Analysis 2: Photovoltaic Glass Replacement

Problem Statement

Building operating costs can be astronomical in this technologically savvy world. Many of these advanced devices require electrical power to function. Photovoltaic glass panels can supplement the electrical power that is streamed to Wisconsin Place from nearby transformers. Even though PV glass is more expensive, I would argue that the windows will pay for themselves eventually and may save the owner/residents a great deal in electric bills.

Goals

I will determine the advantages and disadvantages of using PV glass in a high rise apartment building in Chevy Chase, Maryland. I aim to quantify the amount of electrical energy that can be generated from one panel of PV glass and how that translates to the entire building. This analysis will quantify the amount of energy savings and utility costs that result from the PV glass replacement and determine if the glass replacement is feasible from a financial and energy standpoint.

Research Steps

1. Research photovoltaic glass, advantages and disadvantages.
2. Estimate the amount of glass in the curtain wall and windows.
3. Compare prices of regular glass to PV panels.
4. Attend Energy10 tutorial session and learn program.
5. Calculate the energy savings associated with switching to PV glass.
6. Calculate life cycle cost.
7. Show schedule impact of replacing glass.
8. Determine whether to stick build or prefab PV glass.
9. Make recommendation on PV glass replacement feasibility.

Tools

1. RS Means 2008 Edition
2. Whole Building Design Guide
3. Energy10
4. National Renewable Energy Laboratory
5. BP Solar

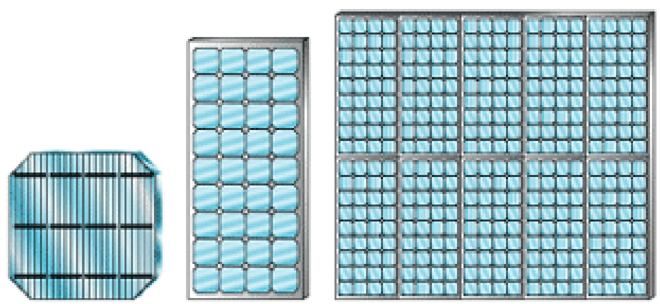
6. US Green Building Council
7. Xantrex
8. US Department of Energy

Expected Outcome

My hope is that this photovoltaic glass will be an upfront investment that saves on operating costs in the long term. Since Wisconsin Place is a rental apartment building, I am assuming the owner will hold onto it for a few years as opposed to selling it immediately following construction. This fact leads me to believe that the owner will buy into the idea of a value-enhancing alternative even if means reaching deeper into their pockets initially.

Photovoltaic Glass

Photovoltaic cells are made of multicrystalline silicon and are used to collect solar radiation from the sun. This solar energy can then be converted into electrical energy to power building systems. These cells can be either transparent or opaque, and light transmission through the cells can be set from 4% to 30% depending upon the spacing. There are two main types of PV modules: thick crystal and thin-film. The thick crystal cells are more efficient than the thin film, but they do not permit as much sunlight to pass through. They produce 10-12 Watts per square foot of PV array. The thin film panels are cheaper but less efficient, producing 4-5 Watts per square foot of PV array.



Photovoltaics are an important energy technology because they are reliable and require little maintenance. PV panels are produced domestically and support energy security in the US. These panels are modular and can be used in various applications due to their flexible design. As an added bonus, PV panels serve the purpose of form and function, as they are being used more and more as architectural features of a building, as opposed to being hidden on a roof or assembled in the middle of a field.

A Building Integrated Photovoltaic (BIPV) system incorporates photovoltaic modules into the building enclosure. This innovative technology serves two functions: the building skin and a source of electricity. I feel that BIPV is a much more economic use of PV panels because they are one product serving two purposes. They are a substitute for a façade element, not an additional component added to the building.

The PV array can either be grid-tied or a stand alone off-grid system. The benefits to a grid-tied system are savings to the utility losses associated with transmission and distribution during peak hours of operation. The utility grid acts as storage and backup for the PV array. Any excess electricity produced by the PV array is fed back into the grid. A stand alone PV system makes more economic sense for smaller applications where it would be too expensive to run power lines to the electrical grid. This cost can range from $15,000 to $50,000 per mile. Typically, buildings in secluded location will opt out of becoming grid-tied for this financial reason.

