Building Integrated Solar Energy Systems Study

(MAE-Alternate Power Sources, Sustainability; Breadth- Electrical)

Problem Background

This analysis topic confronts the issue of rising energy costs in the United States. Onsite energy production has the ability to drastically lower or even “zero out” the building’s energy cost. A developing area of onsite energy production is in the field of building integrated solar energy systems, also known as building integrated photovoltaics (BIPV). These systems integrate a PV material into a building component such as the façade or roofing material. The most common area of integration in commercial applications is within the curtain wall system that is a prominent part of new commercial design. As for residential applications the focus is more on roofing materials such as shingles and metal seam roofing. The use of a curtain wall integrated system at Crystal Plaza II provides the owner with an opportunity to market green energy onsite or sell the energy back to the utility for profit. This analysis provides research into graduate level material on sustainability and renewable energy, as well as a breadth in electrical in terms of the energy distribution.

Problem Statement

The current façade material at Crystal Plaza II is a non-typical residential façade material. The system is a unitized curtain wall system that contains operable windows. The ability to incorporate a BIPV system into the curtain wall would allow the building to create energy using the PV material. The use of a BIPV system would need to have little effect on the schedule as the curtain wall is currently a critical path item and has been in production since the beginning of the project, even through the suspension phase. While it is uneconomical to begin fabrication now or to replace the previously installed, custom panels, the ability to see the potential for similar buildings in the complex would greatly benefit the owner.

Figure 39 Potential areas for BIPV System in curtain wall

Goals

The goal of this analysis is to provide research into a BIPV system that is integrated into the curtain wall system. The research includes the distribution of the resulting energy produced via a DC system to components that use DC power or to efficient inverters to provide AC power. The cost implementations along with the potential production of such a system will be necessary to calculate the estimated payback period to install the system. Contacts with industry members will be key to understand lead time for such a system and the requirements of installation. The overall goal is to provide a “what if” scenario to the owner to market the use of BIPV and DC distribution in future projects at Crystal Plaza.

Research Procedure

1. Research BIPV systems
2. Evaluate BIPV systems based on desired use with advantages/disadvantages
3. Estimate various scenarios of BIPV implementation, access building façade/exposure
4. Research and develop equipment powered by DC or efficient AC inverters
5. Develop simplistic and basic AC distribution system
6. Estimate total cost of BIPV and AC distribution system
7. Calculate energy savings
8. Determine payback period
9. Make suggestion of implementation of BIPV on current and future projects

Tools and Resources

1. Various manufacturer and supplier data
2. Photovoltaics in the Built Environment by Steven Strong
3. Whole Building Design Guide
4. National Renewable Energy Laboratory
5. Energy10 or similar energy modeling program
6. RS Means 2008

Expected Outcome

The expected outcome of this analysis is to provide a positive suggestion for the use of BIPV and a large scale DC distribution system for use on a limited scale at Crystal Plaza II, but can be incorporated into other projects by the owner at Crystal Plaza. It is expected that the BIPV system will create a larger upfront cost and a minimal time extension during the manufacturing phase, but installation will be at nearly the same time rate. Given the consistent ownership of Crystal Plaza II, the payback period may be longer than the industry average of 3-5 years, allowing for such a system to be profitable to the owner.

Building Integrated Photovoltaics

Building Integrated Photovoltaics (BIPV) is the process or product of directly incorporating a photovoltaic (PV) component into a building system. Most commonly, the PV is integrated into a roofing material, façade material, or windows. Typically, BIPV utilizes the newer thin film technology that is cheaper and easier to mass produce. However, thin film typically has a lower efficiency when compared to standard crystalline silicon PV's, but does allow for light transmission through its medium. The ability to allow light transmission and its thinness allows the thin film to be integrated into double pane glazing, insulated glass, and curtain wall systems easily. According to the Whole Building Design Guide, crystalline silicon systems tend to produce 10-12 watts per square foot, while the thin film products tend to produce only 4-5 watts per square foot.

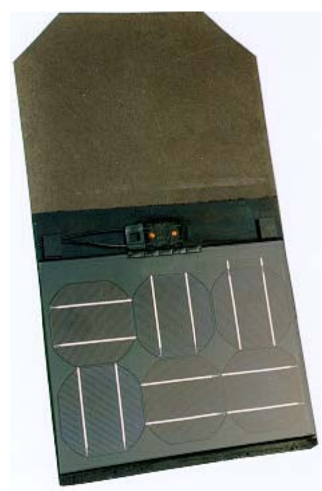
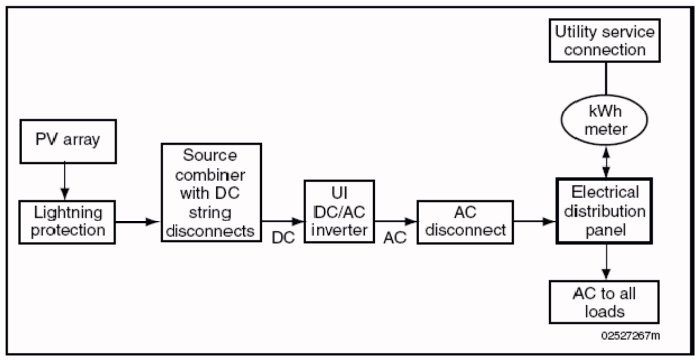


Figure 40 BIPV SunSlate roofing

The use of solar power is an important, and emerging, source of energy as the push for green continues. New developments in thin film technologies allow for lower cost PV's, and government incentives only aide in lowering the initial investment cost. Utilizing PV's as part of the building in an integrated system also helps with costs, as the BIPV systems can now serve two functions. This eliminates the cost of a support system for the PV's and potentially the façade or roofing material it is replacing. In terms of this analysis the BIPV system will be incorporated into the windows, thus not replacing a façade system, but creating an energy producing system, or system with benefit. In cases where the PV material is to be placed in an environment that requires light transmission, as it does at Crystal Plaza II for views, the ability of the material to appear transparent is vital.

