BIPV systems are attractive because they have the potential to reduce other building materials and thus have an added value. After speaking with several experts in the PV industry, there is a wide range of estimates about the magnitude of this value. Table 8 presents the material cost savings estimates from interviews and Figure 9 is based on information from a 1995 report. The savings estimates range from $0/ft^2 to about $15/ft^2. Some estimates were even higher than this.

Table 8. Material cost savings for various types of BIPV systems.

BIPV Type	Savings Description	Savings Amount
Vision	Front glass panel of insulated window	$8 to $15/ft^2
Spandrel	Spandrel Glass	$3 to $10/ft^2
Sun Shades	Awing material	?
Sunroof	Laminated glass	?
Roof - Horizontal	Insulation/roof life extension for Power Light type systems[18]	$0 to $15/ft^2
Roof - Tilted	None	$0

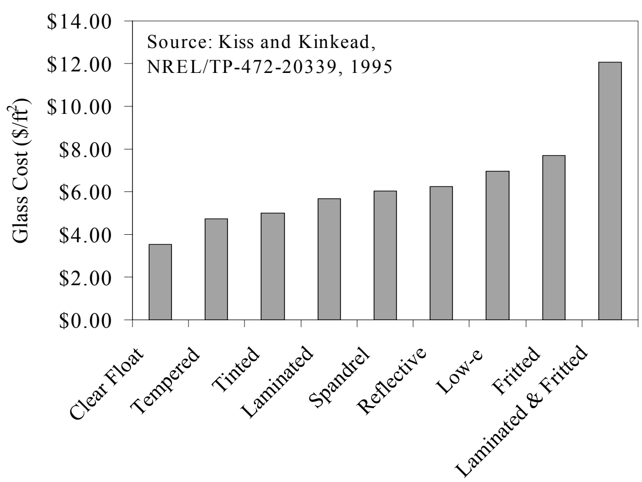


Figure 9. Costs for various types of glass.[19]

[18] The cost savings depend upon the assumptions made. On the one hand, PowerLight claims that the Area savings due to preserving roof life and added insulation includes $3/ft^2 in years 10 and 20 (avoid roof replacement) and $0.10/ft^2-year to $0.50/ft^2-year (added insulation). The present value equals between $6 and $15/ft^2 based on these claims and a 2.65 percent discount rate. On the other hand, it could be argued that it is more appropriate to value the savings in building materials rather than the energy savings/roof extension life because it would be less costly to purchase the same insulation (DOW's upside down roofing) on which the PV modules are mounted.

[19] Gregory Kiss and Jennifer Kinkead, Optimal Building-Integrated Photovoltaic Applications, NREL/TP-472-20339, 1995, p. 14.

Visible Transmittance for Insulating Glass

Table 9. Visible Transmittance for Insulating Glass.[20]

Glass	Substrate	
Gray		Clear
Reflective Surfaces		
Crystal Chrome	3% - 9%	7% - 18%
Stainless Steel	4% - 9%	8% - 18%
Antique Silver	7% - 17%	14% - 34%
Titanium Blue	10% - 18%	19% - 36%
Cinnamon	11% 22%	
Low-E	18% - 38%	36% - 76%
Uncoated	39% 78%	

[20] This table is based on data presented on the glass manufacturer Viracon's website at http://www.viracon.com/info/literature/1.shtml for insulating glass. Similar values apply for their other types of glass.