Grid-tied systems are 100% efficient and can benefit both the building owner and the utility system. This is because the on-site production of solar electricity is usually greatest at the time of the building's peak utility loads. The contribution from the solar panels reduces the energy costs for the building owner and supports the utility grid during the time of its greatest demand. So BIPV is a joint effort between owners and utility services because both benefit simultaneously from the PV module implementation.

Photovoltaic Skylight Array

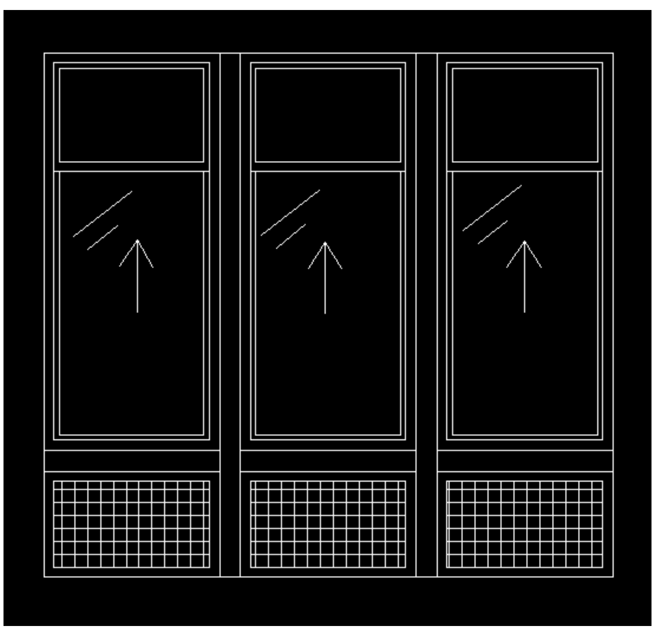
The Public Utility Regulatory Policy Act of 1978 requires power providers to purchase excess power from grid-connected renewable energy systems at a rate equal to what it costs the power provider to produce the power itself. Power providers in most states including Maryland now allow net metering, an arrangement where the excess electricity generated by grid-connected renewable energy systems "turns back" the electricity meter as it is fed back into the grid. A bi-directional meter allows users to record both electricity they draw from the grid and the excess electricity their system feeds back into the grid. The meter spins forward as they draw electricity, and it spins backward as the excess is fed into the grid. At the end of the month, if they use more electricity than the system produced, they pay retail price for that extra electricity. If they produce more than they used, the power provider generally pays you for the extra electricity at its avoided cost. The real benefit of net metering is that the power provider essentially pays the user retail price for the electricity they feed back into the grid.

Some power providers will now let users carry over the balance of any net extra electricity their system generates from month to month, which can be an advantage if the resource they are using to generate their electricity is seasonal. If, at the end of the year, they produce more than they use they forfeit the excess generation to the power provider.

The local, state, and federal governments often provide valuable incentives and rebates to owners looking to incorporate renewable energy systems into their building. Federal incentives include a 30% investment tax credit for owners who purchase solar electric systems and an accelerated depreciation of the solar panels. On the website Database of Incentives for Renewables and Efficiency, the state of Maryland offers a vast amount of financial incentives including corporate and personal tax credit, rebates, tax exemption, and loan programs.

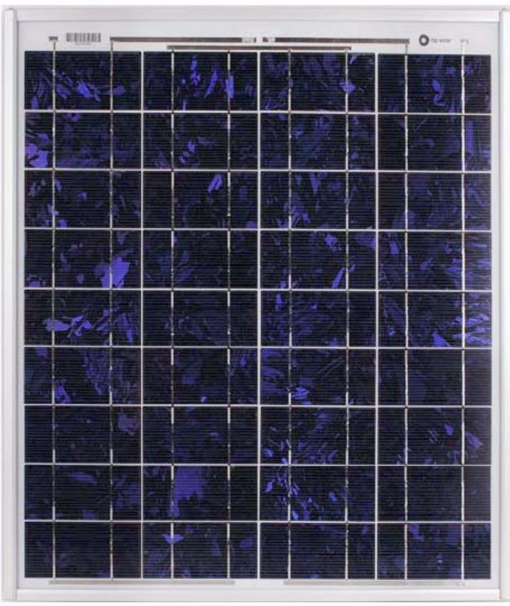
PRODUCT INFORMATION

In an attempt to lower utility costs of Wisconsin Place Residential, I have decided to implement photovoltaic panels into the façade of the building. This was achieved by replacing all of the foot level tempered glass panels with PV glass panels as shown below. This should be a relatively simple adjustment to the project. It only requires that the PV panels be provided to the aluminum window manufacturer so that they can install them in the factory. This way, the windows are still produced as one unit, and no additional installation time is associated with the change. In total, 2,342 PV panels (about 33% of the total façade glass) will replace the tempered glass foot panels for this analysis.



