PV Integration in Building: Potential and Application

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Based on a presentation by Andrew McCalla

Introduction

A variety of photovoltaic (PV) systems are available on the market today, but none are simple plug-in applications. Each system must be custom designed for its specific location and intended use. This chapter will serve as a guide for the architect, homeowner, student, and public or private industry interested in understanding the basics of selecting, designing and integrating a PV system into a new or existing building project. In an effort to simplify and streamline the multitude of decisions that must be made in order to make solar harvesting a reality, five steps will be defined: site analysis, PV selection, PV design, PV integration, and PV operation. It must be noted, however, that this process is not completely linear, so some steps will overlap.

Step 1: Site analysis

The first step in considering the installation of a PV system is site analysis. There are a number of site and client specific factors that need to be considered and understood before an educated analysis of potential systems may occur. This stage may be divided into at least three considerations: energy requirements, surface area, and budget.

Energy requirements

The energy requirements of the building to be serviced must be analyzed. Most applications of PV systems do not provide all of a building’s required energy, but the comparison of potential supply to demand must be understood. Two tools that are helpful in understanding potential energy production are feasibility studies, which look at the overall context of a project with respect to desired results, and energy production modeling, which looks at the amount of energy that can be produced from a given installation based on type of system, location, orientation, and tilt. One such example may be seen in figure 3. This table compares an 11 kW system and a 58 kW system to a projected household need. A potential user can immediately understand the comparison in energy production from this data and in turn begin to make educated decisions about what systems might be appropriate.

Surface area

Perhaps one of the greatest limitations of a PV system is the requirement for surface area due to a typical efficiency of 11-20%. Since the first modern solar cell was patented in 1946, many advancements have been made in terms of chemistry and efficiency, but not much has advanced in terms of requirements for surface area. Urban areas, where horizontal surface areas are extremely limited compared to den-
sity, are especially difficult. A quick method for approximating the required surface area uses the rule of thumb that the average modern PV panel yields approximately 12 watts of energy per square foot. Any prospective owner of a PV system must consider the area available for installing PV panels. rooftops are an obvious choice for panels but may not be suitable based on orientation, slope, shape, size, or shading. Ground mounted, wall mounted, and freestanding systems are possible, but must address issues of efficiency, aesthetics, and in some cases, security. At this stage it is advisable to conduct a site analysis to understand any and all potential locations for panels. All equator facing roofs and walls are potential areas, while all non-equator facing roofs and/or walls are typically eliminated from consideration. Shaded areas should not be considered as viable based on the fact that most panels are installed in series, which means that shade on even one small portion of a panel system can result in zero gain from the entire array. Highly visible areas may not be desirable unless a statement about solar energy is intended. Google Earth imaging may prove helpful for this analysis. A new plug-in application for Google Earth called Roof Ray (http://www.roofray.com) will go so far as to calculate potential solar gains for specific roof tops and conduct a basic cost analysis based on typical energy consumption (input from user) and local power costs (input from national database).

**Budget:**

As with any project, purpose and preference will determine the amount of money someone is willing to spend. One of the first questions asked by potential installers of PV systems is: “When is the financial break even point?” The answer to this question varies greatly according to power cost, system, location, and use. Generally speaking, a panel’s carbon footprint from being manufactured is not recovered until after approximately four years of use. Another three to five years are typically required to cover the cost of purchasing and installing the panels. These numbers vary greatly, however, and should be analyzed locally. In terms of actual cost, a typical silicon based PV system will cost $7 to $9 per watt (installed), so a 5 kW system would cost on the order of $35,000-$45,000 and an 8 kW system would be anywhere from $56,000 to $72,000. Many areas are offering incentives to install PV systems in the form of subsidies, which may cover as much as 50% of the initial cost. In summary, this phase of the research should aim to match a potential user’s expectations with actual costs.

**Step 2: PV selection:**

The next step in this process is PV selection. There are a variety of solar technologies, developed in the later half of the twentieth century, which continue to be developed and expanded. The single most important driving factor in solar cell technology is efficiency. Efficiency of a solar cell should be compared to the potential energy of a given area of sunlight and the cell’s theoretical maximum. The first modern cell, patented in 1946, had an efficiency of less than 1%. Since that time the highest rating of efficiency that has been obtained is approximately 40%. The technology that achieved this relatively high efficiency, a multi-junction concentrator solar cell, was developed by Boeing for the U.S. government. Unfortunately it is extremely expensive to manufacture and therefore will not be commercially viable for decades to come. Other emerging technologies, such as dye-sensitized and organic cells, are being developed and show promise of higher efficiencies. At present there are two types of panels that dominate the market: crystalline panels and thin film panels. As with any viable option, each type has strengths and weaknesses. A potential user should understand the basic properties of each and how each will assist in achieving a desired outcome.

