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Evaluation Of Photovoltaic Building Integration And Optimization Of Tilt Angles In Riyadh City Hot Dry Climate

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***Abstract*—This paper explores the potential of building integrated photovoltaic in Riyadh city. It quantifies the available solar power through a comparison of two sources of solar energy measurements. Best integration strategies are discussed as well as an optimization to the tilt angle of the solar panel in Riyadh is investigated. An appraisal of the current advancement in PV technologies is carried out, with special reference to their suitability for integration within the environmental setting of the city. Manual seasonal adjustment of tilt angles of the photovoltaic panels is calculates through simple equations that can be handy for designers where access for more sophisticated tools is limited. Optimum tilt angles would be due South at 48.1 degrees from horizontal level in the winter solstice, while it should be 1.1 degrees from the horizontal level in the summer Solstice. In both equinoxes the tilt angle should be 24.6 degrees from the horizontal level. Results are compared with available software results.**

Keywords: Building integrated photovoltaic, tilt angle optimization, solar energy, Photovoltaic

1. Introduction:

High efficiencies of concentrated photovoltaic cells have been reported for multiple junctions lately by German Fraunhofer Institute for Solar Energy Systems3, Soitec, CEA-Leti and the Helmholtz Centre with efficiency of 44.7% last September 2013.

Riyadh city (Latitude 24.6° North and Longitude 46.7° East) is characterized by its hot desert climate according to Koppen World climate classification which is extremely hot in summer approaching 50 °C sometimes. The average high temperature in July is 44 °C (111 °F). Winters are warm with cold, windy nights. The overall climate is arid, and the city experiences very little rainfall, especially in summer, but receives a fair amount of rain in March and April. It is also known to have many dust storms. The dust is often so thick that visibility is under 10 m.

However, the Sun shines most of the year with clear skies during hot summer months, with maximum direct radiation reaching 1066.19 W/m2, according to King Abdel Aziz's solar village. Maximum total/culminative radiation is 4 to 6 folds of this figure. Even in dusty storm or cloudy conditions, the solar radiation received is high above 700 W/m2. These conditions render the city with high potential for solar energy harnessing for all types of solar collectors especially solar Photovoltaic PV.

Solar photovoltaic PV are cells that produce electricity from direct conversion of sun light by means of specially fabricated semi-conductors forming positive (top) and negative (bottom) sides of a single cell. When light falls on the top side it releases electrons that is encouraged to move to the other side being of a different type and hence an electric current would flowi

Major solar photovoltaic PV Types are Monocrystalline, Polycrystalline and Amorphous cells. The first being the most efficient with efficiency ranging from 15-25% and the latter two types the efficiency ranges from 14-172.

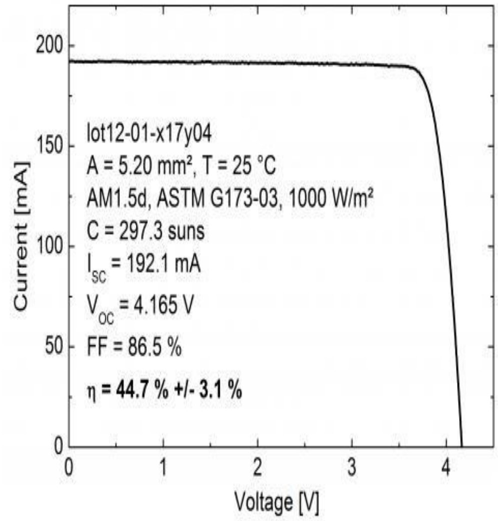

Figure 1. IV-characteristic for the current best four-junction solar cell under AM1.5d ASTM G173-03 spectrum at a concentration of 297 suns. The measurements were carried out at the Fraunhofer ISE CalLab. Credit: Fraunhofer ISE.

Although these cells are still under research and not available on the market now, concentrated photovoltaic in the market nowadays can produce up to 25% efficiencies. All types of photovoltaic PV cells are suited to Riyadh climate. However, Monocrystalline are more susceptible to loss of efficiency with high temperatures4, unless a mechanism for cooling is in place. Dust storms may provide a natural cooling, however, it may necessitate daily cleaning to shed away sand depress.

No doubt that higher efficiency cells would generate more energy at lower costs, limited area for the panels and better investment or payback returns. Nevertheless, in practice the efficiency of the whole system or performance rating is the main issue. Since the other parts of the system are necessary to be able to make use properly of the PV generated energy. Typical system efficiencies are between 85-90% of the cell's efficiency. Power generated can be calculated by multiplying incident radiation to PV panel size (area) by system efficiency, as shown in figure 2.