The crystalline cells are opaque and let significantly less light pass through than regular glass, so these panels cannot be placed at eye-level. The view from the apartments will not be obstructed and the addition of PV glass will add texture and dimension the façade. I have elected to use 50 Watt solar panels from BP Solar. One panel contains 72 cells in a 4 x 18 matrix connected in 2 parallel strings of 36 in series. The cells are enclosed in an aluminum frame that will easily connect with the masonry façade. The panel face is made of 1/8 inch tempered glass, so this will still hold up to resident traffic. Each panel weighs around 13 pounds, and has dimensions of 2.75' x 1.75' x 2". The panel and technical information can be found below.

bp solar



Electrical Characteristics		
Typical Data At STC		
Rated Power	Pr	30W
Peak Power	Pmpp	30W
Peak Power Voltage	Vmpp	18.0V
Peak Power Current	Impp	1.67A
Open Circuit Voltage	Voc	22.1V
Short Circuit Current	Isc	1.80A

The performance of the solar cells is measured at Standard Test Conditions (STC): 1000 W/m^2 irridiance, AM 1.5 spectrum and 25° C cell temperature.

Physical Characteristics		
Length	Inches (mm)	26.2 (666)
Width	Inches (mm)	16.2 (412)
Thickness	Inches (mm)	1.31 (33)

Cable Type	18/2	
Cable Length	feet (cm)	15.0 (457.2)

BP Solar 50 Watt Photovoltaic Module

Design Considerations

The PV panels will be delivered to the glass manufacturer to install in the aluminum casement. This way, the window is delivered in one solid piece and there are not field complications with installing the panels. The schedule time to install the PV glass panels is unaffected since the panels are factory installed into the aluminum window frames as shown in the diagram above. There is, however, a lead time associated with ordering the PV panels, which must be coordinated with the glazing contractor in advance.

Upon obtaining panel weight information from manufacturers, it was concluded that the PV panels will not introduce a significantly higher load to the window array. Refer to the tables below.

Existing

Component	Weight per Panel (lbs)
Reinforced Glass Foot Panels	10.8

Proposed

Component	Weight per Panel (lbs)
Reinforced PV Glass Foot Panels	13.2

The addition of PV panels to the façade will add a new dimension to the overall look of the building. Below is a part of an elevation depicting the contrast in color of the window panels. Overall, I do not feel that the panels alter the architecture of the building.

The National Renewable Energy Laboratory created a program called PV Watts that calculates the amount of energy produced by a PV system in any location in the US. The PV Watts Calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. There is some power loss associated with changing DC power into AC power, which is why a derate factor must be used in the conversion from DC to AC. The AC energy for each hour is calculated by multiplying the DC energy by the DC to AC derate factor. In this case, the derate factor for Baltimore, MD was determined to be 0.77. These hourly values are summed to calculate monthly and annual AC energy production, shown in the figures below.

Station Identification	
City:	Baltimore
State:	MD
Latitude:	39.18° N
Longitude:	76.67° W
Elevation:	47 m
PV System Specifications	
DC Rating:	4.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.08 kW
Array Type:	Fixed Tilt
Array Tilt:	39.2°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	7.8 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.47	339	26.44
2	4.40	386	30.11
3	4.79	447	34.87
4	5.12	452	35.26
5	5.28	463	36.11
6	5.70	465	36.27
7	5.61	471	36.74
8	5.28	444	34.63
9	4.95	410	31.98
10	4.90	440	34.32
11	3.58	324	25.27
12	2.85	270	21.06
Year	4.66	4911	383.06

Inverter Sizing

To convert from DC to AC power, inverters are needed for the system of modules. I selected a GT5.0 Grid-Tied Inverter from Xantrex to convert the DC energy from the panels into AC power that can be utilized by the apartment building.