**Crystalline panels**

Crystalline Panels are by far the most historically dominant of all solar panels. They are made of extremely stable solar cells with efficiencies of 16-25% (1/3 to 1/2 of theoretical maximum). Crystalline solar cells were developed by the microelectronics industry using semiconductor process technology. Solar contacts are screen-printed and applied to the front and rear of a solar cell. These cells are then hermetically sealed under toughened, high transmission glass to produce highly reliable, weather resistant modules that may carry warranties of up to 25 years. These panels can typically withstand hail of up to one inch in diameter at 50 mph and windstorms of up to 150 mph, when installed correctly.

Two types of crystalline cells have been developed using this process: Monocrystalline and Multicrystalline. Monocrystalline cells are produced by slicing wafers (up to 150mm diameter and 350 microns thick) from a high-purity single crystal boule or from a ribbon of silicon. Multicrystalline cells are made by sawing a cast block of silicon first into bars and then into wafers. Monocrystalline cells typically have a greater efficiency than multicrystalline cells, but they produce more material waste in the manufacturing process, which increases cost.

**Thin film panels**

Thin film technology was first developed in 1976 at an extremely low efficiency (See Figure 5). Since that time, derivative technologies...
have been developed and higher efficiencies have been obtained, but efficiency still peaks at approximately 20%. Thin film semiconductor layers are made from an intricate deposit of silicon on coated glass or a stainless steel sheet. A variety of chemical compounds and elements have been developed to create these cells, but amorphous silicon is the most developed and reliable. It suffers significant degradation in its power output (in the range of 15-35%) when exposed to sun (the Staebler-Wronski Effect) and thus requires the use of multiple thin layers in order to increase the electric field strength across the material. This reduces light absorption and hence cell efficiency, which is typically from 5-8%. Perhaps the major disadvantage of thin film technologies is the fact that they typically require twice the amount of area to achieve the same amount of energy as a crystalline based technology. This not only doubles the amount of surface area required, but also doubles the amount of wiring and labor associated with installing such a system. These systems usually become cost effective at extremely large economies of scale and so are not typically used for residential applications. An advantage of this technology, however, is cost. They are typically less expensive than crystalline panels due to lower material costs. This technology is continuing to develop and may prove to achieve greater efficiencies and more applications in the near future.

To quickly compare the two on a general basis: typically a crystalline panel will achieve an efficiency of 11-20% and cost $3.50/Watt, with a turn key cost of $6/watt. A thin film panel will achieve an efficiency of 5-8% and cost $3/Watt, with a turn key cost of $6.15/watt.

Step 3: PV design

Once steps one and two have been completed and considered, the potential user of a PV system should proceed to consider how the system should be designed to interface with a given power grid (if one exists). There are typically three types of PV systems that may be considered at this stage: stand-alone, grid tied with battery back-up, and grid tied; with the additional consideration of whether or not it is beneficial to install a PV system at all.

Stand alone

Stand Alone systems provide 100% of a building’s energy. These systems are not tied to a grid but may have a back up source of power, such as a diesel powered generator. Due to the high energy requirements of even a humble household, these systems are still fairly rare for homes in the United States. The most common examples of stand alone systems are those used for boat docks, water pumps, and isolated lighting. These systems are typically battery based, with a charging source to maintain supply in the batteries. Solar panels may charge the batteries during sunny times, with a back-up generator used to charge the batteries when needed. These types of systems may be integrated with systems that harness energy generated from wind turbines or hydraulically propelled systems.

Grid tied with back up battery

A grid tied system with back up battery uses both a solar array and an existing power grid to maintain a battery pack. This system allows for power generated by the solar panels to be stored in batteries on site. When these are full, the excess power is banked on the grid. These types of systems are highly effective in areas prone to frequent power outages or natural disasters. Such a system is often designed for a critical load, which is the power required to run essential items, for example refrigerators and cooling in hot areas. Exact sizing of the inverters and battery bank for these systems is critical.

