ANALYSIS 2: Photovoltaic Glass Replacement

Problem Identification

Bridgeside II is designed to accommodate 80 percent lab space and 20 percent office space. Laboratory equipment can consume a considerable amount of energy compared to a typical office building and this will increase the life cycle costs of the building. The goal of the Ferchill Group is to lease the building as quickly as possible and energy saving features could a be strong selling point. Photovoltaic glass panels can provide significant energy savings if installed on a south facing façade that has unobstructed solar views. The U.S. Department of Energy selected Pittsburgh, PA as one of the thirteen inaugural Solar America Cities. Installing photovoltaic glass panels on Bridgeside II would also help support the solar power movement in Pittsburgh.

Proposal

Photovoltaic glass modules have the potential to reduce the energy costs for Bridgeside II as long as the payback period is reasonable. For this analysis I plan on investigating the initial costs of the system as well as the payback period. I will also perform an energy analysis to determine if using photovoltaic glass in Pittsburgh will supply Bridgeside II with enough energy to result in a beneficial investment.

Goal

The goal of this analysis is to research photovoltaic glass modules and determine the amount of energy savings if they were to be implemented in the Bridgeside II facade. The calculation of the payback period and the energy production by the panels will determine whether or not the system is feasible. Ideally the panels will provide enough energy to offset the initial costs and to provide the owner and tenants with a cost savings. Another goal of implementing photovoltaic panels is to make the building more appealing to potential tenants.

Methodology

1) Research photovoltaic panels and the opportunities for solar energy in Pittsburgh, PA.
2) Investigate the design of the panels and determine where they would be appropriate on the Bridgeside II façade.
3) Determine the initial costs of adding photovoltaic panels.
4) Determine the schedule impacts of the panels.
5) Calculate the energy savings and the payback period of the panels.

Solar Benefits

The demand for solar power increases each year especially with the growing popularity of LEED certified buildings. Home owners are also demanding solar panels to help offset some of their rising energy costs. Prices for solar panels have drastically reduced over the past 20 years, making them more affordable to home owners and commercial developers. The sun emits enough energy to power human kind for an entire year in 1/816,000th of a second. Solar panels harness this energy and reduce the need for fossil fuels, which is good for the environment and helps lower energy costs. One photovoltaic module also has the potential to offset 7.5 tons of CO_2 emissions over its 25 year life span.

Solar energy continues to prove that it can reduce energy costs for commercial buildings and residential homes; however, the initial costs cannot be afforded by everyone, especially in areas where the payback period is longer. Cities are starting to realize the potential of solar energy and are aiding solar energy investors with tax credits, federal grants, and rebates. The U.S. Department of Energy is also encouraging cities to adopt solar power by providing grant money. Pittsburgh, PA was named one of the thirteen inaugural Solar America Cities. The title comes with $200,000 in grant money and an additional $250,000 in technical assistance from the Department of Energy. Pittsburgh will be using the money to provide solar power to the city infrastructure. The first project is to install a solar hot water system at one of the firehouses. This is especially beneficial to Pittsburgh because in the next few years the electricity rate caps will be removed from the majority of Pennsylvania's power companies resulting in increased rates.

Photovoltaic Modules

Photovoltaic modules are constructed with many cells that consist of two or more layers of silicon and create electrical charges when exposed to sunlight. The silicon forms a positive and negative layer that absorbs the energy packets from the sun and release electrons. The electrons then flow along the metal contacts as direct current. An inverter is required to convert the direct current into alternating current, which is required for most building applications. Figure 2.1 illustrates the process of collecting electrons that are absorbed by the silicon.