50 V / 21.8 Voc = 2.29 → 3 panels in series

(2,342 panels x 50 W/panel) / (4500 W/inverter) = 26.02 → **26 inverters**

Xantrex GT5.0 Inverter

Model	Features	xantrex
GT2.8 Inverter	208VAC Max. Output: 2700W 240VAC Max. Output: 2800W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	 *Xantrex GT Series Inverter*
GT3.3N Inverter	208VAC Max. Output: 3100W 240VAC Max. Output: 3300W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	
GT4.0N Inverter	208VAC Max. Output: 3800W 240VAC Max. Output: 4000W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	
GT5.0 Inverter	208VAC Max. Output: 4500W 240VAC Max. Output: 5000W Convection cooled (no fan) Outdoor Rated NEMA 3R 10 year warranty	

Budget Review

Existing

Component	Quantity	Cost per Unit	Total Cost
Reinforced Glass Foot Panels	2342	$175	$409,850

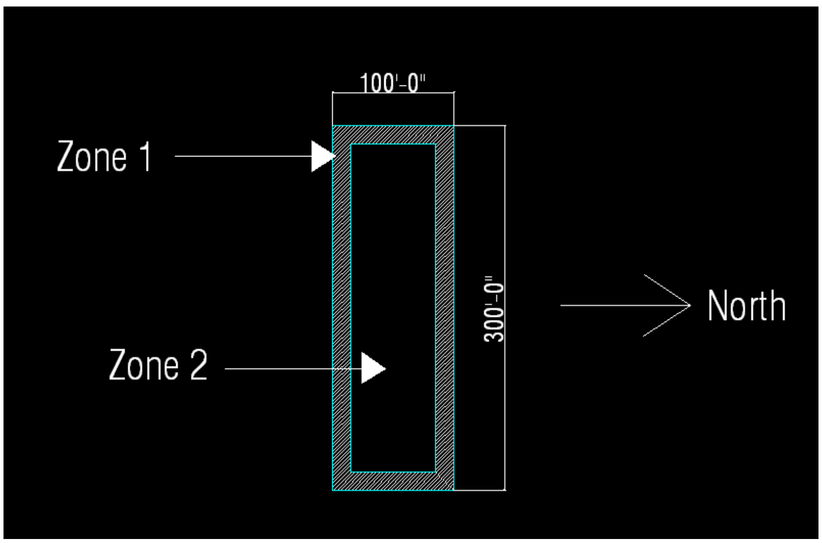
Proposed

Component	Quantity	Cost per Unit	Total Cost
Reinforced PV Glass Foot Panels	2342	$305	$714,310
Inverters	26	$3,059	$79,534
		Total	**$793,844**

The added cost to implement this photovoltaic glass system is $383,994. This initial cost was used in Energy10 to calculate the payback period of the proposed system and determine the life cycle cost.

MECHANICAL ENERGY ANALYSIS

Wisconsin Place was modeled in Energy10 to obtain energy and cost savings data. Energy10 is a software tool developed by the National Renewable Energy Laboratory's (NREL) Center for Building and Thermal Systems. The program calculates energy performance of buildings based upon information like the building mechanical and electrical systems and the skin materials. To model Wisconsin Place in Energy10, I created a simple model of a 100' x 300' building with two separate zones, and interior and exterior, as depicted below. The perimeter is Zone 1, which is the outer 15 feet of the apartment building. This is where all of the building skin and window information is input into Energy10. Zone 2 is the interior space that is treated as a windowless space.