PV systems come in two forms, grid tied and stand alone. The system of focus for this analysis is a grid tied system that allows integration into the Dominion of Virginia Power grid. Essentially a grid tied system that does not use battery backup, as is the case in this analysis, uses the grid as its storage system. Excess energy from the production of the BIPV system is serviced back to the grid, with potential of earning the producer credit from the local utility through reverse metering. Grid tied systems also tend to be a win-win solution for the owner and the utility. Typical peak demands for energy occur at times when PV production is near its peak, thus allowing the PV system to lower the demand of the installed facility with the overall effect of lowering the demand on the utility.



Block diagram of a utility-interactive PV system

Figure 41 Schematic of a utility tied system (Kiss)

Benefit to the owner of the on-site generation is many fold. To begin with, the sustainable production of energy on-site allows for energy bills to be lowered, a cost savings to the facility owner. Also, when used as an integrated component, the system can have added benefit in increasing R or U values of the standard material. Finally is the revenue generation potential. While the system can not directly affect the outcome in a demand response or similar program, the energy produced can be "sold" to the local utility. According the Public Utility Regulatory Policy Act passed in 1978, the local utility is required to purchase the energy produced by the on-site generator at a value at least equal to the value of producing that energy. Typically the utility will apply a credit for the amount of energy returned to the grid in the next month's bill or at the end of a billing year the utility will evaluate the difference in energy produced and consumed with a charge applied when consumption exceeds production. However, in the later case, excess production beyond the needed consumption is forfeited to the utility. This process is typically referred to as reverse metering. There is also a potential for a larger return if the contract between the utility and the generator allows for the sale of electricity at real time prices. During peak times, the real time price of electricity increases, so if coordinated correctly, the generator could sell excess energy at a premium, and then when requiring energy during the off hours of the PV, the cost for energy is usually lower.

With all these benefits, it seems that these systems should be installed on a much more common basis. The detriment, however, is in the cost. A typical array costs between $7 and $12 per watt according to various sources meaning a system capable of producing 3,000 kWh per year (2,000 W system) would cost between $14,000 and $24,000 to install. While multiple aide and incentive programs exist, applications, understanding, and simply located the applicable program are difficult. As part of the Critical Industry Issue analysis, this topic is looked at in more depth. While this value may not seem so expensive, the estimated energy savings of the system using an average rate of $0.06/kWh (average value in PA) would only be about $180 per year. This means that in a best case scenario with a tax rebate of 30% from the federal government, the lower cost, and the annual savings the simple payback is 54 years, well outside the range sought by home owners, especially considering the life of a PV panel is about 20 years.

Another issue plaguing current thin film technology is the open circuit voltage or Voc. This value is used to size system inverters, and is often very high in comparison to conventional panels of similar size. For instance a BP crystalline panel may have a Voc of 22-25 Voc, while a similar sized thin film array would be closer to 60 Voc. This is problematic when sizing the system for inverters, as NEC section 690.7(C) does not allow voltages over 600Voc in one of two family dwellings. Also many UL inverters are designed for the 600Voc limit; inverters above this value tend to be limited in quantity and much more expensive.

Figure 42 4 Times Square (left) and The Solaire (right)

Case Studies

As references for this analysis, two case study buildings have been reviewed that have incorporated BIPV on various levels in New York City. The first of which is 4 Times Square. Completed in July 2001, the Conde Nast Building located at 4 Times Square uses a 20 kW peak capacity BIPV system that has been integrated into custom triple laminated 40 W a-Si (amorphous silicon) modules. At the time of its completion it was described as the most environmentally friendly skyscraper in the United States. The BIPV system was designed by TerraSolar and incorporates the panels on the south façade, from floors 37-43, replacing the mirrored spandrel panels. The system has provided some unique results in that it captures both low and fluorescent lighting, meaning it produces energy 24 hours a day. The energy output is enough to power about five offices.

A second, more recent case is the Solaire residential building, located in the Battery Park area. The project was the first residential building to be issued a Gold LEED Certification. The BIPV system is a 33 kW spandrel panel replacement. Also included is a typical roof top system. The solar system was designed to provide 5% of the buildings overall power to achieve LEED requirements, however, it is estimated that the actual production is less than 1%. ISES NY UN office representative Roma Stibravy estimates this production is enough to supply power to about 20 of the 293 units. Differences in this project when compared with Crystal Plaza is the size of the array and the issue of shading, as operation of a system that is un-shaded will produce more power, and in New York City, the height restrictions are much different.

