METHODOLOGY FOR ESTIMATING THE ROOFTOP SOLAR FEASIBILITY ON AN URBAN SCALE

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ABSTRACT

With an increasing number of photovoltaic (PV) systems being installed on buildings and the fact that rooftops are being used as a platform for PV installation many building owners are looking at installation of PV on a large scale. To determine which building rooftops have higher potential for PV installation, we have designed a methodology that makes the process faster, easier and reduces the number of site studies. A case study that was conducted by a team at Arizona State University to assess in preparing a solar feasibility study for the City of Phoenix's public buildings is used as an example to describe the process. This methodology can be applied to a city or a campus or any facility with large number of buildings.

1. INTRODUCTION

The rooftops of North America offer an attractive platform to achieve long term energy independence while reducing environmental impact. According to US Census data, the rooftops of the United States alone offer over 200 billion square feet[1] of potential surface area for the installation of PV systems. Assuming only 25% of this area is suitable for unobstructed and continuous PV operation, the total potential installed capacity exceeds 250,000 megawatts[2]. In general, roof-mounted systems are preferred because they require shorter wire runs, reduce land investment, provide better land use, are less vulnerable to vandalism and are often more aesthetically appealing than ground-mounted systems. With an increasing number of PV systems being installed in commercial buildings, clients are looking at installation of PV on a large scale. To determine which building rooftops have higher potential for PV installation from a large number of buildings at an urban scale, we have designed a methodology that makes the process faster, easier and reduces the number of individual site studies.

2. PROJECT BACKGROUND

A study of the solar feasibility for all the city of Phoenix public buildings was done at Arizona State University by a group of 5 students and a faculty member. The study was conducted for 364 city buildings out of which 100 buildings were determined to have rooftops with high potential for solar installation. Of these 100 building, 85 were made available for on-site assessment that accounted for approximately 4,338,000 ft^2 of predominately flat rooftop area. Additional area calculations were performed to determine rooftop obstructions and the amount of spacing needed for optimal collector layout and were subtracted from the above value. Thus, the effective rooftop area available for PV solar systems was determined to be approximately 2,340,500 ft^2.

Arizona's ample amount of solar radiation (see Fig. 1) coupled with a large area of flat and well maintained rooftops creates an opportunity for the City of Phoenix to install a significant amount of PV. Depending on the type of PV system installed, the City of Phoenix could potentially generate 15.58 to 27.71 MWp of electricity. If built out to its potential area the City of Phoenix will have the largest distributed rooftop PV installations of any city in the U.S.

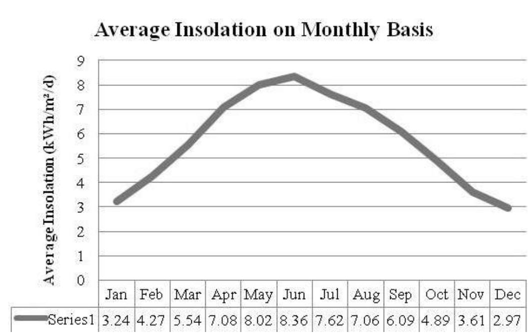


Fig. 1. Monthly average insolation in Phoenix

3. INITIAL ASSESSMENT

The purpose of the study is to identify the valuable solar energy potential of the rooftops of the City of Phoenix public buildings. The study was intended to help the municipal governments to target the opportunities for solar installation quickly, efficiently and economically.

The process commenced by identifying and preparing a list of all the city buildings along with their addresses. The team gathered basic information about the buildings from their specific department websites and filled in the information in a spreadsheet. Subsequently, the city was able to provide a list of city owned buildings to the team. This list was compared with the spreadsheet and buildings were added as necessary, creating a total list of 364 city owned buildings that were analyzed in this study.