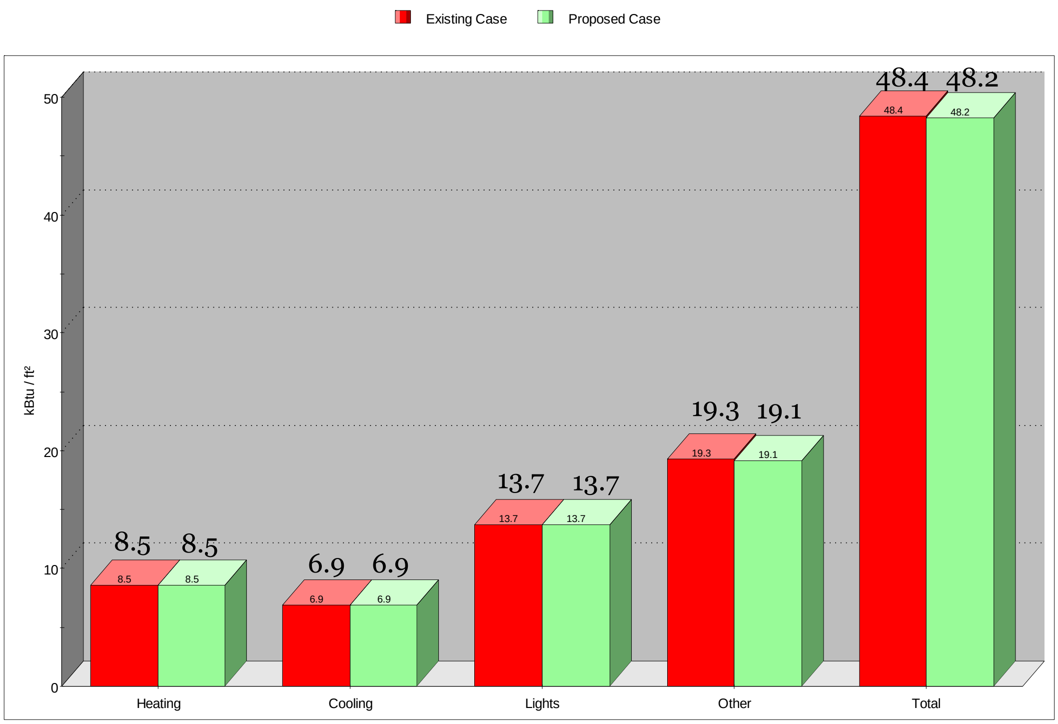


After all of the existing building information was added to the program, I created a second building model that was similar to the first in every way, except that I added in the PV panels. I ran a simulation was that calculated energy usage over a one year period for both buildings. The results indicate slight changes in energy use from installing the PV modules in the exterior. However, the cost savings is a mere $1,800 per year, which I do not feel is a substantial reduction considering the initial investment of $383,994. Below are some output graphs showing annual energy use breakdowns and life cycle costs of the existing and proposed glass systems. Additional graphs showing peak energy usage, emissions comparisons, and life cycle costs can be found in Appendix C.

Energy Use Comparison Report - 50 Watt Panels

Results	Existing Case	Proposed Case	% Change
Energy cost			
$/Therm	0.4	0.4	
$/kWh	0.078	0.078	
$/kW	2.47	2.47	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kBtu	21765730	21693586	-0.33
Energy cost, $	546526	544872	-0.3
Saved by daylighting, kWh	-	-	
Total Electric, kWh	6378610	6357468	-0.33
Internal Lights, kWh	1768050	1768050	0
External Lights, kWh	38556	38556	0
Heating, kWh	1126022	1126022	0
Cooling, kWh	904783	904783	0
Fan, kWh	179306	179306	0
Hot water, kWh	1290020	1290020	0
Unregulated/process loads	1071873	1071873	0
Peak Electric, kW	2973.2	2973.2	0
Annual Emissions			
CO2, lbs	8572851	8544436	-0.33
SO2, lbs	50391	50224	-0.33
NOx, lbs	26152	26066	-0.33
Construction Costs	**$82,087,992**	**$82,267,384**	**0.22**
Life-Cycle Cost	**$100,265,040**	**$100,374,976**	**0.11**

Note that both the construction cost and life cycle cost are higher for the proposed PV system. Energy costs are reduced by $1,654 over the course of a year, and emissions are also slightly lessened. Still, these are miniscule improvements in the grand scheme of things. The chart below shows this data in graphical form.