Products and Design

The general BIPV system modeled in this analysis is similar to a system produced by SUNTECH called See Thru. This system allows for multiple size PV within glazing for custom applications and has a varying transparency from 1%-10%. The system most likely to be utilized at Crystal Plaza II would be of the 5% or 10 % transparency, as the system would be applied to the entire curtain wall façade. The visual aspects of the system would resemble the current façade's mirrored/tinted finish, thus allowing for integration of the system into the facades at different levels or on different sides without a visual contrast between the two façade types. This is a vital necessity as the visual appeal of the structure is highly valued by the owner, and a uniform exterior is a must. When modeled, the Whole Building Design Guide estimate of 5 watts per square foot was used as a production value for the BIPV.

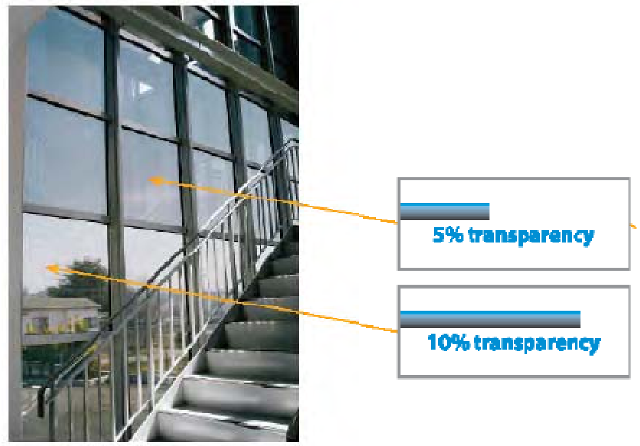


Figure 43 SUNTECH See Thru PV system transparency

The BIPV system will be integrated into the unitized curtain wall system in various arrangements during the analysis. The only area's not receiving the PV material will be terrace walls, notch backs, and the operable window sections of the curtain wall system. For reference, each unit of curtain wall is 4' x 10', effectively spanning a single story. In all analyses performed, only the new, upper floors were in consideration. These floors are at an elevation above all surrounding buildings, and therefore experience no shading, as can be seen in the shadow study that follows.

Constructability

By implementing BIPV into the façade, many concerns in constructability arise. Will this affect the schedule? Will the BIPV affect the water/air barrier? Is installation more complex? Will the lead time change? All of these are valid questions.

As for the initial construction of the system, the thin film would be delivered to the curtain wall manufacturer. This provides the first area for issues. The manufacturer would need the proper facilities to install the PV medium. Given the nature of the manufacturer/contractor on Crystal Plaza II, this could create an issue. As mentioned earlier, the company is a small outfit located in New York. Their ability to keep on schedule was questioned throughout the entire process, and it seems without the two month delay period by the owner, they would not be on schedule. Therefore implementing the PV medium may not be feasible for this contractor. In general, the lead time may increase slightly due to procurement of the PV medium and connection devices, but it should not affect the project when done correctly.

The BIPV system also adds little weight as it is incorporated in the glazing system, thus requiring no additional structural support. An area of concern is the placement of the inverters. The inverters can be of substantial size and with the system being thin film, multiple may be required per floor. The Xantrex inverter selected for analysis has dimensions of 28.5" x 16" x 5.75" and a weight of 58 pounds. Given the limited space on each floor to maximize rentable area, this becomes an issue, as two or more inverters may be need per floor.

Shadow study

To begin the analysis, a shadow study was conducted using Google SketchUp. The premise for this study was to analyze the areas to receive BIPV. The areas of concern are floors above the 12th floor. Reasoning behind the limitation in area is that all surrounding buildings have a limited height of 12 stories, as Crystal Plaza II is the first break that limit. Also, the developer does not intend to renovate the other buildings in the complex to the height of Crystal Plaza II for some time, thus allowing the system to obtain full sunlight for the duration of the life of the implemented PV's (about 20 years). Future efforts could allow the surrounding buildings to reflect light onto the façade at Crystal Plaza II, thus allowing for better generation results.

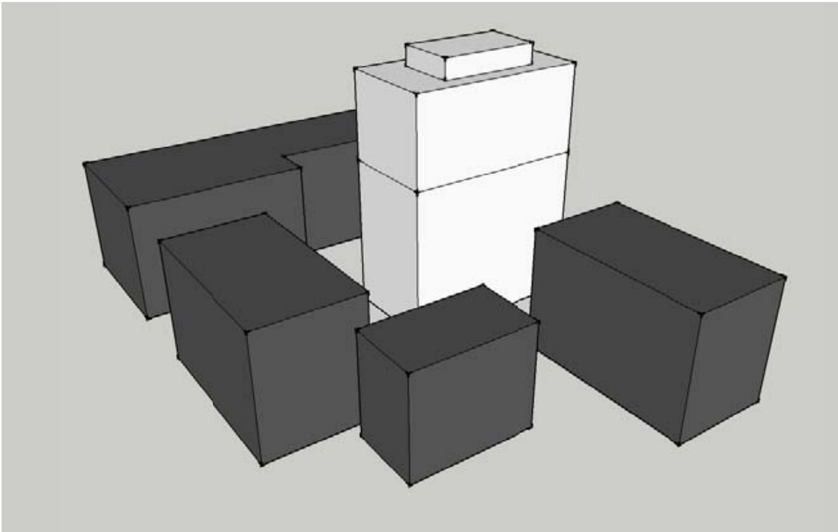
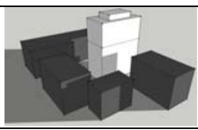
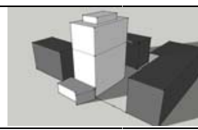
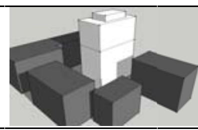
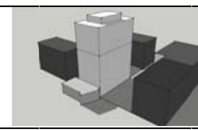
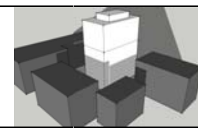
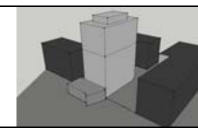