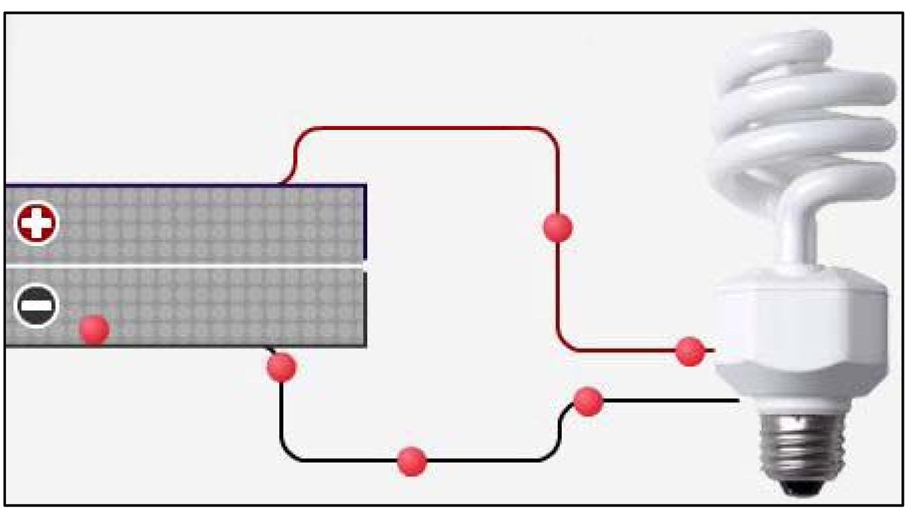

Figure 2.1 – Electron Flow Diagram

The photovoltaic cells are grouped together and housed in a module that has the ability to create useable amounts of energy. There are two types of PV cells; Monocrystalline cells and Polycrystalline cells. Monocrystalline cells are cut from a single cylindrical crystal of silicon and are capable of converting up to 18 percent of the incident sunlight into energy. Polycrystalline cells are cut from recrystallized silicon and are cheaper to manufacturer but they also have a lower efficiency rate of 14 percent. The two types of photovoltaic cells can be seen in figure 2.2. In addition to material, they also differ in color, shape, and size.

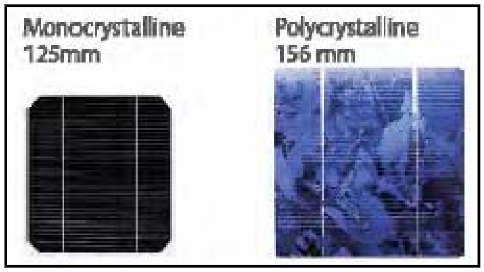

Figure 2.2 – Photovoltaic Cells

For buildings that utilize photovoltaic modules, there are two options for managing electricity use. The first option is to connect to the local power grid. The method will use all of the electricity generated by the modules and any excess electricity is sold back to the power company for the price that it costs them to produce it. The other option is to use an off grid PV system. Off grid systems are typically utilized for small and mobile applications. It is also used in developing countries where a power grid is unavailable. Figure 2.3 shows the typical components of a grid connected photovoltaic system.

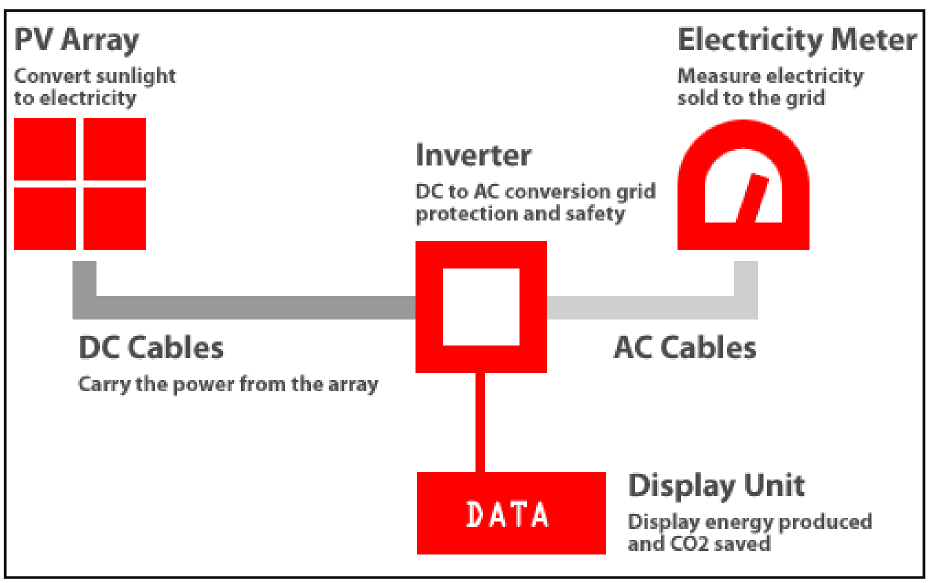

Figure 2.3 – Typical Photovoltaic Components

Suntech Photovoltaic Modules

Building Integrated Photovoltaic systems provide a more aesthetically pleasing design than standard photovoltaic modules. BIPV modules are built into the building's skin rather than serving as an add-on component. They are installed like a typical building material with the added benefit of generating electricity. This reduces unnecessary costs for materials that are covered by the panels. In addition the glass BIPV modules create shading, which reduces the amount of heat entering the building and reduces the energy required to cool the space.