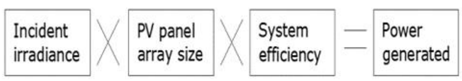

Figure 2. Estimation of PV power generation.

Asowata O. et al 20145, tested several PV outputs at latitude 26 degrees on orientation of 0degrees north ±15 with tilt angle of 36 degrees. He concluded that the tilt angle and orientation angles are the main determinants for higher PV output. On the other hand, Ghazi, S. and IP Kenneth6, studied the effect of weather conditions on the efficiency of PV panels in lab tests and found that fine particles can reduce light transmittance up to 11%.

2. Methodology:

The approach adopted in this paper examines the actually measured solar radiation in Riyadh city (obtained from King Abdel Aziz Solar Village, section 5). Then comparing the information with to that obtained from one of the climate database for Riyadh city available in one of building simulation software (ECOTECT) to establish accuracy of the software in estimating the amount of radiation received by a collector throughout the year. The second step is to undertake an optimization study to investigate solar collectors tilt angles to receive maximum available direct solar radiation at critical sun positions during the year. Namely winter, spring, autumn and summer solstices.

Many researcher such as Liu BYH, Jordan7 RC 1963 has studied estimations for the available solar radiation at any specific location. They studied the inter-relation and characteristics distribution of direct, diffuse and total radiation in the isotropic sky model later refined by Duffie and Beckman8. In which they converted the values of solar radiation on a horizontal plane into values of solar radiation on a tilted plane (tilt of 24◦).

Ian Richardson and Murray Thomson9, 2012, presented an integrated model that provides data at a one-minute time resolution for solar radiation used to estimate Photovoltaic generation in relation to demand and available total solar radiation in a given location but for a single run. When performed for Riyadh city yielded 1039.25 W/m2.

3. Optimizing solar incidence angles for energy harnessing:

Ostensibly, direct solar radiation would be at its highest magnitude if it falls perpendicular to a receiving surface. This means that the angle of incidence is zero. (Angle of incidence is the angle between the incident rays and the normal at the point of incidence) In this situation, the entire solar radiation falls on the receiving surface. When radiation is falling at an inclination to a surface, its share of radiation diminishes by a factor equals to Cosine (the incidence angle). Therefore tracking the sun movement to maintain radiation normal to a receiving surface would be the most successful way to achieve the highest incident radiation. However, the tracking process may need sophisticated algorisms, maintenance to moving parts and limited size of receiving surface to allow mobility. When the tracking device is building mounted, it has to be installed where it should be able to perform the tracking, predominantly on top of buildings, or louvers in facades. A cheaper alternative to tracking is seasonal adjustments to the receiving surfaces. Where the tilt angle of the receiving surface adjusted for summer solstice and winter Solstice. Namely 21st of June for the former and 21st of December for the latter. In addition to Equinoxes 21st of March and September.

For the City of Riyadh (24.6° Latitude 46.7°)

Sun inclination in equinoxes 21st of both March and September would be at (90-Latitude),

Which is 90°-24.6° = 65.4°

Sun inclination in Summer Solstice would be 65.4°+23.5° = 88.9°

Therefore according to figure 3, the Optimum tilt angle of the receiving surface would be:

90-Sun Inclination = 90°- 88.9° = 1.1°

Otherwise, adjusting the receiving surface for Summer Solstice will be:

At 21st June, (Latitude -23.5°) = 24.6° - 23.5° =1.1°

Adjusting the receiving surface for winter Solstice will be:

At 21st December, (Latitude+-23.5°) = 24.6° +23.5° =48.1°

Otherwise according to figure 1, = 90-Sun Inclination

Sun inclination in winter =90°- 24.6°- 23.5° = 41.9°

Therefore the Optimum tilt angle of the receiving surface should be adjusted in winter would be = 90°- 41.9° = 48.1°

Optimum tilt angle for the receiving surface in equinoxes 21st of both March and September would be:

90°- 65.4 °= 24.6° (which is the same angle of the latitude).