Grid tied systems

Grid tied systems are presently the most common type of solar application in the United States. They are the least expensive, the least complex, the most efficient, and require the least amount of maintenance. With no expensive and inefficient batteries to deal with, a grid tied system simply draws energy from a solar array to complement power from the grid.
or ideally, sometimes replace it completely. Because they do not include a battery bank, these systems do not provide power during outages. A bi-directional meter is installed that can spin either backwards or forwards. This allows overproduction of energy by a solar array to be sold back to the grid. This “sale” of energy is usually compensated for in terms of credits applied to the overall energy bill. Such a system is comprised of a solar array connected to the grid via an inverter. This system offers great flexibility in size, due to the fact that all energy produced by the array is meant to simply alleviate the burden on the grid system. More recently, metering technologies are being developed that monitor real time use of energy from the grid along with associated costs. These meters can assess the cost of energy at all times, and determine when, at peak times for example, it is most beneficial to sell energy to the grid. Such smart metering technologies will undoubtedly be further developed in the future and should become a part of all successful solar energy systems.

No system

A healthy comparison of systems must also include the option of doing nothing. There are many steps that can be taken to reduce energy consumption in a building that are extremely cost effective and require less material, labor, energy consumption, and cost than installing a PV system. The following measures can be effective energy saving techniques:

**Insulate:** Insulation is quantified using an “R” value, which measures the resistance of thermal transfer. High “R” value (insulating) materials are typically installed in walls and roofs to reduce thermal transfer. Maximizing the resistance to thermal transfer will yield greater efficiencies for heating and cooling, thus reducing energy consumption. Building codes typically dictate a minimum requirement for insulation, but these are by no means a limit. Exceeding these minimum requirements can yield great gains in energy conservation.

**Weather Strip:** All penetrations to a building (windows, doors, utility connections) are typically sealed with weather stripping. Rubber gaskets, foam, and caulking are the most commonly used materials. These are critical in making a building “air tight,” which prevents heat or cold from leaking out, and they should be continuously monitored for effectiveness and maintained to ensure efficiency.

**Replace Appliances with Energy Star Rated Products:** In 1992 the US Environmental Protection Agency (EPA) introduced ENERGY STAR as a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. In 1996 Energy Star partnered with the US Department of Energy to further promote energy efficient products. As stated on the Energy Star website, “Americans, with the help of ENERGY STAR, saved enough energy in 2007 alone to avoid greenhouse gas emissions equivalent to those from 27 million cars — all while saving $16 billion on their utility bills.”

**Replace light bulbs:** Fluorescent light bulbs are superior to incandescent light bulbs for at least three reasons: their life is drastically longer than incandescent bulbs, they have a greater efficiency, and they generate far less heat. The U.S. Department of Energy states: “If every American home replaced just one light bulb with an Energy Star-qualified bulb, we would save enough energy to light more than 3 million homes for a year, more than $600 million in annual energy costs, and prevent greenhouse gases equivalent to the emissions of more than 800,000 cars.”

**Programmable Thermostats:** This is an example of a “smart” product that will automatically adjust building temperatures based on habitual use. Zones may be established so that, for example, less energy will be used to heat an unused family room during the night, or conversely, an unused bedroom during the day.

**Clean Refrigerator Coils:** As noted in Figure 2, the refrigerator consumes about 6% of the average American household’s energy. Cleaning the coils once a year can yield energy savings of up to 6%.

**Close Fireplace Damper:** Thermal transfer through a fireplace can yield great inefficiencies of both heating and cooling. Care should be taken to ensure the damper is always shut when a fireplace is not in use.

**Plant Shade Trees:** In hotter climates especially, trees may provide a wonderful source of shading during hot summer months and drastically reduce energy requirements for cooling. Deciduous trees provide the benefit of shedding their leaves in winter to allow light penetration and desired heat gain.

**Treat Windows:** Windows have an extremely low “R” value: a single glass window pane has a typical “R” value of one, while a double glass pane is rated at about two. Treating or protecting windows can have drastic effects on energy consumption. Exterior shades and curtains may provide small resistance to heat

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Figure 5: PV panels integrated with a building at Solar City Malmo, Sweden
transfer into a building, but given enough time (depending on the size of the room they are servicing) will yield no benefit whatsoever. On the other hand, curtains may provide small gains in the resistance to heated and cooled air leaving a building. Glass treatments such as "low E" coatings (a measure of emissivity) can increase the “R” value of a window pane from one to three. This may not sound like much, but it actually provides a 50% gain in efficiency when compared to an untreated double pane window.