Additional BIPV module benefits include:

- Higher resale value of the building
- Reduction of interior damage by UV rays
- Thermal and acoustic protection
- Educational value

Suntech Power manufacturers several BIPV modules that can be implemented on vertical facades. Each of the BIPV modules allows light to pass between the cells and the See Thru module can be seen through similar to a tinted pane of glass. For the Bridgeside II project I am proposing to implement the Suntech Light Thru panels on the south and west facades. The two proposed facades face southwest and southeast respectively and are adjacent to the Monongahela River allowing for unobstructed solar views. The Light Thru modules cannot be seen through but they will provide light into the building and have a lower cost per watt than the See Thru modules. They also can be ordered in custom sizes, unlike the See Thru modules, and will generate 10 watts per square foot when the cells are spaced at the minimum of 4 mm. The cells are sandwiched between two sheets of tempered clear glass and can be spaced according to preference. More space between the cells will allow more light to pass through but it will reduce the output of the modules. Figures 2.4 and 2.5 are images of the Suntech Light Thru modules.

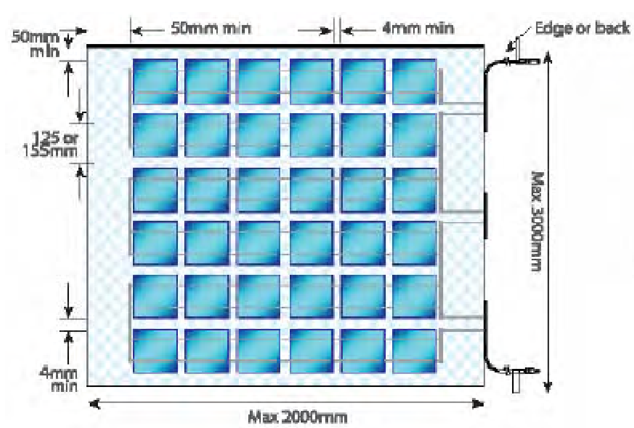

Figure 2.4 – Light Thru module Diagram

Figure 2.5 – Light Thru modules

Design and Constructability Considerations
The window walls on the south and west elevations are a selling point for Bridgeside II because they provide excellent views of the Monongahela River and the Pittsburgh skyline. It is important to consider these views when proposing BIPV modules. In the original design the top 4 feet of each window is non-vision spandrel glass. The spandrel glass allows the façade to be a continuous window wall and it prevents views of the elevated slab edges. The Suntech Light Thru panels will still prevent views of the slab edges and will allow up to 10 percent light transmittance. The Light Thru panels will accomplish all the goals of the spandrel panels and they will blend in with the modern, industrial design of the building. Figures 2.6 and 2.7 are sketches to compare the original and proposed designs.