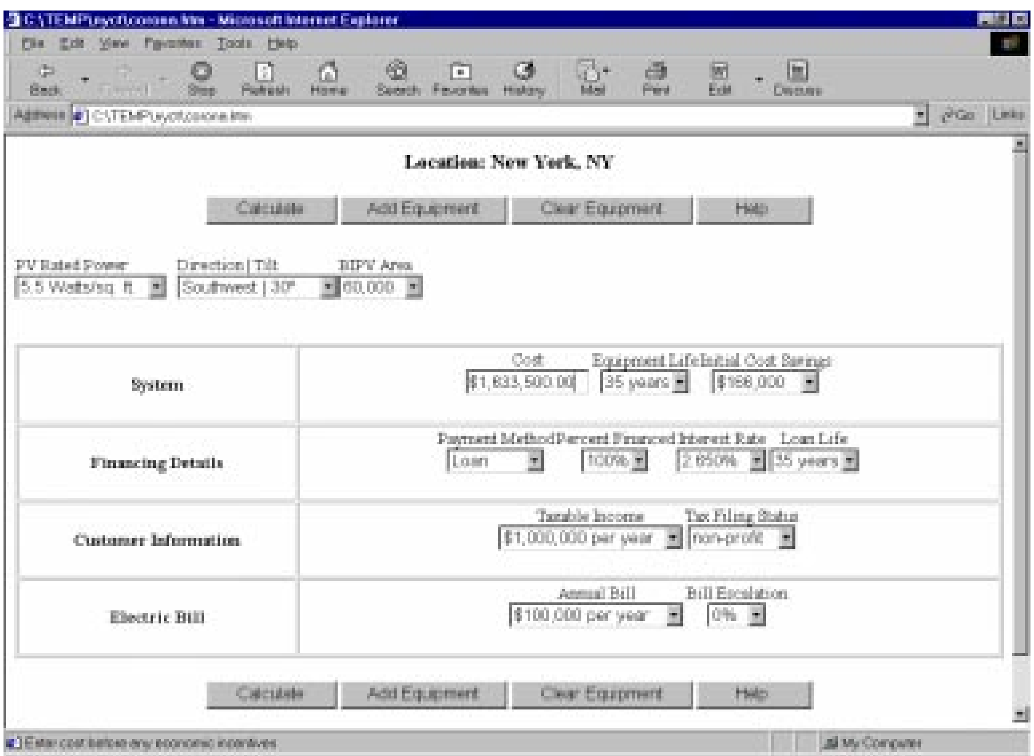
Clean Power Estimator

The Clean Power Estimator tool was used to calculate the energy value for the three systems under consideration. This section presents the energy value for the low-efficiency PV skylights system (PV system with power density of 5.5 Watts/ft^2 facing southwest at a 30° tilt).

Figure 10 presents the input screen for the analysis. Figure 11 presents the energy value screen.[21] Figure 11 shows that 60,000 ft^2 of 5.5 Watt/ft^2 PV (this system has a rating of 330.0 kW_{DC} and 247.5 kW_{AC}) has an energy value of $64,535/year. This translates to $261/$kW_{AC}$ of PV. This is the result that is used in Table 3. The results for all other system configurations were calculated using this tool.

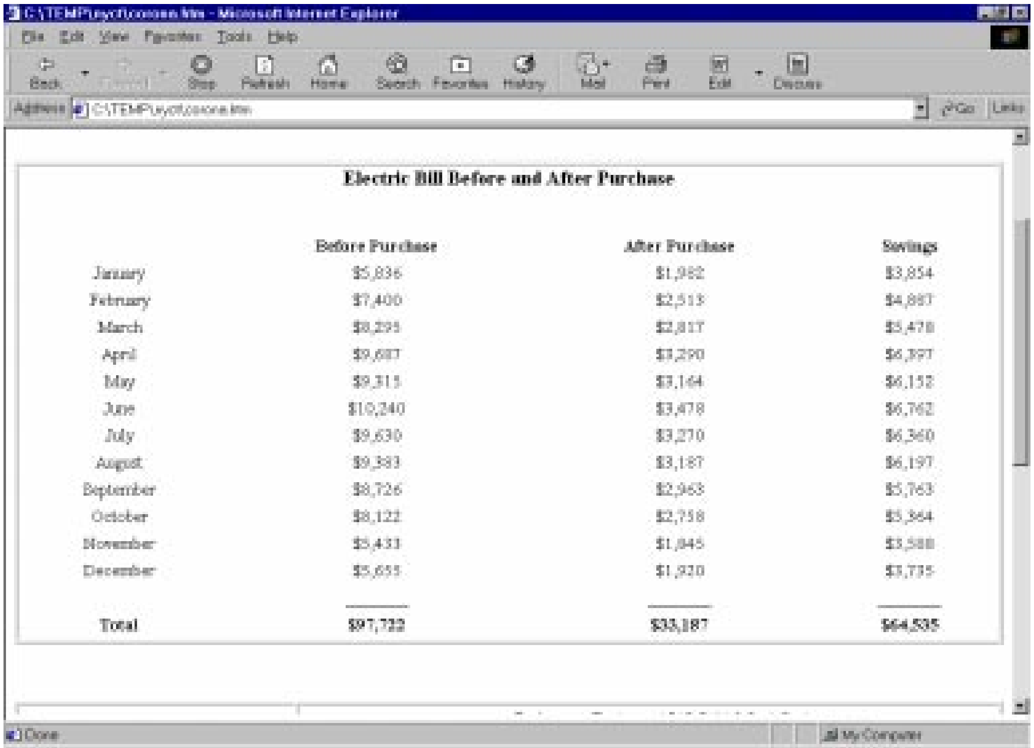
It is important to note that the tool can be used to perform the complete economic analysis if the area savings are known. For example, Figure 12 presents the net present value of skylights that cost $6.60/$kW_{AC}$ and have area savings of $2.80/ft^2 ($166,000 entered in the Initial Cost Savings box).

Figure 10. Inputs for the Clean Power Estimator tool.



[21] There are a number of different results that can be displayed with the program, but only the energy value is presented here.

Figure 11. Energy value for 60,000 ft^2 of low-efficiency skylights.



Electric Bill Before and After Purchase

	Before Purchase	After Purchase	Savings
January	$5,836	$1,982	$3,854
February	$7,400	$2,513	$4,887
March	$8,295	$2,817	$5,478
April	$9,687	$3,290	$6,397
May	$9,315	$3,164	$6,152
June	$10,240	$3,478	$6,762
July	$9,630	$3,270	$6,360
August	$9,383	$3,187	$6,197
September	$8,726	$2,963	$5,763
October	$8,122	$2,758	$5,364
November	$5,433	$1,845	$3,588
December	$5,655	$1,920	$3,735
Total	**$97,722**	**$33,187**	**$64,535**

Figure 12. Net present value of low-efficiency skylights with $2.80/ft^2 area savings.