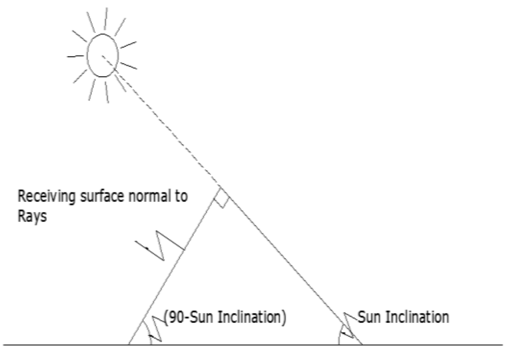

Figure 3. Sun Inclination angle and its relation with receiving surface tilt angle.

This issue of angle of solar rays' incidence on Photovoltaic panels is more critical than in any other types of solar collectors. As thermal solar collectors can still absorb solar energy with the right colours of the collectors with little or no significance influence of losses due to incidence angles. With photovoltaic panels the more the solar rays are perpendicular to the panel the more energy yield and the less losses due to reflection of the panel's surface. The more the solar rays are inclined on the Photovoltaic panel the more the losses due to reflection.

Reflection losses can be reduced by proper tilting or tracking as discussed above or by using antireflection quoting which adds to the cost of the panels. Anti-reflection10 can reduce from 100-70% of reflection, however, zero percentage of reflection is possible only for light waves lengths of 0.6 microns.

4. Solar Energy Estimation for Riyadh City:

Table 1. Average Maximum Monthly radiation on horizontal surfaces in Riyadh.

Av. Max w/ m2)	Measured 2010	Measured 2003	ECOTECT-Simulated
JAN	744.55	716.13	720
FEB	841.94	786.71	721
MAR	952.53	930.15	811
APR	953.5	990.05	991
MAY	965.46	1033.82	1064.88
JUN	1022.93	1060.95	1035.2
JUL	1054.92	1066.19	1038.56
AUG	1059.59	1023.98	1001
SEP	1040.92	1004.69	965
OCT	928.69	901.61	811
NOV	827.65	743.2	810
DEC	751.17	647.15	720
Yearly Av.	928.6541667	908.7191667	890.72

The available solar insolation on a horizontal surface in Riyadh obtained from measurement performed by King Abdel Aziz Solar Village presented in table 1. The Data received from the Solar Village contains average maximum monthly radiation for two years, 2003 and 2010. On the other hand, the building simulation software ECOTECT11 has a built in Climatic data for Riyadh city on its bases solar incidence on horizontal surfaces can be estimated. The average maximum monthly radiation on horizontal surface in Riyadh is therefore calculated. Comparison of the Solar village measurements in Riyadh with that simulated using ECOTECT software for building simulations reveals that agreement is evident as in figure 4.

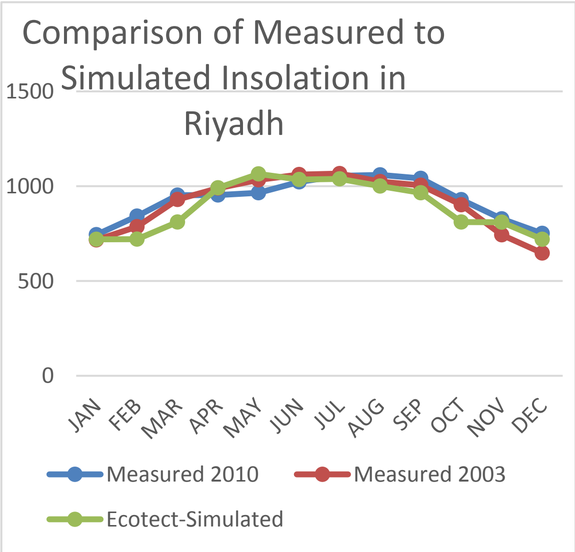

Figure 4. Comparison between measure and simulated insolation in Riyadh in W/m2

Yearly average radiation throughout the year calculated by averaging the monthly values throughout months of the year for both the measured and simulated radiation values. The deviation of the simulated from measured data is presented in table 2, and it mounted from 1.98% to 4.08%. This gives an accuracy for the simulated values of 98.02% to 95.92% respectively.

Table 2 Deviation and accuracy estimation for average yearly irradiance

	Yearly Av.	Deviation	Accuracy
Measured 2010	928.65	-4.08%	95.92 %
Measured 2003	908 .72	-1.98%	98.02 %
ECOTEC T-Simulated	890 .72	0	100

5. Simulation of Incidence Insolation on receiving surfaces at different tilt angles:

An investigation into the amount of irradiance received by a solar collector as it increases its tilt angle is performed at winter and summer solstices to deduce the optimum tilt angles for harnessing solar energy in Riyadh City.