The team then performed the initial study of all buildings by acquiring aerial images of the buildings using Google Earth. All the buildings were searched in Google Earth by entering the addresses and the aerial views of buildings were collected. In some instances, Google Earth did not identify the correct location and additional searching was needed to find the correct aerial image. There are some buildings that did not have aerial images available as they were new buildings. In these cases a site visit was necessary to identify the buildings and to take field measurements. Google Earth was also used to take one reference measurement of each building, usually a wall in the aerial view, which was used to scale the image once it was imported into AutoCAD or Sketch-up. This scaling of the image was necessary to get accurate roof square footage from the aerial view. Each team member was responsible for a section of the spreadsheet and the subsequent aerial images and square footage calculations.

Once imported into AutoCAD or Sketch-up, the team highlighted specific areas that could be suitable for solar panel installation. A number of factors were incorporated into the analysis of solar installation including: orientation, roof slope, tree shading, roof equipment, parapet shading, and shading by adjacent buildings. Once each individual team member completed a series of buildings, the team examined each of the buildings as a group to confirm accurate solar highlights. During these meetings the team rated each building. This rating system was based on a 1 to 5 point scale, with a building rated a 5 having the greatest potential and a building rated 1 having the least potential for PV installation (see Fig. 2). These rankings were based on the rooftop area available for PV, the number of obstructions on the roof, type of roof, the angle and orientation of the roof, and the amount of shade present on the roof. The following was used to define a building's rating:

(1) - Least feasible for rooftop PV installation due to excessive shading, small roof area, obstructions etc.

(2) - Less feasible for rooftop PV installation due to factors of building orientation (i.e. north facing sloped roof), roof structure, size, shade causing obstructions

(3) - Somewhat feasible due to slightly larger area available for PV installation, east or west orientation and limited shade causing obstructions

(4) - Quite feasible for rooftop PV installation due to good orientation and limited shading and sound roof structure.

(5) - Ideal for PV installation with maximum usable space, no shade causing obstructions and sound roof structure.

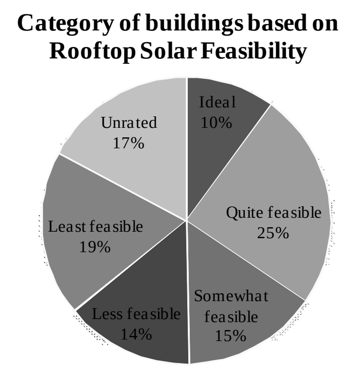


Fig. 2. Chart showing the percentage distribution of buildings rated under each category for their PV potential

The remaining buildings were either not given a rating or were rated 0 due to various reasons such as historic designation, or being leased to other entities, or the site being completely shaded by adjacent buildings.

4. FIELD VISITS

To verify the initial estimation from the aerial image study the team conducted field visits to all the buildings that were rated as 4 and 5 as well. The visits were necessary to confirm roof type and structure, as well as confirming roof obstructions. These visits also aided in the recommendation of specific PV systems for each roof. Often, truss structures are limited by the amount of additional load that they can carry by code, thus requiring the recommendation of a laminate system on those roofs. Other buildings seemed to have an adequate structure to carry heavier loads, and may be able to carry a ballasted PV based system. Our structural assessment was only preliminary and it was suggested that a detailed structural analysis should be done to determine loads that each roof can safely handle before installation.

After the site visits, the team updated the spreadsheet with any changes or observations that were made on site.
In most cases the initial aerial observations proved to be fairly accurate, although there were cases where trees had increased in height, thus shading more roof area, or parapets turned out to be much higher than was apparent from the aerial image. In rare occasions, the aerial image did not make some important issues apparent, such as in the cases of a Library building or the Drivers Training Center building where the roof slope was steeper than estimated. In these cases, the site visit prompted a reduction of the rating initially given to the building. Throughout the survey, the team came across some city structures that were built and designed with a specific aesthetic in mind. For instance, there were certain buildings as in case of one of the fire stations which had a copper colored roof that is visible from the street. Any type of solar panel installation can compromise the building's aesthetics and cause potential negative feedback from the building occupant or the neighborhood.

