Architectural Integration of Solar PV into Building Design
Agenda

1. New Construction is the Best Time for PV
2. Design Considerations to Maximize Solar Potential
3. Lousy Design Decisions
4. Architectural Integration of PV
5. What is "Solar Ready"?
New Construction is the Best Opportunity to Consider PV
There are many benefits for the property owner for incorporating solar into new construction. Benefits include:

- Lower upfront cost of installation
- Service panel design to incorporate 100% electric load

Lower upfront cost of installation, since the solar plans will be included in the building design. It will not be a separate process.

Additionally, because adding solar PV to electrical services equipment has limitations which are based on the size of the electrical service itself, therefore to install the desired solar capacity may require a main electrical service upgrade to comply with the National Electrical code. However, on new construction the service panel will be designed to incorporate 100% electric load and address solar capacity considerations. This not only allows the property to bypass the use of natural gas (i.e. sizing service panel for all electric home), but also prevents the property owner having to upsize the service panel to fit the solar capacity.
Another of the many benefits for the property owner for incorporating solar into new construction is that the design can include Electric Vehicle (EV) charging station and storage capacity, adding EV charging to existing facilities is another component which may also require an upgrade to the main electrical service on existing properties.
Benefit of incorporating PV into new construction

- Roof tilt and azimuth can be designed for optimal sun exposure
- Efficient conduit runs that have been predetermined

Roof tilt and azimuth designed for optimal sun exposure efficient
Incorporating Solar in Existing Buildings

Solar PV works on EXISTING BUILDINGS. The existing building market is huge (about half of all commercial buildings were constructed before 1980), so to ignore that market is to ignore a massive opportunity to include solar on the many rooftops that could be working to reduce energy costs for the people and companies under those roofs.

The bar graph above shows how the SIZE of newer commercial buildings has been getting larger.
Existing Structures - Design Considerations

- Age of roof (roof replacement = ideal time)
- Shading by adjacent buildings/trees
- Design for energy efficiency FIRST to reduce cost of solar

Solar can be considered for **ALL existing building design projects**; solar PV can be an option for **EVERY client** you design for. Architects are in the ideal position to be able to talk with clients about the possibility of adding solar PV to any project they're considering, because solar is an independent add-on to any project. Solar will reduce their energy bills and provide their business with a social message to customers that shows that their business is ahead of the curve, modern and forward thinking – all qualities that lend prestige, respect and trust to their reputation.
Design Considerations to Maximize Solar Potential
FIRST – Design for Energy Efficiency (EE)

• Efficient building construction
• Efficient systems and appliances
• Operations and maintenance
• Change in user behavior
• Natural daylighting
• Natural ventilation

First make the building energy efficient which will reduce the electric demand load, so that you’ll need fewer PV panels, thereby dropping the cost of adding solar considerably.

**Efficiency** reduces the electric demand load
- Maximize natural daylighting to reduce lighting needs
- High efficiency lighting; automatic daylighting controls, strategic manual switching
- Minimize plug loads; use Energy Star equipment/appliances
- Maximize natural ventilation (operable windows with EE glazing)
- Consider interior/exterior shading to reduce heat gains

EE = fewer PV panels needed
Fewer PV panels needed = lower cost

The difference between energy "Efficiency" and energy "Conservation" is:
• Energy efficiency is using technology that requires less energy to perform the same function. Using a compact fluorescent light bulb that requires less energy instead of using an incandescent bulb to produce the same amount of light is an example of energy efficiency.
• Energy conservation is any behavior that results in the use of less energy. Turning the lights off when leaving the room and recycling aluminum cans are both ways of conserving energy.

Source: U.S. Energy Information Administration
https://www.eia.gov/energyexplained/index.cfm?page=about_energy_efficiency
According to the Building Codes Assistance Program’s Maureen Guttman

Also, “a growing body of research shows that energy-efficient properties have higher occupancy levels, lease-up rates, and sale prices than less-efficient properties.”

