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Loss In Efficiency Of Solar Collectors Due To Inclination Angle

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***Abstract*—Solar technologies for hot water production in residential buildings today constitute the widest spread and the highest rate of development among renewable energy technologies. Use of the sun's energy for hot water production depends on the region, the type of solar collector and application used and on the type of system operation. Inclination angle of a solar system with horizon is another important parameter influencing the efficiency of solar energy intake. Focus of our study is calculation of loss in solar energy intake if the solar collector is settled at a fixed inclination angle, equal to the optimal angle, compared with energy intake in the case of monthly change of inclination angle in the city of Vlora. At first, solar energy values were obtained for each month, taking the maximum angle of the respective month, while for the whole year, the amount of energy was calculated for the 32.5° angle value. Annual energy intake for every square meter of solar system in case of monthly change of inclination angle is 1959,82kWh/m^2 compared with 1868,8 kWh/m^2 in case of fixed inclination angle or 4.88% more.**

Keywords—solar collector, solar energy, inclination angle, loss in efficiency

I. INTRODUCTION

Use of renewable energies is grown rapidly all around the world, bringing consequently emerge of new markets for both centralized and distributed renewable energy. The improving cost-competitiveness of renewable technologies, policy initiatives, better access to financing, energy security and environmental concerns, growing demand for energy in developing and emerging economies, and the need for access to modern energy are the advantages of renewable energy sources. In the New Policies Scenario, global energy needs will expand by 30% between today and 2040 **[1].** Solar energy nowadays is the most diverse and effective among renewable energies. It is used worldwide and is increasingly popular for generating electricity or heating and desalinating water **[2].** Solar water heating technology is one of the most useful applications of solar energy all around the word including Albania **[3].** The installed capacity of solar collectors at the end of 2018 worldwide exceeded 480 GWth. Consumption of the renewable energy is predicted to achieve 42% of total energy consumption in 2030 **[4].**

In our country solar energy has been used mainly for production of thermal energy by solar collectors. Solar collectors' technology used in Albania is dominated by glazed flat - plate solar collectors with the total area of 282,703 m^2, compared with only 11,262 m^{2}of evacuated tube solar collectors by the end of 2020 **[5].** Flat plate solar collectors are actually the best financial option **[6].** Efficiency of a solar system is related to the technology of solar collector used but to the solar energy amount too **[7].**

The quantity of energy intake by a solar collector at a specific area is related on the of the sun's energy that reaches in it, inclination's angle and the solar collector's orientation. In this paper we have calculated loss in solar energy intake if the solar collector is settled at a fixed inclination angle, equal to the optimal angle, compared with energy intake in the case of monthly change of inclination angle in the city of Vlora.

an important impact on the possibility of practical use of this potential.

A solar collector of sufficient installed thermal capacity or active area to cover daily needs for hot water, due to uneven distribution of daily, monthly or yearly potential of solar energy in a given region, can results in certain periods insufficient to cover the needs. In this case, an alternative source of energy is needed to supply energy. In case of Albania, the only alternative source of energy is the electrical energy from central grid. This study we have estimated amount and added cost of electrical energy needed to assure e normal daily supply of hot water through the year in an apartment house for a normal family of four persons situated in the city of Tirana.

II. MATERIALS AND METHOD

Focus of our study is calculation of loss in solar energy intake if the solar collector is settled at a fixed inclination angle, equal to the optimal angle, compared with energy intake in the case of monthly change of inclination angle in the city of Vlora. Meteorological data were taken from NASA surface meteorology and solar energy for operation of software RetScreen expert, even though they are overestimated compared to the ground measured data **[8].** But there are a lot of factors, such as measurement uncertain-ties, operational uncertainties, or data gaps for ground site data sets that makes the difference between these two data

sources less significant. In 1989, the World Climate Research Pro-gram estimated that most routine-operation ground sites had "end-to-end" uncertainties from 6 to 12%

It is commonly suggested, in lack of accurate data for yearly distribution of solar insolation for a specific site, that a solar collector should be tilt at an angle equal to the geographical latitude of that region.

III. RESULTS AND DISCUSSION

A. Optimal inclination of solar collector for the city of Vlora

Albania is one of the most susceptible to climate change among the other countries of the European South East part, corresponding to seasonal and regional variation. Our country has a high potential of solar radiation more than 1500 kWh/m^2 per year. Many regions receive up to 7.63 kWh/d of solar energy: Agjensia Kombetare e Energjise(2020).

The energy intake at a specific area and at a certain month is depending on the solar insolation, as well as on the inclination angle of the solar collector. This is In kWh per day.

The angle of the azimuth, for the northern hemisphere where Albania is positioned, is suggested 0 degree, so the collector plan was set facing the south.