When determining the suitability of solar installations, unique architectural features, designs and historical context should be respected and considered before installing photovoltaic panels. However, the presence and visibility of panels also present aesthetic considerations, as well as providing a positive public image for the city and should be weighted accordingly. The buildings surveyed that may fall into this category were highlighted in the individual building descriptions in the appendix we provided to the city. Through the initial study and the field visits we could determine the roof attributes like its material, structure, condition, slope, etc. We gathered information about the roof age, roof replacement period, and warranty period from other sources and updated all this information into a database. Based on this information we also suggested which installation system would be most appropriate for that roof type and condition.

5. SYSTEM PERFORMANCE

Based on the total area available for PV on each roof that was derived from the calculations using Google earth and AutoCAD, we estimated the total power production capacity of the roofs of all the buildings rated 4 and 5 for 8 different combinations of PV systems. To determine the peak wattage and annual power production we used the software RET Screen PV[3]. RETScreen PV is a unique decision support tool designed to evaluate the energy production and savings, life-cycle costs, emission reductions and financial viability for various types of renewable energy technologies.

We calculated the peak wattage and annual kWh production for a 100 ft^2 area for three different PV types: thin film/amorphous silicon with 8% efficiency; poly-crystalline silicon with 12% efficiency; and mono-crystalline silicon with 16% efficiency for three different mounting systems; a horizontal laminate system, a ballasted system with 18˚ tilt and a one way tracking system. A peak wattage factor per ft^2 and annual energy production factor per sqft was determined for all system types using RETScreen analysis and was corrected to the area by considering the space required for circulation and the area loss that occurs due to the shading created by each row in case of the system with the tilt or one way tracking (see Table 1).

TABLE 1: PEAK WATTAGE AND ANNUAL kWh PRODUCTION FOR DIFFERENT TYPES OF PV SYSTEMS

Thin film/amorphous	**Fixed 0˚ tilt**	**Fixed 18˚ tilt**	**Single-Axis**
PV array power ($kWp/100ft^2$)	0.666	0.592	x
PV array area (ft^2)	100	100	x
Annual kWh/100 ft^2	1158.3	1120.8	x
Peak kWp/ft^2	0.00666	0.00592	x
kWh/ft^2	11.583	11.208	x
Poly-crystalline	**Fixed 0˚ tilt**	**Fixed 18˚ tilt**	**Single-Axis**
PV array power ($kWp/100ft^2$)	1.008	0.896	0.896
PV array area (ft^2)	100	100	100
Annual $kWh/100ft^2$	1647.9	1591.2	2109.6
Peak kWp/ft^2	0.01008	0.00896	0.00896
kWh/ft^2	16.479	15.912	21.096
Mono-crystalline	**Fixed 0˚ tilt**	**Fixed 18˚ tilt**	**Single-Axis**
PV array power ($kWp/100ft^2$)	1.332	1.184	1.184
PV array area (ft^2)	100	100	100
Annual $kWh/100ft^2$	2178	2102.4	2788
Peak kWp/ft^2	0.01332	0.01184	0.01184
kWh/ft^2.	21.78	21.024	27.88

6. RECOMMENDATIONS

From the study and site visits it was determined that the majority of these rooftops are covered with membrane products. Given this information and the fact that Arizona's low latitude produces ample horizontal solar radiation, it was determined that horizontal or slightly tilted collectors would be most appropriate. In addition, membrane rooftops suggest that ballasted or laminated systems that can be applied directly to those surfaces would be the best type of PV solution. Both types of systems would be light in weight and minimize roof penetrations, which were major concerns voiced by Public Works Department staff. Direct roof mounted ballasted or laminated PV systems have become very popular of late, primarily because of the large number of these systems that have been built and are successfully operating.

RETScreen modeling suggested these ranges for both horizontal and slightly tilted systems under typical Phoenix solar conditions, with performance ranging from peak solar output from 6.66 W/ft^2 to 11.84 W/ft^2. Thus the peak electrical output that could be generated from 2,340,500 square feet of available rooftop would be 15.58 MWp for the low end assumptions and 27.71 MWp for the high end assumptions. Annual energy produced would be 27,110,400 kWh for the low end assumptions and 49,207,300 kWh for the high end assumptions. The 15 buildings that we determined to have solar potential for which we could not perform an on-site rooftop assessment could potentially add another 1.7 to 3.84 MWp to the above estimate. Parking areas that exist adjacent to many of the buildings surveyed were not included in this study, but we estimate could potentially generate an additional 13 to 23 MWp of electricity.