Figure 44 SketchUp model for shadow study viewed from SW

The building was analyzed over the entire year during various times throughout a given day. The BIPV generation analysis looked at three scenarios. The first was implementation on the south façade only, the second was on the south, east, and west facades, and the third was on all façades. The model below shows the layout of the surrounding area. Surrounding buildings are shown in darker color, and the lower limit for BIPV implementation is shown as a line on Crystal Plaza II.

For view in this report are critical points in the year. The first set of images below will be for December, taken in early morning, noon, and late evening for each side. The next set will be from March, then June, and finally September.

Morning		**Noon**		**Evening**	
SW	**NE**	**SW**	**NE**	**SW**	**NE**
December					
					
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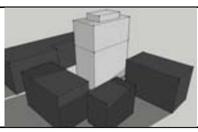	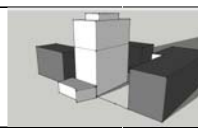	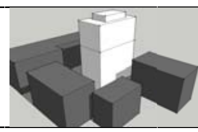	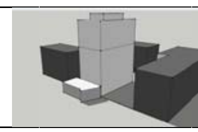	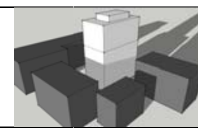	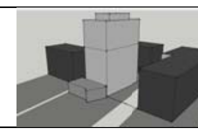
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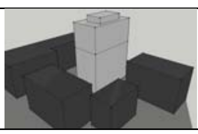	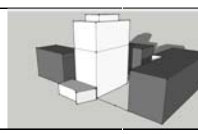	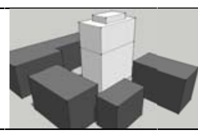	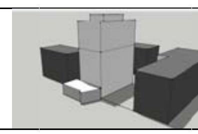	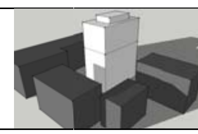	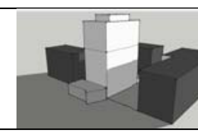
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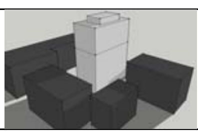	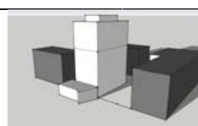	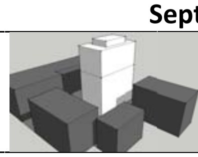	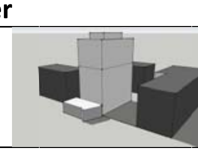	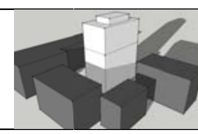	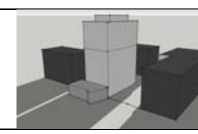

Production Analysis

To begin the production analysis, a basis utility structure and cost was selected. The rate schedule selected was Dominion of Virginia Residential Schedule 1 and is as follows:

Service Charge		$7.00000	per month
Dist	1st 800kWh	$0.02233	per kWh
	over 800kWh	$0.01260	per kWh
Sup	Jun-Sep		
	1st 800kWh	$0.04073	per kWh
	over 800kWh	$0.06051	per kWh
	Oct-May		
	1st 800kWh	$0.04073	per kWh
	over 800kWh	$0.03205	per kWh

To calculate the use of the system the 120/240V system max demand of 1513.93 kW was adjusted with a use factor of 0.6 (entire system not in use all at once) to give an adjusted demand of 908.36 kW. This yields a daily kWh usage for the entire complex of 21,800 kWh or about 80 kWh per day per unit. The following table shows the breakdown of the utility bills for the 120/240V system that powers the individual units.

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Service Charge	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862	$1,862
Dist Charge	$8,523	$7,699	$8,523	$8,248	$8,523	$8,248	$8,523	$8,523	$8,248	$8,523	$8,248	$8,523
Supply Charge	$21,667	$19,571	$21,667	$20,968	$21,667	$39,559	$40,878	$40,878	$39,559	$21,667	$20,968	$21,667
Total	$32,052	$29,132	$32,052	$31,079	$32,052	$49,669	$51,263	$51,263	$49,669	$32,052	$31,079	$32,052
Total/ unit	$120	$110	$120	$117	$120	$187	$193	$193	$187	$120	$117	$120

The following is data that was collected to perform the necessary calculations for production.