[https://energy.gov/eere/better-buildings-neighborhood-program/california-homebuyers-find-more-value-energy-efficient](https://energy.gov/eere/better-buildings-neighborhood-program/california-homebuyers-find-more-value-energy-efficient)

Los Angeles: EE upgraded homes sell for an average of 9% higher than those that are less energy efficient, 2013
Portland: Efficiency-labeled homes sold for 30% more than non-labeled homes in 2011
All EE things you should do first

• FOCUS on energy efficiency – it’s CORE to modern architecture
• Drive down demand as low as possible – extremely important; you’ll need fewer panels and drive down the cost of solar
• Consider orientation! Face south!
• Use daylighting so you need fewer light bulbs
First make the building energy efficient which will reduce the electric demand load, so that you’ll need fewer PV panels, thereby dropping the cost of adding solar considerably.

http://energy.gov/eere/buildings/zero-energy-buildings

What is the optimal level of efficiency that should be achieved before renewables are deployed in order to reach net zero? Maybe 70%?
Zero Energy Building is an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

SOURCE: http://energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campuses-and

“Site-based” energy is the total amount of energy a building consumes. This can be easily identified by the building’s utility bill. Source energy is the site-based energy PLUS the energy losses due to transmission, delivery and production of the energy off site.
According to the National Renewable Energy Laboratory (NREL), rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of ZNE buildings.

According to the National Renewable Energy Laboratory, the hierarchy of renewable energy sources in context of ZNE is weighted toward technologies that are available within the building footprint and at the site. Rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of Zero Net Energy buildings.
For more information on Zero Energy Building, refer to Profiting from the Sun white paper.

The white paper includes:
- Net Zero Energy Market Update
- “cost Recovery” – creating an ROI for commercial building PV systems
- Financing PV systems investments
- Getting a building NZE ready
- PV systems and Net Zero as a competitive edge
Solar PV gives points for rating systems

For example, these are some of the rating systems that give points (toward certification or labeling) for solar PV.

Additionally, both solar thermal and Solar PV installations offer points toward Green point and HERS rating systems. Although points will vary based on the adopted ordinances of the varying jurisdictions.
Solar PV design considerations

- Building orientation
- Tilt of system
- Site layout
- Shading from other structures and landscape

Solar PV should be considered in the schematic design stage of the project. During this stage, design professionals should consider the site layout, building orientation, shading from current and future structures and landscape, and the available space for the preferred system size.

Ideally, buildings should be designed so that the windows are south-facing to allow the sun to enter and provide natural heat to occupants in the winter, reducing heating needs. Windows should be minimized on the north side of the building because every square footage of window area reduces the R-value of the total wall. For example, a wall might be R-20, but the windows may be about R-3 (even if they’re Energy Star rated). On cold days/nights, heat will transfer more quickly out of the R-3 areas of the wall than the R-20 areas of the wall. So the fewer windows on the north side of a building, the better for energy efficiency. This only impacts solar PV if the building is heated with electricity. If the building is heated with natural gas or oil, it won’t impact solar PV, but it’s still always a good idea to design a building that needs as little energy as possible, for long-term occupant affordability and comfort.
Run long axis east/west to give large southern exposure for roofs and walls

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Solar PV design considerations - ORIENTATION

In the last few hours of daylight, west-facing PV panels have an advantage over south-facing panels as they're tilted towards the setting sun.

Although solar radiation peaks around noon, electricity demand often peaks in the early afternoon or evening. In these last few hours of daylight, west-facing PV panels have an advantage over south-facing panels, as they're tilted towards the setting sun.

Higher PV output at this time of day is often beneficial to grid operators working to increase electric supply to balance high levels of demand, but customers generally will not see this benefit unless they are on time-of-use electric rates.
Maximum solar production can be achieved when the PV panels are tilted towards the sun. Based on this California data, about two-thirds of the fixed-tilt systems that were installed in recent years are tilted between 11 and 30 degrees.