Supply and availability of PV product have made PV cost extremely difficult to determine. Historically PV cost has been steadily decreasing; however, recent oversupply of product has led to a very rapid decrease in prices in the last year. It is difficult to predict if this trend will continue. The cost estimates that were used for this study were generated by the RETScreen PV software. It was reviewed by several individuals who were knowledgeable in this area and were determined to be within the high side of the acceptable range. The installed cost of low end approach would be approximately $140,000,000 while the high end approach would be approximately $230,000,000. These costs could potentially be reduced because of the scale of this project with strategies like bulk purchasing, available utility incentives and innovative financing strategies.

7. QUERYING THE DATABASE

There are 85 buildings assessed to have a good potential for solar installation (rated 4 and 5 on a scale of 5) on their rooftops. All the details of each building such as its roof material, roof condition, area available for PV, age, warranty, etc. of are entered in an electronic database and submitted to the City of Phoenix. In order to prioritize the buildings or to decide on which roofs to have the solar panels installed in each phase, one can query the database by sorting the list by the increasing or decreasing order of any chosen column. For example "the rooftop area available for PV" for each building can be sorted from largest to the smallest or from the smallest to the largest by selecting from the down arrow button found on first row of every column as shown in Fig. 3.

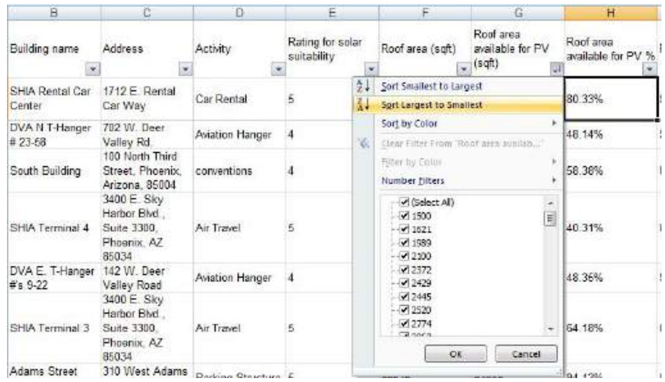


Fig. 3. Screenshot illustrating how the database can be queried.

Then one can view the data sorted in either ascending or descending order based on one's criteria. The similar sorting approach can be applied for any column. By using this method of querying the database one can categorize the buildings into phases for PV installation after studying the rest of the attributes of each building by age, roof type, etc. One can also decide about which type of PV system and installation type to opt for on a particular building based on its PV output data for different types of systems. An appendix with all the information related to all the 85 buildings with its respective photographs and roof images highlighted with the area available for PV in yellow color was provided to the city authorities in the form of a report accompanied by the electronic spreadsheet.

Newly created funding made available by the American Recovery and Reinvestment Act, as well as innovative financing mechanisms, allows the City of Phoenix to partner with energy financing institutions that can eliminate up-front capital expenses for the installation of the actual PV system. The City of Phoenix needs to carefully review these options and if determined to be appropriate, begin to structure a series of RFQ's that would highlight the opportunities present in Phoenix, which would attract proposals from the country's best energy financing institutions. This study has played an important role in helping the city of Phoenix to prepare such documents. Some design guidelines were also suggested to be considered while designing all the city buildings in the future to make the roofs solar ready for the future installation of the PV system at no additional cost.

8. <u>EXAMPLE SHOWING THE PROCESS FOR ESTIMATION OF ROOFTOP PV POTENTIAL</u>

Step 1: Find the aerial image of the building in Google Earth

Step 2: Eyeball the aerial image for initial estimation of the PV potential based on orientation, slope, obstructions etc.