Station Identification	
City:	Sterling
State:	Virginia
Latitude:	38.95° N
Longitude:	77.45° W
Elevation:	82 m
PV System Specifications	
DC Rating:	89.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	68.5 kW
Array Type:	Fixed Tilt
Array Tilt:	0.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.14	4292	343.36
2	2.97	5590	447.20
3	3.98	8263	661.04
4	5.07	9913	793.04
5	5.64	10889	871.12
6	6.30	11756	940.48
7	5.93	11153	892.24
8	5.31	10121	809.68
9	4.43	8294	663.52
10	3.42	6659	532.72
11	2.24	4217	337.36
12	1.74	3281	262.48
Year	4.10	94430	7554.40

Figure 46 Data output from PV Watts by NREL for Sterling VA

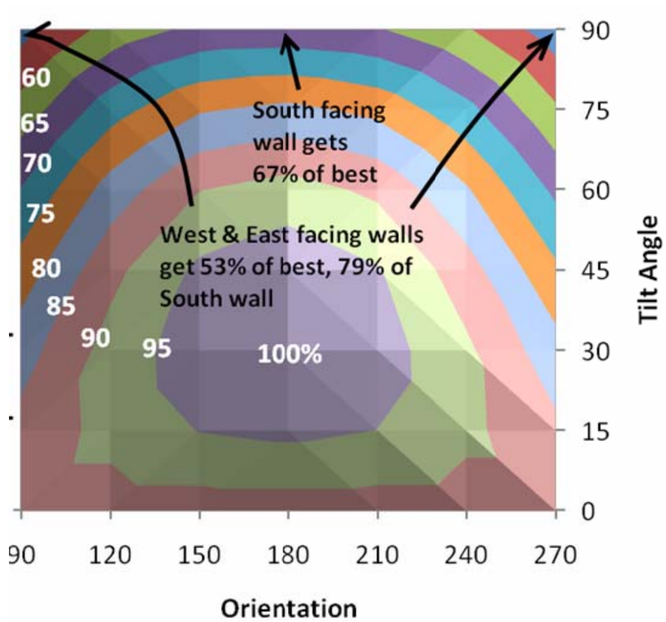

Figure 45 PV Efficiency for given orientation and tilt angle (Lau, 2009)

Equation

$E_{sol} = I_t A \eta t$

where:

I_t = long-term average solar per day per unit area at specific tilt and orientation from insolation table above (W/m^2-day)

A = total area receiving sun (m^2 or ft^2)

η = annual efficiency of converting sunlight to useful energy

t = time, if I_t is annual average per day and analysis is for a year then t=365 days

South Facade

This is the first analysis showing the potential for solar energy generation is using the south façade. A table can be seen in the Appendix A with a more detailed breakdown. Using the following equation and values, the monthly kWh production of the PV's was calculated and subtracted from that used without the PV's. The savings is then calculated in the same manner as the original utility bill.

Location	Area (sq meters)	Area (sq feet)	Efficiency Material	Efficiency Orientation
South	1,655.38	17,818.51	7.0%	67.0%

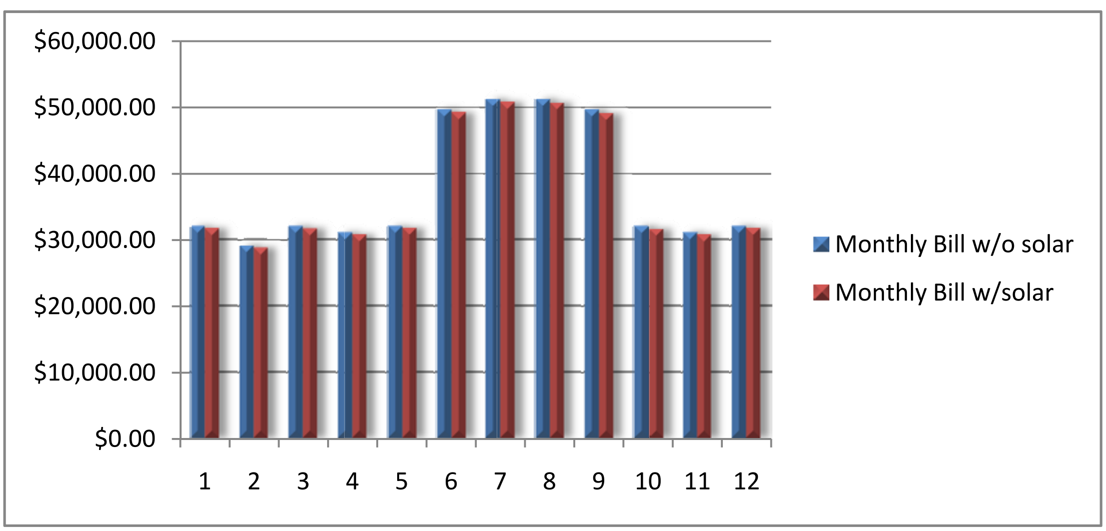

Figure 47 Monthly energy bill comparison for south facade implementation

Figure 48 Monthly savings for south facade implementation

Using the calculations above, about 89,000 kWh can be produced by the BIPV system. Typically a grid connected system has a loss associated with it, rendering the system about 90% efficient. This produces a value of 79,800 kWh per year. Using an estimated state average cost of $0.06 this equates to cost savings of about $4,700. To estimate the cost of the system a median value of $8,500 per installed kW (89 kW system) was used for a system cost of $756,500. With the savings and a simple payback calculation, the payback period is in the range of 160 years. This does not include benefits in terms of rebates, tax credits, incentives, or resale of produced energy at a premium. However using a rough rule of thumb for costing, in that about 70% of the system can be paid for by tax credits, rebates, or incentives, the system can now be paid of it approximately 50 years. These numbers are still unfeasible for the owner due to the large cost with little production.