According to EnergySage, “Ideally, a fixed, roof-mounted solar energy system should be at an angle that is equal to the latitude of the location where it is installed. However, pitch angles between 30 and 45 degrees will work well in most situations. Overall, the angle of your rooftop has less impact on solar panel performance than the direction your roof faces.”


Residential and small commercial systems generally have higher tilt angles, likely matching the pitch of the roofs these systems are often installed on.

The default value is a tilt angle equal to the station's latitude plus 15 degrees in winter, or minus 15 degrees in summer (1). This normally maximizes annual energy production. However, throughout the year the sun’s path and the solar altitude vary. You do not need to adjust the tilt for each season, instead you determine which season the client uses the most electricity and tilt the panels according to that season’s optimal tilt. For example, if the building uses the most electricity in the winter to heat the building, then the panels should be tilted for either production. For most buildings, the highest electricity consumption will be in the summer when the AC is running.

To optimize capture of solar panels a tilt angle of 28° - 30° is recommended. However, tilt angles between 20° - 60° are possible without great yield losses. Increasing the tilt angle favors energy production in the winter, while decreasing the tilt angle favors energy production in the summer.
Tracking can maximize solar production by tracking the sun’s position throughout the day. Tracking systems will produce the highest production of the available systems, but will also have the highest cost. Tracking systems are typically ground mounted.
Solar Photovoltaic output depends on orientation, tilt and tracking. This chart shows the simulated average energy production of one kilowatt of solar PV capacity in Los Angeles California based on tracking, tilt angle, and orientation.
Site layout can determine the feasibility of solar PV

System location will be dictated by the available area for the desired system size. Roof, parking lots, and open land are all areas a solar PV system can be placed.

In most cases, the layout of a site can determine whether a solar system is feasible or not. In this diagram we see two example scenarios where site layout greatly changes solar potential. In Site 1, a large amount of open space is available north of the buildings, but because of shading from the buildings, the area will be shaded for a large part of the year. In Site 2, the buildings and the parking lot were shifted to the north side of the site. This left the open space on the south side of the site, where shading from the buildings will not fall on the solar panels. By placing the buildings on a site with solar resource and shading in mind, the area available for solar panels can be greatly increased. Think about this as you design the layout of your site. Also, although these images seem to promote putting solar over open ground (rather than the building itself), please note that covering permeable ground is not as ideal (from a rainwater, open space, potential vandalism perspective) as putting them on the rooftop, and should be used as a last resort – that is, putting solar onto buildings is best. If rooftop is not available, using solar awnings (which we’ll see in just a minute) is another option.
Shading will play a major role in the available area for the desired system size.

Consideration of jurisdictions where there may be solar access laws (you cannot be prevented from putting solar on your building - by a homeowner's association, for example) and solar easement laws (guaranteed unobstructed access to the sun). Neither exists in Pennsylvania. [www.solarresourceguide.org/solar-laws](http://www.solarresourceguide.org/solar-laws)
Shading greatly affects solar PV production

PV panel performance is exceptionally susceptible to shading. When shade falls on a PV panel, that portion of the panel is no longer able to collect the high-energy beam radiation from the sun. If that shading happens during the peak hours of operation (10 a.m. – 2 p.m.), the production of the panel can be greatly reduced.

As a rule of thumb, no panel should be shaded more than 10% during the peak hours of operation.
Self shading is where rooftop elements of the building or structure could potentially shade the solar PV array.

Strategies to prevent self-shading include:

For roof arrays, put all equipment and vents on the north side of the roof. For façade arrays, put roof access staircases to the north. Separate trees from PV facades and if possible use deciduous trees which are free of leaves in winter when shadows are long.
Design to Minimize Shading

Interconnect ribbons

Lose the shaded cell’s production
Design to Minimize Shading

Interconnect ribbons

Lose the *entire* module’s production
In addition, if you are designing the PV system in rows, each row will need to be spaced far enough apart, so one row does not shade the next.

We can see in this picture, the shadow from the first row is close to shading the panels in the second row. If this shadow is the longest shadow of the year, then this spacing would be ideal. The rows are not spaced too far apart where the client is losing space and the panels are not shaded.