Step 3: Determine one dimension of the building in Google Earth by using the scale tool.

Step 4: Scale the aerial image in drawing software with reference of a measurement and determine the roof area.

Step 5: Highlight the area suitable for PV on the rooftop in color and determine what would be the most suitable PV system for that building based on all the information available.

Link To File	Address	Activity	Notes	Suitability	Roof Area	Roof Area	Roof Area
Station 1	323 N. 4th	Fire Suppression	Small area.	3	13900	3066	22.06%
Station 3	1257 W. Pierce	Fire Suppression		4	8957	4200	46.89%
Station 4	1601 N. 3rd	Fire Suppression	Roof in poor	4	7822	3720	47.56%
Station 5	1840 E.	Fire Suppression	Roof in poor	4	6121	4221	68.96%
Station 6	368 W. Apache	Fire Suppression		2	5670	3900	68.78%
Station 7	403 E. Hatcher	Fire Suppression	Needs new	4 if new	5325	3371	63.31%
Station 8	1025 E. Polk	Fire Suppression		4	12150	5622	46.27%
Station 9	330 E. Fairmont	Fire Suppression		4	11400	6577	57.69%
Station 10	2731 N. 24th	Fire Suppression	Potential	4	7574	4500	59.41%

Step 6: Fill in all the estimated information into a database.

Step 7: Take a field trip to verify the estimated information from aerial image study and take a few photographs. Identify any other issues that couldn't be determined from the aerial image study.

Roof Area	Roof Area	Roof Structure	Roof	Roof Condition
3066	22.06%	Steel Beam	Standing Seam	Good
4200	46.89%	Steel Beam	Urethane/Standin	Good
3720	47.56%	Metal truss	Tar Paper w/	Fair/Poor
4221	68.96%	Glue lams	Urethane/Standin	Fair
3900	68.78%	Truss	Standing Seam	Unkn
3371	63.31%	Glue lams	Standing Seam	poor/ good
5622	46.27%	Steel Beam	Urethane/Standin	Very good
6577	57.69%	Steel Beam	Tar Paper w/	Very good
4500	59.41%	Steel Beam	Urethane/Standin	Good

Step 8: Gather information about the age of the roof, roof replacement period, and warranty period from other sources and update the information into the database

Recommended installation (Ballasted/Laminated)	Peak kWp A-Si 0° tilt	Annual kwh A-Si 0° tilt	Peak kWp A-Si 18° tilt	Annual kwh A-Si 18° tilt
Laminate	785.85	1366747.67	696.54	1322499.17
Laminate	368.18	640331.41	327.27	619600.66
Laminate	=G61*0.00666	3307178.16	1690.28	3200108.16
Laminate	498.39	866790.64	443.01	838728.26
Laminate	442.24	769134.37	393.10	744233.62

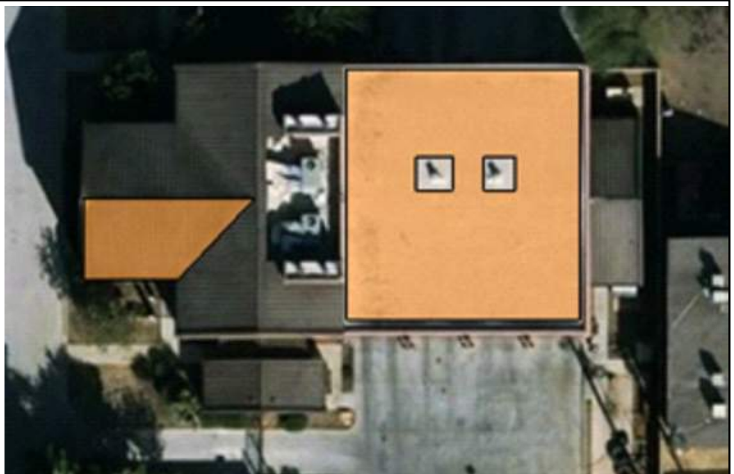
Step 9: Estimate the total photovoltaic output potential for each building for 8 combinations of PV systems