South, East, and West Façades

For this analysis the BIPV façade was expanded to include the east and west facades, as they are still able to produce a substantial amount of energy. Even when not at optimal tilt or orientation, these panels can still produce about 53% of that produced by a properly oriented and tilted panel. A more detailed breakdown can be found in the Appendix A.

Location	Area (sq meters)	Area (sq feet)	Efficiency Material	Efficiency Orientation
South	1,655.38	17,818.51	7.0%	67.0%
East	927.92	9,988.08	7.0%	53.0%
West	927.92	9,988.08	7.0%	53.0%

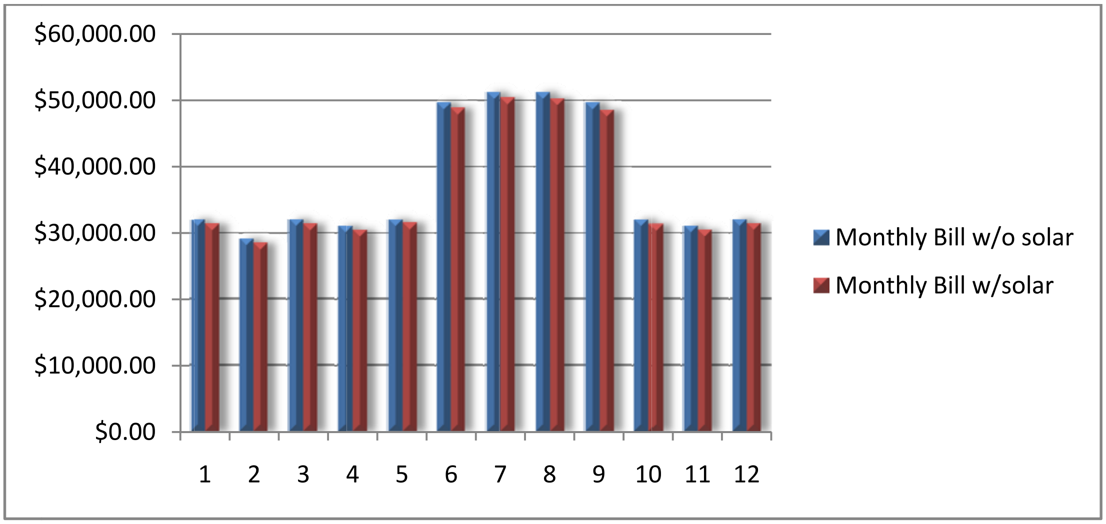

Figure 50 Monthly energy cost for south, east, and west facade implementation

Figure 49 Monthly savings with south, east, and west facade implementation

Using the calculations similar to above, about 167,000 kWh can be produced by the BIPV system. Again a grid connected system has a loss associated with it, rendering the system about 90% efficient. This produces a value of 150,600 kWh per year. Using an estimated state average cost of $0.06 this equates to cost savings of about $9,000. To estimate the cost of the system a median value of $8,500 per installed kW (189 kW system) was used for a system cost of $1,606,700. With the savings and a simple payback calculation, the payback period is in the range of 180 years.

All Façade Areas

This analysis looks at utilizing the entire façade area above the 12th floor, including the north. The value for efficiency of the north façade is estimated based on figure 45 above. This value assumes that the façade will generate power from reflections off of surrounding buildings, artificial light, and for the limited time that it is under sun. A more detailed breakdown can be seen in the Appendix A.

Location	Area (sq meters)	Area (sq feet)	Efficiency Material	Efficiency Orientation
South	1,655.38	17,818.51	7.0%	67.0%
East	927.92	9,988.08	7.0%	53.0%
West	927.92	9,988.08	7.0%	53.0%
North	1,655.38	17,818.51	7.0%	25.0%

The all façade system can produce about 192,700 kWh. Again a grid connected system has a loss