Most modeling systems, like AutoCAD, will have a shading model that you can run to see if one row will shade the next. When using a modeling software, be sure to use December 21 (winter solstice) as the day.
If you do not have access to a modeling software, here is an equation that will give you the minimum distance between rows. You will need:

- The height differential between the top of the panel and the ground, and
- Solar altitude angle at 10am on December 21

\[ d = h \div \tan a \]
Now that you have the height differential, between the top of the panel and the ground, you will visit the NOAA calculator and put in the latitude and longitude of the system location (first animation). The calculator will then give you the solar altitude angle for 10 a.m. on Dec 21.

The NOAA calculator: [https://www.esrl.noaa.gov/gmd/grad/solcalc/](https://www.esrl.noaa.gov/gmd/grad/solcalc/)

The latitude in Philadelphia is approximately 40, and the sun altitude is approximately 21 degrees.
Design to Minimize Shading

Assume $h = 24''$ and $a = 21°$, find $d$

$$d = h \div \tan a$$

If you do not have access to a modeling software, here is an equation that will give you the minimum distance between rows. You will need:

- The height differential between the top of the panel and the ground, and
- Solar altitude angle at 10am on December 21
Design to Minimize Shading

Example calculation for inter-row spacing:

\[ d = h \div \tan a \]

\[ 61.86 \text{ in} = 24 \text{ in} \div \tan 21^\circ \]

Now let’s put the height differential and the solar altitude angle into the equation and we get 61.86 inches. This will be the minimum distance between the rows so that the subsequent rows are not shading at any time of the year.
Most modeling software's now include energy simulation. The software will not only calculate the total buildings energy use, but will show where the energy is being used. An energy simulation is best used throughout the design process and not just run when the design is complete or in the final stages.
Rule of Thumb
1kW = approx. 100 sf
You can use the known variables provided by the module manufacturer to determine the approximate size of the photovoltaic array, by knowing the dimensions of the proposed modules and the voltage of the module, simple math will give you the approximate voltage per square foot of roof area which the array will occupy.

Or… for system sizing use the free tools available from NREL and others, like PV watts and The System Advisor Model (SAM)

**Average PV system size**
- Residential - 5 kW
- Small Commercial - 10-20 kW
- Medium Commercial - 30-50 kW
- Large Commercial - 50 kW +
When designing the roof, the PV panels and racking along will add 2-4 lbs/sqft dead load, while ballasted systems will add 5-9 lb/sqft dead load. Note, in locations with high winds, ballasted systems will need to have more weight added.

Is this dead load or live load?

For snow load – talk to your structural engineer! Snow loading becomes point loads with Solar PV and glass surface is “slippery” allowing for more rapid elimination of snow in some roof zones.
Lousy Design Decisions
Now let’s talk about a few solar installation failures.

A common mistake is designing the system where a portion of the panels are shaded. This can be from the surrounding landscape or buildings, equipment on the rooftop where the system is installed, or other panels in the system. Keep in mind landscape will grow and if the property owner has permission, trees may need to be trimmed every few years. Also, neighboring new construction should be considered as well.

“After a solar system is installed it is important to properly commission the solar system. This means taking a volt meter through the system to verify you have the correct voltage inputs to the equipment being used.” http://pveducation.com/solar-installation-failures/inverter-commissioning/

For more examples of ‘what not to do’: http://pveducation.com/solar-installation-failures/

OR Aurora Solar: http://blog.aurorasolar.com/shading-losses-for-pv-systems-and-techniques-to-mitigate-them/
Lousy design decisions

Damaged roofing

Potential snow dam

Poor design/installation

Damaged roof shingle
Lousy design decisions

Orientation

North facing system
Lousy design decisions

String inverters

Different azimuths or inclinations in the same string

Modules of different power ratings in the same string
Lousy design decisions

Cables

- Too loose
- No bending support

Source: First Green

More information on planning cable layouts: http://www.firstgreen.co/2013/05/dc-cable-layout-planning-in-solar-power-projects/