These actions should be considered necessary considerations and maintenance concerns for all buildings, but unfortunately they are not. A conscientious homeowner or building supervisor should make great efforts to ensure that these items are maintained to their full capacity. Whether or not a PV system is installed, all of these items can significantly reduce energy consumption and in turn, associated costs.

**Step 4: PV integration**

This step deals with how a PV system should be integrated with an existing building, site, or new construction. The information in this section will complement the considerations of the Site Analysis section to focus in on an exact location and method of installation. Panel angles and orientation, roof considerations, wall mounts, and free-standing units will be discussed.

**Angle and orientation of PV installation**

Perhaps the most important consideration for the installation of a solar array is the orientation and angle at which the PV panels should be installed. As previously discussed, efficiency of cells varies greatly between types of technology, but within each of these technologies, efficiencies vary to yet another degree based on the inclination and orientation of the solar cells relative to the sun’s rays. In regard to orientation we have already briefly mentioned that panels are most effective when facing toward the equator. Other orientations may be considered, but known inefficiencies will occur. In regard to inclination, a standard rule of thumb is that panels should be installed facing the equator at the same degree of inclination as the panel’s latitude. Austin, Texas, for example, is located at 30° North latitude. A panel in Austin is typically most efficient when placed facing directly South (towards the equator) at 30 degrees from horizontal. This does not mean that other angles of installation should not be considered, but as with orientation, their efficiencies (or inefficiencies) must be understood, as this factor will greatly influence the amount of energy generated by an
array. Figure 6 displays the energy production and cost savings for panels with varying orientations and inclinations in Austin. Such an analysis is critical in understanding the costs and benefits of alternative panel systems.

**Roof considerations**

Due to the fact that most solar arrays are installed on rooftops, this section will discuss bracketing and roof types. Taking the information from the previous section on angle of PV installation, one can now look at an existing or proposed roof with more understanding. For example, consider an asphalt shingle roof pitched at 20° to the south. Would it be easier to install a solar array parallel to the roof at 20°, or should brackets be installed at a 10° pitch to create an overall pitch of 30°? The answer to this question depends on at least four local factors: cost of materials, amount of available surface area, cost of labor, and line of sight to the array. Typically, the easiest and most efficient installation of an array is executed parallel to a roof surface. A gap of at least three inches is needed between the panels and the roof to allow for the circulation of air, which helps to cool the panels, increasing their efficiency. The brackets that are angled are typically more costly than parallel brackets and have at least two additional considerations: increased wind load and shading. Due to strong uplift from winds, most panels are considered to be ballasted down rather than held up. Increasing the pitch of a panel system will most often create a greater potential for uplift and therefore require heavier brackets and more secure mechanical fasteners to attach them to the roof. In this example it will be necessary to verify that the existing roof will be strong enough to withstand such forces. Shading must now be considered as well, because panels in one row of an array may partially block a small portion of sun from hitting the row behind it. The spacing required to prevent this may be a very small distance for panels at 10°, but becomes much more substantial at greater inclinations. In such circumstances more surface area will be required for the array. Labor for the installation of such pitched brackets is typically slightly greater and if the panels are in a critical line of sight their appearance must also be considered. From an aesthetic standpoint solar arrays pitched at different angles than their supporting roof are generally considered to be less harmonious, and thus less attractive, than arrays that run parallel to their supporting roof.

The main consideration regarding the type of roof upon which an array may be installed is how that array might affect the roof’s warranty. Roof manufacturers typically offer a warranty from 10-25 years as long as certain installation conditions are met.

![Figure 8: Solar array installed on flat roof of downtown Austin, Texas](image)

![Figure 9: Wall mounted solar array](image)
and maintenance requirements are upheld. The installation of an array on a roofing system has the potential to nullify this warranty. Standing seam metal roofs are often recommended by energy consultants and installers due to the fact that brackets may be installed on the vertical seams of the roofing system and typically do not violate the roof manufacturers warranty. Standing seam roofs are also intended for pitched roofs and therefore offer a significant incline to support an array. PV systems are often installed on asphalt shingle roofs, but they require many penetrations through the waterproofing membrane and may nullify the manufacturer’s warranty. Many such installations have been done, however, and simply require professional know-how and careful fitting.