5.1. Firstly Winter Solar Solstice tilt angles:

Figure 5, reveals the resulting solar insolation on a receiving surface as it increases its tilt from 10 degrees up to 80 degrees in Riyadh. The estimated Mean Culminative (total) Irradiance, Mean Peak and Mean direct Peak radiation in Watts per hour are simulated using ECOTECT building simulation software.

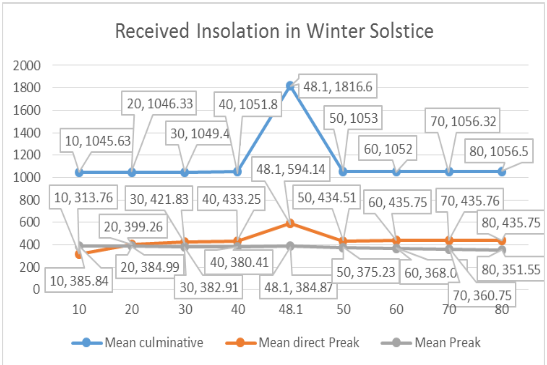

Figure 5. Simulated received radiation at different tilt angles in winter solstice.

Steady radiation levels are estimated in all the studied angles of incidence for the mean culminative radiation at just above 1000 W/h for the majority of the tilt angles except at angle of 48.1 degrees were a spike in radiation is reported about 1800 W/h. This spike is a result of the tilt angle 48.1 degrees being at normal to the Sunrays in winter Solstice in Riyadh. Therefore provides a further validation to the calculated optimum angle of tilt in Riyadh for Winter solstice calculated in earlier in section 3. Mean direct Peak radiation and mean peak radiation explicit the same trend as the mean culminative radiation, however, the spike at the tilt angle of 48.1 degrees is less pronounced.

5.2. Secondly Summer Solstice tilt angles:

When examining the effect of altering tilt angles for the receiving surface we find a slightly different story in summer than in winter. Although, the general trend is that there is a single peak value for received irradiance happening on tilt angle of 1.1 degrees. This also support the optimization performed in section 4, as that witnessed in winter solstice. However, as figure 6 shows increasing the tilt angle further from 1.1 resulted in a decline in the received irradiance. Nevertheless, in a way different from that in winter solstice. The decline of irradiance is more of a cyclic nature with local peaks points between lower points. In winter solstice, it was more of a uniform radiation with a single major peak.

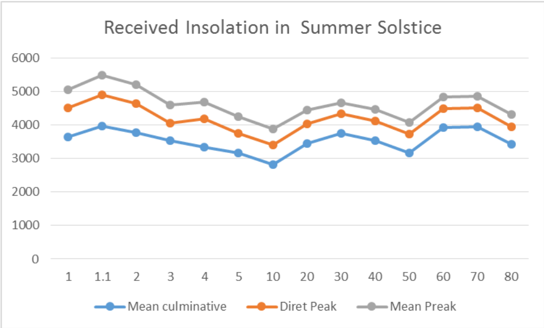

Figure 6. Simulated received radiation at different tilt angles in summer solstice.

5.3. Estimated losses of Solar Radiation due to Tilt angles in Riyadh City:

As explained in point 4 above that maximum solar rays harnessing is attained when they are normal on the receiving surface. One way of achieving this is through optimized tilt angle/s. Major loses of not achieving the right tilt angle would come from solar rays reflected off surfaces when they fall at oblique angles. An estimation to reflection losses off the PV surface as its tilt angle increase from 1 degree over the horizontal up to 12 degrees consecutively is illustrated in figure 7. Tilt angles are further increased by a step of 10 degrees from 20 up to 90 degrees.

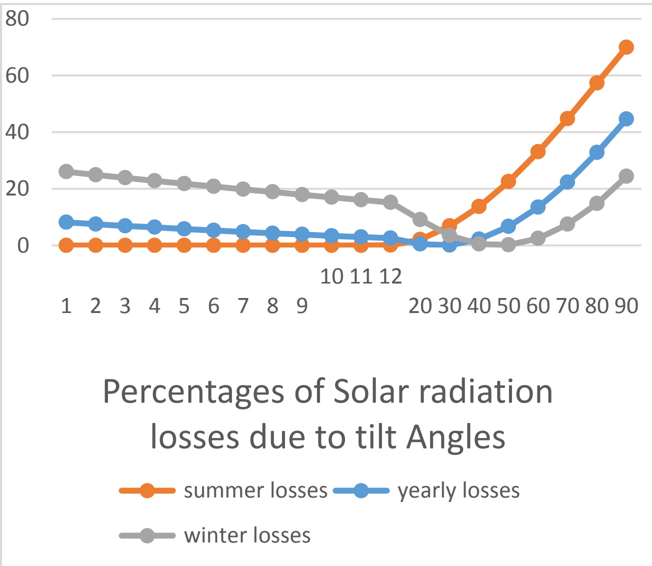

Figure 7. Radiation Losses due to tilt angles change in Riyadh city.