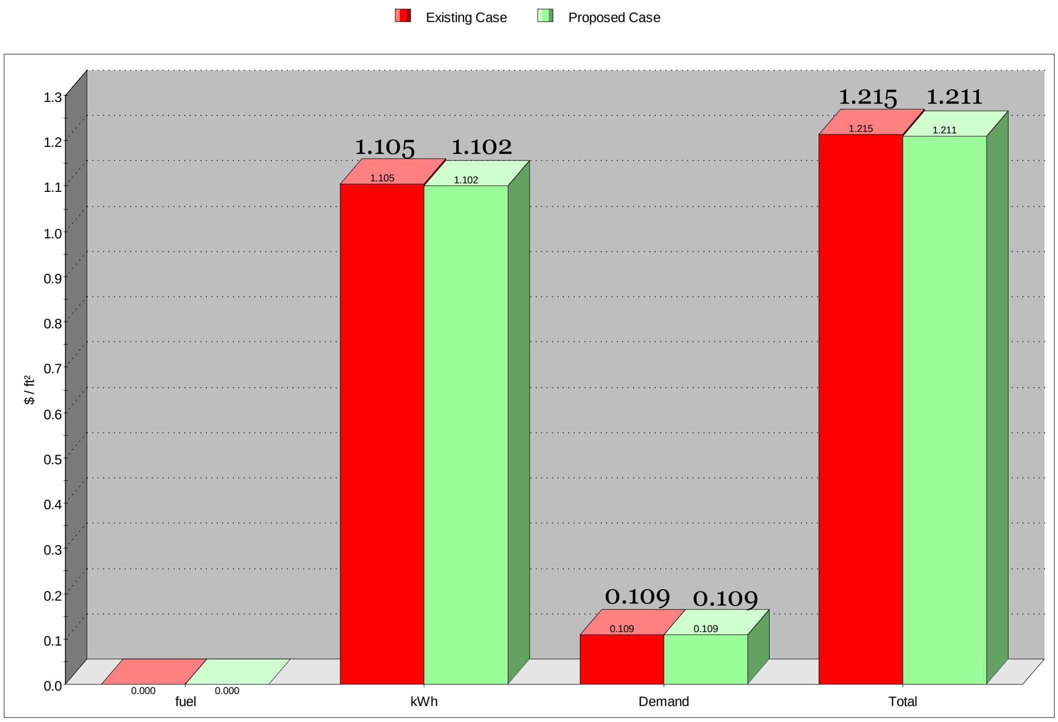


Annual Energy Use – 50 Watt Panels

Cost Summary Report - 50 Watt Panels

Scheme Name	Existing Case	Proposed Case	Difference
Construction	$82,087,989	$82,267,383	-$179,394
Fixed	$78,750,000	$78,750,000	$0
EE strategies	$0	$179,394	-$179,394
HVAC installation	$3,337,989	$3,337,989	$0
Mortgage payment	$7,530,966	$7,547,424	-$16,458
HVAC replacement	$2,503,491	$2,503,491	$0
Annual fuel	$0	$0	$0
Annual electric	$546,526	$544,872	$1,654
Annual maintenance	$225,000	$225,000	$0

Life Cycle Cost Results	Existing Case	Proposed Case	NetPresentValue
Capital	$16,027,146	$16,062,172	-$35,026
Property taxes	$5,926,513	$5,939,464	-$12,951
Mortgage	$77,531,169	$77,700,605	-$169,436
Utilities	$25,128,064	$25,052,017	$76,047
Maintenance	$8,122,171	$8,122,171	$0
HVAC replacement	$4,357,429	$4,357,429	$0
Tax deductions	-$36,827,452	-$36,858,882	$31,430
Life-Cycle Cost	**$100,265,040**	**$100,374,976**	**-$109,936**
Internal Rate of Return, IRR,	**1.70%**		