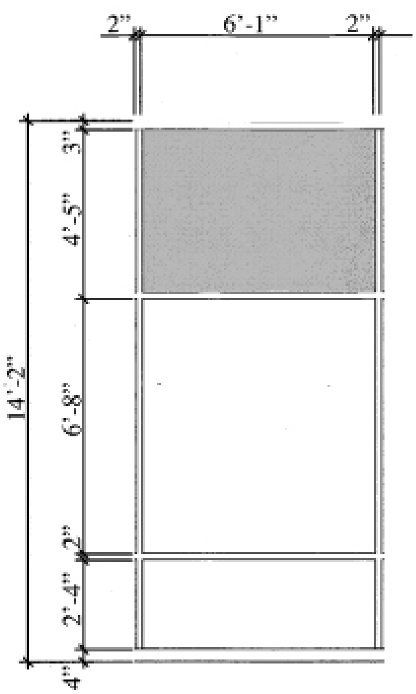

Figure 2.6 – Original Window Design

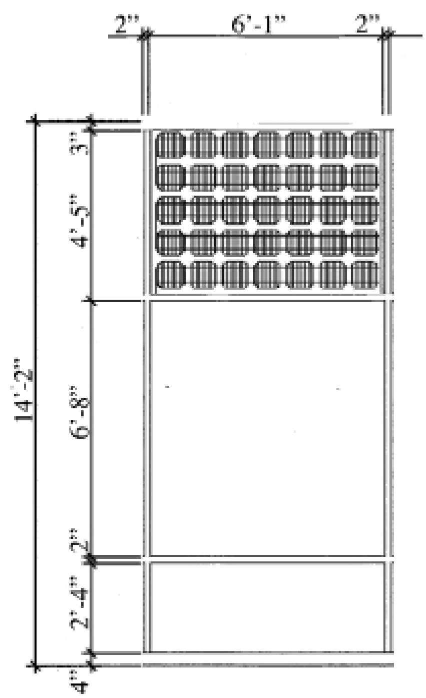

Figure 2.7 – Proposed Window Design

The Light Thru module is unique to the other Suntech modules because it can be manufactured in any size up to 9.5'x6.5'. It also varies in thickness from 3.2mm to 12mm (.12in to .5in). This is important because the Light Thru modules can be manufactured with the same dimensions as the spandrel panels and the aluminum frames will be able to accommodate the PV modules without a redesign of the window wall. As long as the lead times for the glass and PV modules are coordinated there will not be an issue with the installation. Each of the Light Thru modules is manufactured with plug and play connectors that allow for simple and efficient installations. Inverters are required to convert the direct current generated by the modules into alternating current that can be use by the building. The inverter I am proposing to use is the GT 5.0 Grid Tie Solar Inverter manufactured by Xantrex. The GT 5.0 inverter has a maximum AC power output of 5000 watts. Tables 2.1 and 2.2 show the technical specifications for the PV modules and inverters.

See Appendices E and F for additional product data for the PV modules and inverters

Design Calculations

Light Thru Modules:

- Number of Modules: 168 modules
- Total Area: 3697 SF

Table 2.1 – Light Thru Module Specs

Light Thru Modules	
Technical Specifications	
Maximum Power (P_{max})	290 W
Optimum Operating Voltage (V_{mp})	66.3 V
Optimum Operating Current (I_{mp})	4.37 A
Open Circuit Voltage (V_{oc})	80 V
Short Circuit Current (I_{sc})	4.8 A

Based on the specifications of the modules and the inverters, each inverter will be able to support three strings of modules. Each string consists of five modules that are connected in series. The goal when sizing the strings is to be near the middle of the inverter voltage range. Temperature will change the voltage generated by the modules and it is important that the voltage variations stay within the inverters operating range. When determining how many strings the inverter can support the total power input must be considered.

Table 2.2 – Inverter Specs

GT 5.0 Xantrex Inverter	
Technical Specifications	
AC Output Voltage(V)	240 V
Max AC Power Output (W)	5000 W
Max Array Open Circuit Voltage (V_{dc})	600 V_{dc}
MPPT Voltage Range (V_{dc})	240-550 V_{dc}
Max Input Current (A_{dc})	22 A_{dc}
Inverter Efficiency	95.90%
Dimensions	28.6x16x5.75"

Xantrex Inverter:

- Number of modules per string:
  - 550 V_{dc} / 80 V = 6.8 modules
  - 240 V_{dc} / 80 V = 3 modules
  - **Use 5 modules per string**
- Number of strings per inverter:
  - 5000 W / (290 W x 5 modules) = 3.44 strings
  - **Use 3 strings per inverter**
  - **Total of 15 modules per inverter**
- Number of Inverters
  - 168 modules / 15 modules per string = 11.2 inverters
  - **Use 12 inverters**

Electrical Panel Loading:

Another aspect of the design that had to be considered is the effect of the inverters on the electrical panels. I am proposing to tie the inverters into an extra panel located in the first floor electrical closet. The reasoning for this is that electrical room 102 is the closest to the PV modules resulting in shorter wiring spans. Also room 102 has enough room to mount the 12 inverters. Panelboard SEM1 has a voltage of 480/277V and a 400 Amp rating. The maximum panel loading is 192 kW and since the panel is empty it has enough room to hold all the inverters, which have a total load of 60 kW. This risk in this decision is that an additional panel may be needed in the future once the building is completely leased. Each inverter will also require a circuit breaker with a 20 Amp capacity.