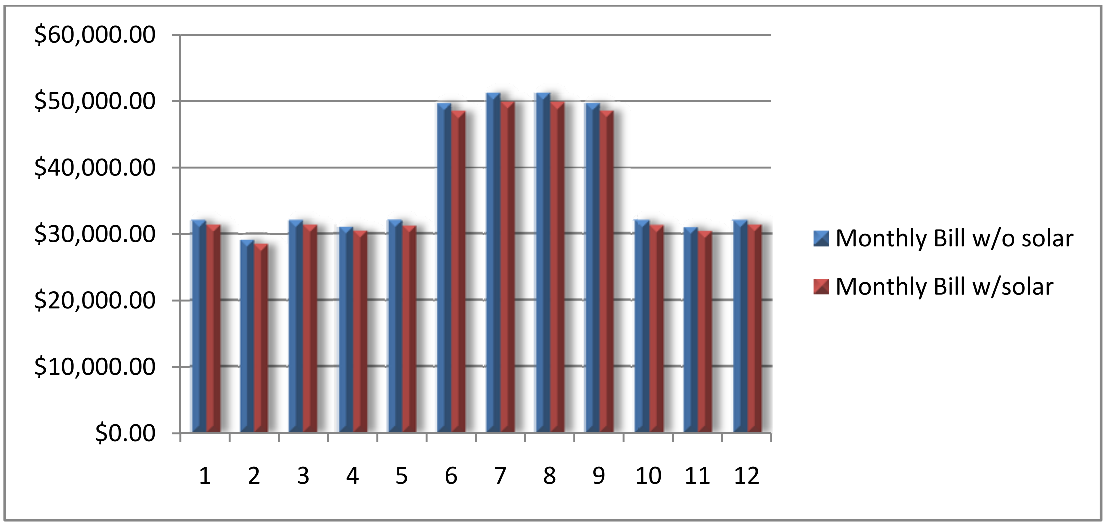

Figure 51 Monthly energy cost with implementation on all facades

associated with it, rendering the system about 90% efficient. This produces a value of 173,000 kWh per year. Using an estimated state average cost of $0.06 this equates to cost savings of about $10,380. To estimate the cost of the system a median value of $8,500 per installed kW (189 kW system) was used for a system cost of $2,363,559. With the savings and a simple payback calculation, the payback period is in the range of 223 years.

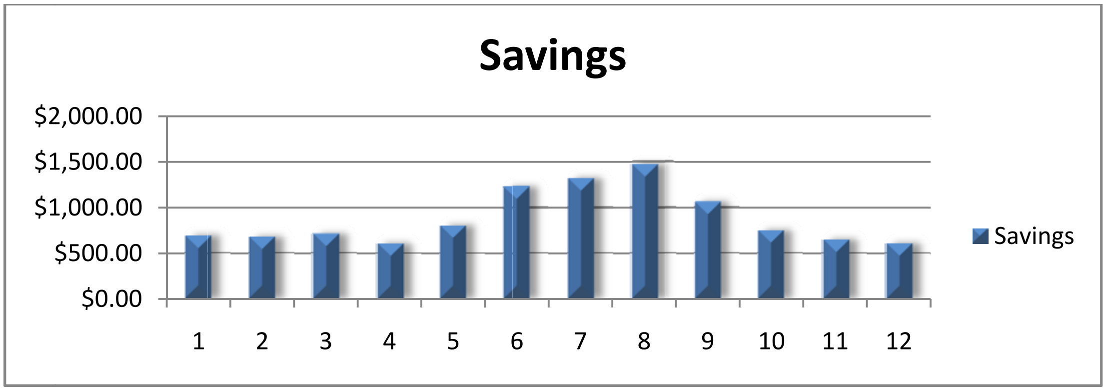

Figure 54 Monthly savings with implementation on all facades

The below chart shows the relative savings between each system, however the cost for the system with the highest savings is more than 2.5 times the cost of the south façade alone.