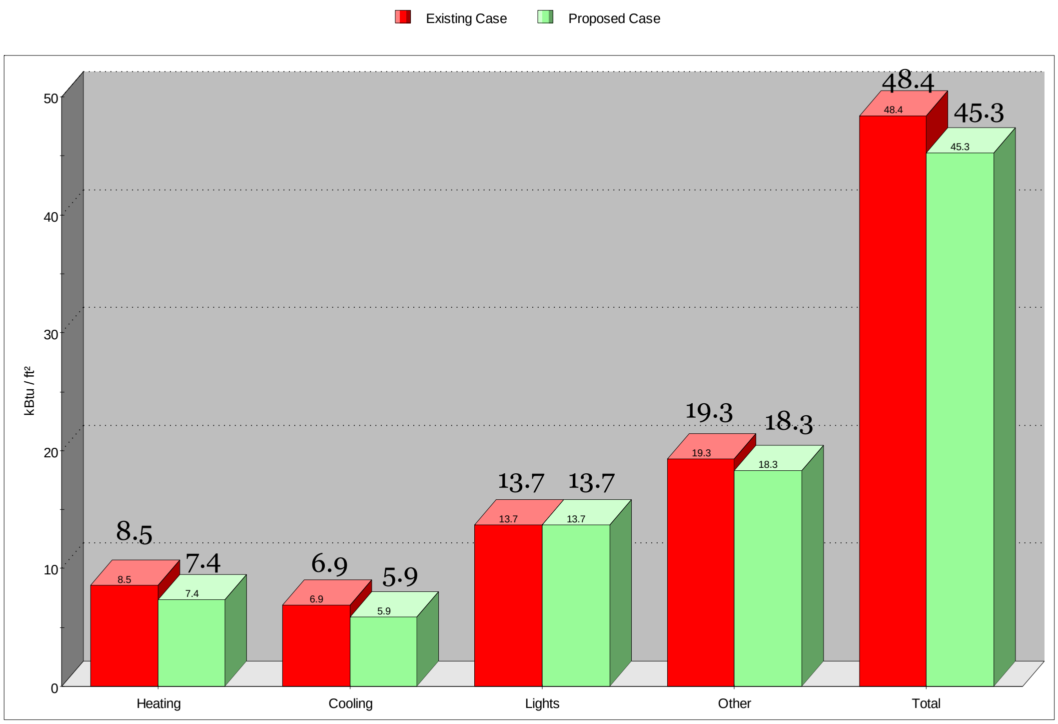
Annual Energy Cost – 50 Watt Panels

Energy10 determined the payback period for this PV system replacement to be 108 years, which is absolutely ridiculous, considering the maintenance life cycle for a building is typically 15 years. I have reached the conclusion that these 50 Watt PV panels do not produce enough energy to make their implementation efficient. To prove this point, I created a new project in Energy10 with the same parameters as the first simulation, except I used 200 Watt PV panels. Those results can be found on the following page.

Energy Use Comparison Report - 200 Watt Panels

Results	Existing Case	Proposed Case	% Change
Energy cost			
$/Therm	0.4	0.4	
$/kWh	0.078	0.078	
$/kW	2.47	2.47	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kBtu	21765730	20370890	-6.41
Energy cost, $	546526	512000	-6.32
Saved by daylighting, kWh	-	-	
Total Electric, kWh	6378610	5969841	-6.41
Internal Lights, kWh	1768050	1768050	0
External Lights, kWh	38556	38556	0
Heating, kWh	1126022	972772	-13.61
Cooling, kWh	904783	780654	-13.72
Fan, kWh	179306	147465	-17.76
Hot water, kWh	1290020	1290020	0
Unregulated/process loads	1071873	1071873	0
Peak Electric, kW	2973.2	2778.8	-6.54
Annual Emissions			
CO2, lbs	8572851	8023466	-6.41
SO2, lbs	50391	47162	-6.41
NOx, lbs	26152	24476	-6.41
Construction Costs	**$82,087,992**	**$82,496,384**	**0.5**
Life-Cycle Cost	**$100,265,040**	**$99,382,231**	**-0.88**

In this revised scenario, the initial construction cost of the PV system is higher than the existing system, but the difference here is that the life cycle cost is lower, meaning there is a point during the lifespan of building operation where the energy savings from the PV panels will be enough to reduce total utility costs.