- Maximum Panel Loading = (1.732)(277V)(400A) = 192 kW
- Total Inverter Load = 12 inverters x 5000W = 60 kW
    - **60 kW < 192 kW - Acceptable**
- Circuit Breaker Size = 5000W / 277V = 18.05
    - **Use 20A circuit breakers**

Cost and Schedule Comparison

The total cost of the Light Thru modules and the inverters, is $306,190. This is a $228,553 increase in cost compared to the original spandrel glass design. An energy analysis will determine how long it will take for the cost savings from the energy production to offset the initial costs of the system. Table 2.3 shows the cost break down of the PV system.

The spandrel glass is constructed with 4 lites in each panel. A typical glass lite takes approximately 15 to 20 minutes to install. The Light Thru modules are constructed as a single unit but they will take longer to install into the aluminum frames. Each module has to be drilled into the frame and connected to the rest of the modules in the string. The time saved by installing only one lite compared to four is about 15 days. This time will be applied to the longer durations of the PV modules and the time it will take to mount and install the inverters. The proposed system should be installed in a similar duration to the original spandrel glass.

Table 2.3 – Proposed PV system costs

Photovoltaic System Costs			
Item	**Quantity**	**Unit Cost**	**Total Cost**
Spandrel Glass	3697 SF	$21/SF	($77,637)
Light Thru Modules	3697 SF	$70/SF	$258,790
Inverters	12	$3,950	$47,400
		Total	**$228,553**

Energy Analysis

In order to perform an energy analysis and calculate a payback period I used a program by the National Renewable Energy Laboratory called PVWatts calculator version 2. PVWatts can determine the energy production and cost savings of grid connected PV systems anywhere in the world. The program works by using historical hourly solar data to create monthly and annual energy estimates for a photovoltaic system. Weather patterns vary every year and as a result PVWatts typically will not be accurate for performing short term estimates compared to long term periods which are accurate to within 10 percent. The input parameters can be modified to accurately represent the size of any system including the panel production, panel orientation, and DC to AC derate factor. The derate factor takes into consideration the inverter efficiency, shading, and panel conditions.

The first step when using PVWatts 2 is to select the location for my building on the solar atlas. Figure 2.8 shows the map and the location of Bridgeside II, which is marked with an X. The solar atlas can render highways and geographical features that allowed me to find the exact location of my building. PVWatts will then use the solar data for that location in the energy estimate.

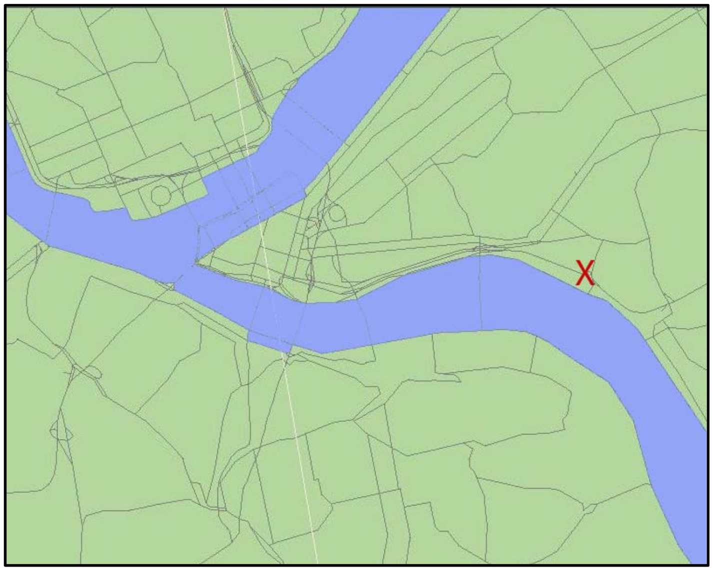

Figure 2.8 – Solar Atlas – Pittsburgh, PA

The next step was to determine the analysis parameters which required a few calculations. I ran two analyzes to provide a more accurate energy estimate of the two proposed facades. One façade faces southwest and the other is southeast; therefore, the azimuth angles had to be adjusted accordingly. Since the modules are being installed on the façade, the tilt angle was set to 90 degrees. Also an electricity rate of 8.19 cents per kWh was entered to determine the cost savings.