During our study firstly we have defined the optimal inclination angle of the solar collector for Vlora city and then we calculated energy yield from each square meter of solar collector for different angles of inclination with horizon, for a fix position of solar collector orientation facing south

why using long term horizontal data of solar energy provided by NASA, we estimated the value of solar energy reaching each day in one square meter of active surface of solar system with change of inclination with horizon. Calculations are made for each month separately.

Table 1 and Table 2 present the estimations of average of solar energy receiving each day in one square meter ofactive surface of solar system with change of inclination angle with horizon separately for each month of the year and also annual mean values for city of Vlora. Inclination angles of solar system were changed from 0 to 180 degrees with a step of 5 degrees while azimuth angle remained unchanged, 0 degrees facing south.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Tilt angle(°)	***Insolation (kWh/m²/d)***												
0	1,99	2,85	4,2	5,24	6,55	7,57	7,66	6,62	5,08	3,44	2,12	1,6	4,59
5	2,22	3,08	4,11	5,37	6,61	7,59	7,7	6,74	5,29	3,68	2,33	1,78	4.74
10	2,43	3,28	4,59	5,47	6,63	7,56	7,7	6,83	5.48	3,89	2.53	1,96	4,87
15	2,63	3,48	4,75	5,54	6,61	7,49	7,65	6,88	5,63	4,08	2,72	2,12	4,97
20	2,82	3,65	4,88	5,58	6,56	7,38	7,56	6,9	5,75	4,25	2,89	2.27	5,05
25	2,98	3,79	4,98	5,59	6,49	7,24	7,44	6,88	5,83	4,4	3,04	2,41	5,1
30	3,13	3,92	5,06	5,56	6,38	7,07	7,29	6,82	5,88	4,52	3,18	2,53	5,12
35	3,26	4,02	5,1	5,51	6,24	6,87	7,09	6,72	5,9	4,61	3,3	2,64	5.11
40	3,37	4,1	5,12	5,43	6.06	6,62	6,86	6,58	5,88	4,68	3,39	2,73	5,07
45	3,46	4,16	5,1	5,32	5,85	6,34	6,59	6,41	5,83	4,71	3,47	2,81	5,01
50	3,53	4,18	5,06	5,18	5,61	6,03	6,28	6,2	5,74	4,72	3,52	2,87	4,91
55	3.58	4,19	4,98	5,01	5,34	5,68	5,94	5,95	5,62	4,7	3,55	2,91	4,79
60	3,6	4,16	4,88	4,81	5,04	5,33	5,57	5,67	5,47	4,65	3,56	2,93	4,64
65	3,6	4,12	4,75	4,59	4,74	4,96	5,2	5,36	5,28	4,58	3,55	2,93	4,47
70	3,58	4,04	4,6	4,35	4,42	4,57	4,81	5,02	5,07	4,47	3,52	2,92	4,28
75	3,53	3,95	4,41	4,08	4,08	4,16	4,39	4,68	4,83	4,34	3,46	2,89	4,07
80	3,46	3,82	4,21	3,8	3,72	3,73	3,95	4,31	4,56	4,19	3,38	2,84	3,83
85	3,38	3,68	3,98	3,51	3,35	3,31	3,5	3,92	4,26	4,01	3.28	2.77	3,58
90	3,26	3,52	3,73	3,2	2,97	2,91	3,08	3,52	3,95	3,8	3,17	2,69	3,31

Table 1: *Average daily insolation per unit active area of solar collector for inclination angle from 0-90^0 for Vlora city*

Month	Jan	Feb	Mar	Apri	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Tilt angle(°)	Insolation (kWh/m²/d)												
95	3,13	3,33	3,46	2,89	2,61	2,49	2,65	3,1	3,61	3,58	3,03	2,58	3,04
100	2,98	3,12	3,17	2,56	2,25	2,14	2,25	2,68	3,26	3,34	2,87	2,47	2,75
105	2,82	2,9	2,87	2,22	1,92	1,84	1,9	2,28	2,89	3,08	2,7	2,34	2,48
110	2,63	2,66	2,55	1,89	1,65	1,74	1,71	1,88	2,51	2,8	2,51	2,19	2,23
115	2,43	2,41	2,23	1,57	1,58	1,72	1,69	1,57	2,12	2,51	2,31	2,03	2,01
120	2,22	2,15	1,9	1,31	1,54	1,69	1,67	1,47	1,73	2,2	2,1	1,86	1,82
125	1,99	1,87	1,56	1,26	1,51	1,66	1,65	1,45	1,35	1,85	1,87	1,68	1,64
130	1,75	1,59	1,22	1,22	1,48	1,64	1,63	1,43	1,13	1,57	1,64	1,5	1,48
135	1,51	1,3	0,97	1,19	1,45	1,62	1,61	1,41	1,11	1,25	1,4	1,3	1,34
140	1,26	1,01	0,94	1,16	1,42	1,6	1,59	1,39	1,09	0,93	1,15	1,1	1,22
145	1	0,75	0,91	1,14	1,39	1,58	1,58	1,38	1,07	0,79	0,9	0,89	1,12
150	0,74	0,66	0,89	1,11	1,37	1,56	1,57	1,36	1,06	0,75	0,65	0,69	1,04
155	0,56	0,62	0,87	1,09	1,35	1,55	1,56	1,35	1,05	0,72	0,54	0,49	0,98
160	0,49	0,59	0,86	1,08	1,34	1,54	1,55	1,34	1,04	0,71	0,48	0,41	0,95
165	0,44	0,58	0,85	1,06	1,33	1,53	1,54	1,33	1,03	0,7	0,46	0,37	0,94
170	0,42	0,57	0,85	1,06	1,32	1,52	1,54	1,33	1,02	0,69	0,44	0,35	0,93
175	0,4	0,57	0,84	1,05	1,31	1,52	1,53	1,33	1,02	0,69	0,42	0,33	0,92
180	0,4	0,57	0,84	1,05	1.31	1,51	1,53	1,32	1,02	0,69	0,42	0,32	0,92