Building name	Address	Activity	Rating for solar suitability	Roof area (sqft)	Roof area available for PV (sqft)	Roof area available for PV
SHIA Rental Car Center	1712 E. Rental Car Way	Car Rental	5	723023	580785	80.33%
DVA N T-Hanger # 23-58	702 W. Deer Valley Rd.	Aviation Hanger	4	593100	285520	48.14%
South Building	100 North Third Street, Phoenix, Arizona, 85004	conventions	4	273950	159921	58.38%
SHIA Terminal 4	3400 E. Sky Harbor Blvd., Suite 3300, Phoenix, AZ 85034	Air Travel	5	367621	148180	40.31%
DVA E. T-Hanger #s 9-22	142 W. Deer Valley Road	Aviation Hanger	4	244037	117996	48.35%

Step 10: Querying the database in order to prioritize the buildings for PV installation.

TABLE 2: INFORMATION OF THE FIRE STATION BUILDING AND THE SOLAR OUTPUT POTENTIAL OF THE BUILDING FOR PV DIFFERENT SYSTEMS

Building category	Fire Station
Building name	Station 3
Address	1257 W. Pierce Street, Phoenix, AZ 85007-2348
Activity	Fire Suppression & Prevention
Rating-solar suitability(1-5)	4
Roof area (sqft)	8957
Roof area available for PV (sqft)	4200
Roof area available for PV%	46.89%
Roof structure	Steel Beam
Roof construction	Urethane/Standing Seam
Roof condition	Good
Roof age	Urethane 2004
Roof warranty	Urethane 2014
Roof replacement period	Unknown
Recommended installation (Ballasted/Laminated)	Ballast/Laminate
Peak kWp A-Si 0° tilt	27.97
Annual kwh A-Si 0° tilt	48648.60
Peak kWp A-Si 18° tilt	24.86
Annual kwh A-Si 18° tilt	47073.60
Peak kWp P-Si 0° tilt	42.34
Annual kwh P-Si 0° tilt	69211.80
Peak kWp P-Si 18° tilt	37.63
Annual kwh P-Si 18° tilt	66830.40
Peak kWp P-Si 1waytrack	28.22
Annual kwh P-Si 1waytrack	66452.40
Peak kWp M-Si 0° tilt	55.94
Annual kwh M-Si 0° tilt	91476.00
Peak kWp M-Si 18° tilt	49.73
Annual kwh M-Si 18° tilt	88300.80
Peak kWp M-Si 1way track	37.30
Annual kwh M-Si 1waytrack	87822.00



Google earth image with the available roof area for PV panels marked out

Photograph of the flat roof area showing the obstructions of the Fire Station building

Photograph of the sloped roof area of the Fire Station building.

9. CONCLUSION

This study demonstrates the significant potential that exists for harnessing solar energy and producing electricity from the building rooftops. By executing this project, the City of Phoenix will set an example to cities across the country as to the environmental and financial benefits of solar energy and how to tap solar energy utilizing building rooftops that are otherwise idle.

The initial assessments were based on a site review and preliminary calculations. A more detailed analysis of the structures and electrical system is needed prior to installation. The methodology outlined above can be applied to any large scale rooftop solar applications such as those owned by cities or clients with a large number of buildings.

10. ACKNOWLEDGMENTS

We would like to thank Mr. Dimitrios Laloudakis, senior administrator at the City of Phoenix's Public Works Department for his help in providing the needed information about the city buildings and for arranging the site visits. We would also like to thank Andrew Krause and Tim Gordon for their help on this project.

11. REFERENCES

(1) J.L. Hoff, "The Expanding Role of the Roof in a Sustainable World" CONSTRUCT 2009 Convention, Indianapolis, Indiana (2009)
(2) Assumes an average 5 watt peak solar power production per square foot of suitable roof surface (200 billion square feet total roof surface x 25% suitable usage factor x 5 watt /square foot)
(3) "www.retscreen.net/download.php/ang/66/0/PV3.pdf" [retrieved 3 March 2010]