- DC Rating
    - Southwest Façade: 2713 SF x 10 W/SF = 27.13 kW
    - Southeast Façade: 984 SF x 10 W/SF = 9.83 kW
- DC to AC Derate Factor: 0.802

Calculator for Overall DC to AC Derate Factor

Component Derate Factors	Component Derate Values	Range of Acceptable Values
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.959	0.88 - 0.96
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	1.00	0.00 - 1.00
Sun-tracking	1.00	0.95 - 1.00
Age	1.00	0.70 - 1.00
Overall DC to AC derate factor	**0.802**	

Figure 2.9 – Derate Factors

Once all the inputs are provided and the analysis is performed, PVWatts outputs the daily solar radiation values, the AC energy production values, and the cost savings that the energy will provide. Figures 2.10 and 2.11 show the output charts for the analysis on each façade.

Station Identification	
Cell ID:	0257372
State:	Pennsylvania
Latitude:	40.3 ° N
Longitude:	79.8 ° W
PV System Specifications	
DC Rating:	27.1 kW
DC to AC Derate Factor:	0.800
AC Rating:	21.7 kW
Array Type:	Fixed Tilt
Array Tilt:	90.0 °
Array Azimuth:	225.0 °
Energy Specifications	
Cost of Electricity:	8.2 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	1.67	1055	86.40
2	2.07	1198	98.12
3	2.71	1658	135.79
4	2.86	1680	137.59
5	2.76	1606	131.53
6	2.80	1504	123.18
7	2.66	1476	120.88
8	2.96	1696	138.90
9	2.92	1627	133.25
10	2.62	1559	127.68
11	1.78	1026	84.03
12	1.58	922	75.51
Year	2.45	17006	1392.79

Figure 2.10 – Southwest Façade Results

Station Identification	
Cell ID:	0257372
State:	Pennsylvania
Latitude:	40.3 ° N
Longitude:	79.8 ° W
PV System Specifications	
DC Rating:	9.84 kW
DC to AC Derate Factor:	0.800
AC Rating:	7.87 kW
Array Type:	Fixed Tilt
Array Tilt:	90.0 °
Array Azimuth:	135.0 °
Energy Specifications	
Cost of Electricity:	8.2 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	1.74	406	33.25
2	2.20	467	38.25
3	2.85	647	52.99
4	2.82	604	49.47
5	2.85	606	49.63
6	2.80	551	45.13
7	2.94	606	49.63
8	2.82	586	47.99
9	3.01	620	50.78
10	2.63	577	47.26
11	1.82	383	31.37
12	1.63	351	28.75
Year	2.51	6403	524.41

Figure 2.11 – Southeast Façade Results

The two facades will produce a total of 23.4 kWh of AC energy per year, which will provide a cost savings of $1917.2 each year.

- Payback period
  - $228,553 / $1917.2 = **119.2 years**
- Payback period after 30% tax incentive
  - $159,987 / $1917.2 = **83.5 years**

Even after the potential 30 percent tax break for applying solar energy the payback period for the Light Thru PV system is 83 years. The typical life of the modules is 25 years which means they would never pay back the initial costs of the system. In order for the payback period to be reasonable the modules would have to generate at least 70 watts per square foot compared to 10 watts per square foot. This would result in a 20 year payback period, which is still slightly long but in the lifetime of the modules.

Conclusions and Recommendations

After analyzing the energy output for the Light Thru modules it was determined that the payback period would be 83 years, which is not acceptable. The payback period would need to fall within the life of the panels so that the initial investment is offset and the owner begins to benefit from the cost savings. Other options include using more efficient modules and increasing the number of modules used. However, this will increase the price of the PV system and it still may not pay off for the owner. Also adding more modules onto the Bridgeside II façade would reduce the light into the building and block the views of the river and Pittsburgh skyline. A PV system is not a valuable investment for Bridgeside II but they are still beneficial. Utilizing solar energy reduces building's carbon output and it reduces the dependence on power companies. Pittsburgh is striving to become a solar city and each investment in solar energy is valuable to the city. In conclusion I do not recommend the use of Suntech Light Thru modules for Bridgeside II, however, solar technology is advancing and I believe there will be a time when PV modules will be more efficient and affordable for cities such as Pittsburgh.