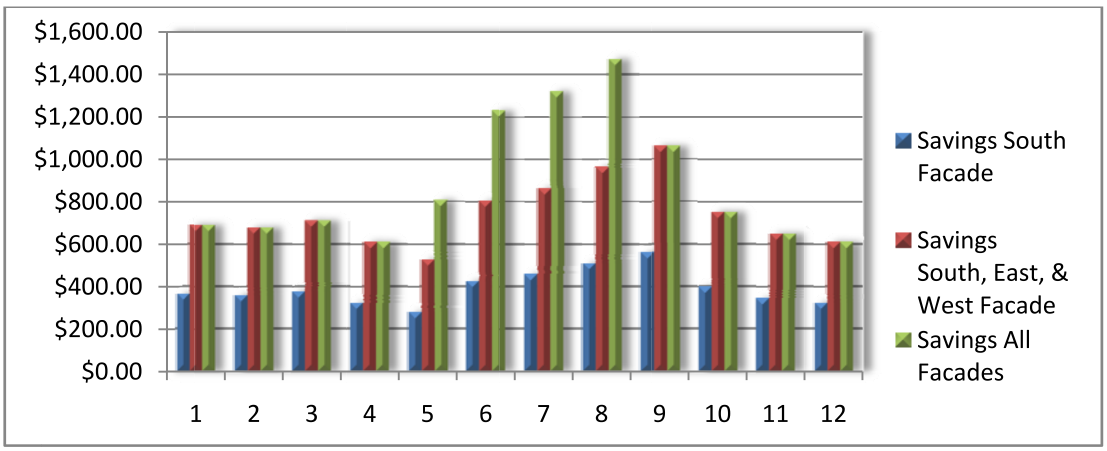

Figure 53 Savings comparison

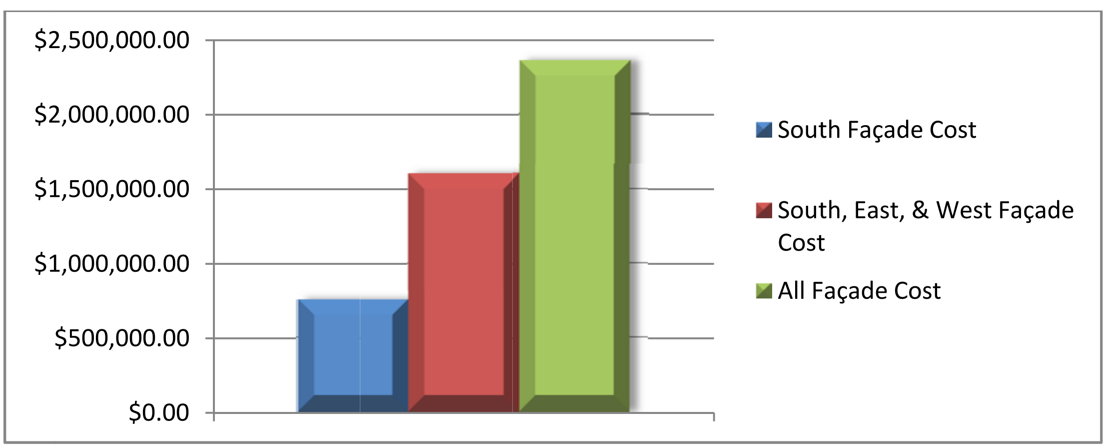

Figure 52 Cost Comparison

Inverter and Wiring

Moving beyond the typical analysis of evaluating production and payback, it is also important to see how the system ties into the building. For this analysis the system is assumed to be installed in the typical manner of stringing together panels on a single floor to an inverter, through a load controller, and into the building system via an electrical panel in the electrical closet. This provides many issues. For instance, how many panels can be wired together and supported by a single inverter? How big are the inverters and where can they be located? What size wiring is required to link the solar panels to the electrical panel?

Inverter Sizing

The inverter selected is a Xantrex GT series grid tie solar inverter, more specifically the GT5.0. As with most inverters it has a limit on open circuit voltage from the PV panels. This is the limiting factor when sizing the system and is often the reason for multiple inverters per floor. Also, in terms of constructability, this is why the series of panels, or array, is wired across a floor rather than vertically, as it allows for a direct connection and shorter runs with less voltage drop.

The system analyzed in unitized within the curtain wall pieces, meaning an area of about 40 square feet, with a production capacity of about 200 w. The Voc for a typical panel in the system is about 60 V. That means that just the south façade alone has a combine open circuit voltage of 1320V (60 x 22 units). Therefore, a minimum of 3 Xantrex GT5.0 inverters will be required (1320/600= 2.20 inverters). Overall, from floors 12 -20, 27 inverters will be needed.

Xantrex™ GT Series Grid Tie Solar Inverters

Electrical Specifications - Output		
Models	GT5.0	
Maximum AC power output	5000 W	4500 W
AC output voltage (nominal)	240 V	208 V
AC output voltage range		
AC frequency (nominal)		
AC frequency range		
Maximum continuous output current	21 A	22 A
Maximum output over-current protection	30 A	
Maximum utility backfeed current		
Total harmonic distortion (THD)		
Power factor		
Utility monitoring, islanding protection		
Output characteristics		
Output current waveform		

Electrical Specifications - Input		
Maximum array open-circuit voltage		
MPPT voltage range (CEC & CSA)	240 - 550 Vdc	
MPPT operating range	235 - 550 Vdc	
Maximum input current	22.0 Adc	20.0 Adc
Maximum array short-circuit current		
Reverse-polarity protection		
Ground-fault protection		
Maximum inverter efficiency	95.9%	95.5%
CEC efficiency	95.5%	95.0%

Figure 55 Xantrex inverter specifics

As for placement of the inverters, the closer to the panels, the better, however, given the size of the panels, about 2' high, 1'6" wide, and 6" deep, location is restricted to the electrical room in the core of the building. Coordination is very important in this potentially crowded area for placement of the inverters.

As for wire sizing, the system is sized according to the National Electric Code (NEC). The short circuit current of the BIPV system is 1.14A, and is used to size the wiring. Given the 22 instances of BIPV and the 3 inverters per floor the break down is 2 inverters with 7 panels and 1 inverter with 8 panels. A wire sizing table was used on the results below to produce an acceptable wire size. The technical specifications for the SUNTECH SeeThru system assisted in the calculations of wire sizing.

Technical specifications

Electrical data

Output power	42.0W	50.0W	52.0W
Max power voltage	59.6V	66.0V	68.0V
Max power current	0.705A	0.758A	0.765A
Open circuit voltage	91.8V	91.8V	91.8V
Short circuit current	0.972A	1.09A	1.14A

Figure 56 Technical Specifications from SUNTECH SeeThru

Inverter	Short Circuit Amp PV	# of Panels in Series	Total Amp
1	1.14	7	7.98
2	1.14	7	7.98
3	1.14	8	9.12

Using these values the wire size from the panel to the inverter is AWG 14.

A similar procedure is necessary from each inverter to a load controller for the system. The Xantrex inverter has an output over current protection of 30 A. Using this information a wire size of AWG 10 was determined. The AWG 10 connects each inverter to the controller that combines and regulates the power to be delivered to the electrical panel.

From the controller to the panel, a maximum current of 90 A (3 inverters x 30 A) is the design load. Using this value the wire from the controller to the electrical panel is AWG 3. All wire is THWN coated and is a common size. This process is repeated on floors 12-20, and in terms of the south façade only, would require 27 inverters and 9 controllers. Addition of facades would increase the inverter number by adding 2-4 more inverters.

Therefore, as a schematic electrical design for the addition of a BIPV system, a typical floor would use AWG 14 wire to connect the BIPV panels to one of three inverters. From the inverter, AWG 10 wire would combine the inverters at the controller with AWG 3 wire running from the controller to the electrical panel.

Summary

In review, the BIPV system is a great way to produce on-site energy, however, with its high initial expense, it becomes difficult to justify. Given the research performed here, it is my suggestion to forgo the installation of a BIPV system. However, it has been shown that the system can produce energy on all facades and is capable of being installed with the selected inverter and wiring. If the system cost were to be lowered by means of rebates, incentives, or tax credits, the project may become feasible.