The flat roofs of industrial and commercial buildings are prime real estate for solar arrays (Figure 8). It must be understood, however, that more surface area will be required to obtain ideal pitches in latitudes farther from the equator, based on the increased spacing between rows required to avoid panels casting shadows on adjacent panels. Panels may be installed parallel to the roof surface (completely horizontal), but this is not advisable as dirt and dust accumulate more readily and therefore cause these flat panels to require far more routine maintenance than inclined panels. A ballasted bracket system is often used on flat roofs so that no penetrations are made through the roofing system. This avoids nullification of the roof manufacturers warranty and allows for easy panel removal if roof repairs are required.

**Wall mounts**

Vertical surfaces are another viable option for the installation of solar arrays (Figure 9). Such arrays are typically far less efficient than panels installed at ideal angles, but yield gains nonetheless. To gain an understanding of the efficiency of a panel installed at 90 degrees in Austin, Texas, for example, refer to Figure 6 and imagine a plotted parabola even lower than the 60 degree plot; there are gains, but the cost-benefit ratio is markedly lower. Wall mounts are usually applied when no other surface area is available or a statement about solar collecting is intended. The benefit of these statements is hard to evaluate, but often contribute in significant ways to the narrative of conservation and the promotion of renewable energy sources.

**Free standing units**

Free standing units are an option to be considered when no surfaces are available on which to mount an array. Such units are highly visible and therefore careful consideration should be given to location and visibility. They are often used in cases where homeowners or institutions intend to make a deliberate statement about solar collection. One such example may be seen in Figure 10. These units require the added cost of significant structural supports and must address issues of security. Until very recently, theft of solar panels had not been a problem, but as panels become more advanced, their security becomes a greater concern.

The integration of the supporting systems must also be addressed, in addition to the placement of the panels. Battery banks, power inverters, meters, breaker panels, and other items need to be located and integrated with existing or proposed power elements. All power related elements are typically placed near each other in easily accessible areas. Battery packs should be stored in cool, dry places.

**Step 5: Operation**

Once the basics of site analysis, PV selection, PV design, and PV integration have been resolved, the potential user of a solar array
should be well informed to make an educated decision as to what kind of system is most appropriate. It should be well understood, however, that a PV system is not a plug and play application that can be set in motion and forgotten about. In order to ensure the highest level of efficiency, routine maintenance and monitoring should occur. Annual service visits are recommended; power inverters usually need replacement after 15 years, and the panels themselves, if properly maintained, can last more than 25 years. Efficiencies may be increased by monitoring solar collection and consumption compared to the use of grid power. Smart metering technologies can inform users of off peak hours when it is least expensive to run high demand loads such as washers and dryers. Or perhaps someone who typically runs a washing machine at night will change to using it during the peak hours of solar energy collection if a surplus is detected. Many actions can be altered to maximize efficiency. This requires a healthy understanding of the PV system and an appreciation for the fact that the system will only be as efficient as the user demands.

Conclusion

Five steps for PV integration in building have been outlined. As noted previously, these steps are intended as simple guidelines for consideration. Each project demands its own unique adaptation and the potential user of a PV system should take these steps into greater detail based on the specific characteristics of the project. In general, the more research that is done, the greater the opportunity to make prudent decisions and create a successful design. Photovoltaic systems, while not in their infancy, are still being developed and do not fit into universal categories. A potential user will understand this and respond by demanding the most current, local information possible. This information can be used to create a PV system that is appropriate to a specific need, at a specific time, in a specific place.
Notes


Figures

Figure 1: Stefan Gara, lluisanunez, 2008
Figure 2: Meridian Energy Systems, Inc., 2008
Figure 3: Ampair, Microwind, 2008
Figure 4: Meridian Energy Systems, Inc., 2008
Figure 5: Christian Svanes Kolding, 2008
Figure 6-10: Meridian Energy Systems, Inc., 2008
Figure 11: David A G Wilson, 2008
Figure 12: Denise Messle, 2008

Biography

Andrew McCalla is the founder and CEO of Meridian Energy Systems, Inc. Andrew has been involved in the solar industry since 1995, when he joined a photovoltaic distribution company as the head of its international sales and design efforts. After 4 years, Andrew founded Meridian to fill a regional need for high-quality solar electric renewable energy system design and installation. One of two inaugural North American Board of Certified Energy Practitioners Certified Installers in Texas, Andrew has served on the boards of both the Texas Renewable Energy Industry Association and the Texas Solar Energy Society and is a regular presenter at industry events and conferences.