This estimation is made by employing the commercial software PVSYST, V.6.3.212 the percentage of reflected solar radiation is calculated as the tilt angle s incrementally increases as mentioned above in three scenarios, winter, summer and Whole year as shown in figure 7.

We find that summer losses are around zero percent from tilt angle 1 up to 11 degrees, but increases gradually beyond that. The fact that coincides with the findings of tilt angle optimization for summer above. Winter time loses also becomes Zero percent at tilt angle from 45-49 degrees in figure 7. Whereas, in calculations of optimum tilt angle winter time it was 48.1 degrees. This also comes as a further re-assurance to the above mentioned optimization.

6. Building integrated Photovoltaic is Riyadh context:

From the collected data above for Riyadh city it is clear that the first strategy to integrate Photovoltaic would be to cater for climatic conditions/possibilities. We find that summertime roofs of buildings would be more susceptible to high direct solar radiation. Whereas, wintertime southern facades would have a comparable advantage to that of roofs over other sides of buildings. Therefore, for BIPV these two sides would be more commended in Riyadh city. Regarding weather conditions, roof BIPV witness dry conditions with some dusty storms that can reduce the amount of radiation receivable on flat surfaces. The fact that may necessitate regular cleaning. Wintertime would have more precipitations therefore, roofs and south facades may have better radiation reception apart from overcast conditions.

The Second strategy would be for building types. Although we can't discriminate building uses with regards to their suitability to integrate Solar power generation and use. But there is a clear advantages for tall buildings compared to low rise ones, no matter what's the activities in side them may be. Tall building would have more areas on their facades that can be used to integrate PV. This is either in horizontal or vertical shading devices, curtain walls, windows and fascia's. Table 3 below lists possible building components and their potential to integrate PV systems. A good example in this regard is Pearl's river tall building in Guangzhou, China. However, fixed tilt angles are not employed but rather panels run in a solar tracker algorithm. In addition to this,

Atriums of various types can be the place where PV can be integrated, which can further assist the visual, lighting and comfort levels inside atria's. Obviously atriums in Tall and Supper tall building can be up to 10-storey height or more, which can enhance stack effect displacement cooling/ventilation.

Table 3: Prospects of PV integration into buildings

Position of PVs	system	Characteristics
Vertical wall	Curtain wall	Standard, economical construction. PVs can be introduced as opaque and semi-transparent.
Vertical wall	Rain screen cladding	Rain screen designs include ventilation gabs which can be used to reduce heat built up and run wiring or cables.
Wallwith inclined PVs	Glazing or rain screen cladding.	PV efficiency improved. Complexity of construction increased. Potential to provide shading for window (if required), but a degree of self-shading.
Inclined wall	Glazing	Potentially enhanced architectural interest. PV output increased compared to vertical walls. Less efficient use of floor area.
Fixed shading devices	Glazing	Can enhance architectural interest entails a loss of daylight.
Moveable shading devices	Glazing	Can enhance architectural interest entails some loss of light but less than fixed shading devices. Increased PV output compared with all fixed systems.

7. Conclusion:

Riyadh city climate has potential for solar powered collectors especially Photovoltaics with over 1066w/m2 direct incident radiation. Total components of radiation can be 4-6 folds this figure, however, this study is based on direct incident radiation for its high intensity and predictability.

Tall buildings have more potential for integrating photovoltaic in their facades, roofs and other individual components such as atriums, louvers, curtain walling and windows.

Manual seasonal adjustment of tilt angles of the photovoltaic panels would be due South at 48.1 degrees from horizontal level in the winter solstice, while it should be 1.1 degrees from the horizontal level in the summer Solstice. In both equinoxes the tilt angle should be 24.6 degrees from the horizontal level. While this optimization is performed for Riyadh City, the same process can be replicated in any given location. The energy gained by such a process can be incremental and would be significant for large areas of PV. Both ECOTECT and PVSYST are design software that optimize the design and inclination with good precision.

Acknowledgement

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