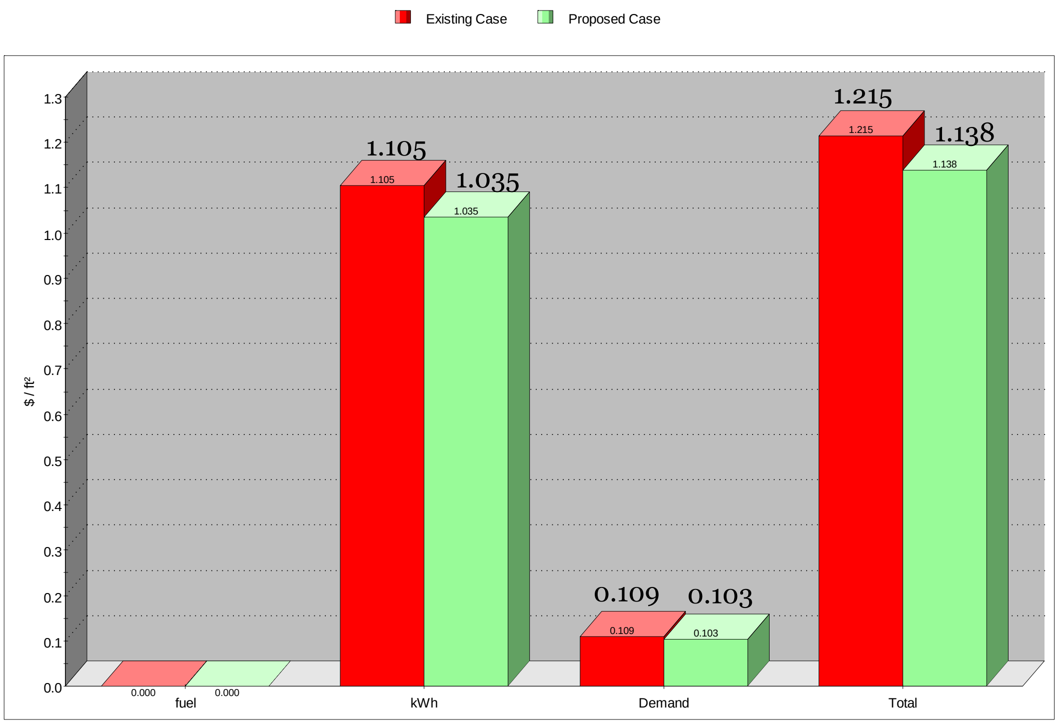
Annual Energy Use – 200 Watt Panels

Cost Summary Report - 200 Watt Panels

Scheme Name	Existing Case	Proposed Case	Difference
Construction	$82,087,989	$82,496,385	-$408,397
Fixed	$78,750,000	$78,750,000	$0
EE strategies	$0	$582,936	-$582,936
HVAC installation	$3,337,989	$3,163,449	$174,539
Mortgage payment	$7,530,966	$7,568,433	-$37,467
HVAC replacement	$2,503,491	$2,372,587	$130,904
Annual fuel	$0	$0	$0
Annual electric	$546,526	$512,000	$34,526
Annual maintenance	$225,000	$225,000	$0

Life Cycle Cost Results	Existing Case	Proposed Case	NetPresentValue
Capital	$16,027,146	$16,106,883	-$79,737
Property taxes	$5,926,513	$5,955,998	-$29,485
Mortgage	$77,531,169	$77,916,895	-$385,726
Utilities	$25,128,064	$23,540,635	$1,587,429
Maintenance	$8,122,171	$8,122,171	$0
HVAC replacement	$4,357,429	$4,129,585	$227,844
Tax deductions	-$36,827,452	-$36,389,936	-$437,516
Life-Cycle Cost	**$100,265,040**	**$99,382,231**	**$882,809**
Internal Rate of Return, IRR,	**16.78%**		

Energy10 determined the payback period for this revised system to be 12 years, a much more reasonable time frame than 108 years. In this situation, the owner pays a higher initial cost, but saves in the end. I was correct in my thinking that the panels did not have a high enough power output to make a difference in the overall building mechanical loads or utility costs.



Annual Energy Cost – 200 Watt Panels

Conclusion & Recommendation

The results of the Energy10 analysis showed that the PV panels were not strong enough to make much of a difference in the energy consumption of Wisconsin Place. If 200Watt panels were used in place of the 50 Watt panels, more positive impacts would result. The problem with using 200 Watt modules is that they do not meet the size requirements to fit within the aluminum window frames. More solar cells in an array produce more energy. However, the larger panels that contain more photovoltaic cells are too large to fit in the frames.

The problem could also be remedied by using more of the 50 Watt panels on the façade, but my concern is that they would block too much light from entering the apartments as well as obstruct the city views tenants pay so much to obtain.

In conclusion, I would not recommend the PV glass replacement because it does not generate enough energy to save tenants in utility costs. This was a good idea in theory, but the calculations show it is not worth the hassle in this instance. At any rate, the research presented in this analysis states numerous benefits to using photovoltaic technology with little to no drawbacks. I would encourage all building owners to consider Building Integrated Photvoltaics on their next project.