Table 2: *Average daily insolation per unit active area of solar collector for inclination angle from 90^0-180^0 for Vlora city*

The data are shown in two separated tables for two reasons:

- To visualize the data with practical interest: we expect that for angles 0 to 90 degrees, (which means direct insolation), to have higher values of solar energy

-To show that there is not a very small contribution on solar energy intake, coming from indirect solar insolation (it is albedo), even in facedown position of the solar system.

Figure 1 shows a graphical summary of data of Tables 1and 2.

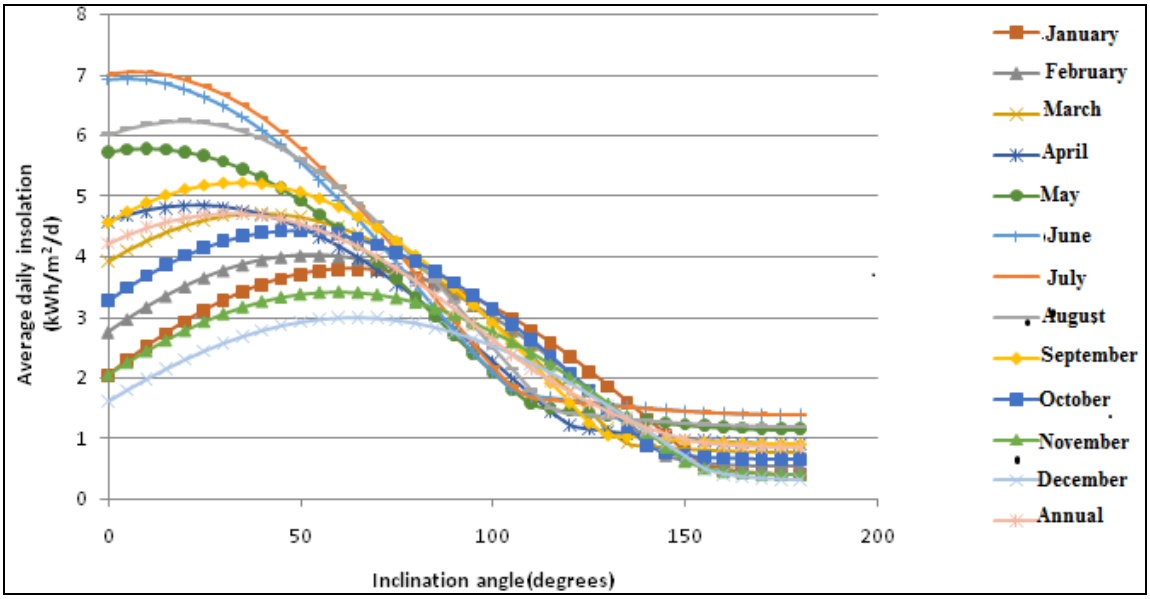

Figure 1: *Average daily insolation versus inclination angle of solar system for Vlora city*

As it shows in the above graphs solar energy intake reaches a maximum at a specific value of inclination angle specific for each month of the year. Solar energy intake decreases in both sides of inclination

angles corresponding to maximum. It would seem of interest to note that solar energy intake does not go to zero but remains almost constant even for inclination angles near 180 degrees. This is due to the Albedo, which is diffused and reflected radiation.
For angles from 0 to 90 degrees all curves can be approximated with parabolas of type:

$$y = ax^2 + b + c \quad (1)$$

Where:
-*y* stands for solar energy intake
-*x* stands for inclination angle.

Approximations were good enough, all correlation coefficients higher than 0.98, and could be used to calculate values of inclination angle for which the energy intake reaches its maximum.
Table 3 shows data corresponding to each approximation curves together with calculated value of inclination angle at which it reaches the maximum energy intake for region of Vlora. As we can see the average optimal inclination angle of solar collector in order to maximize yearly solar energy intake is aproximately 32,5 degrees. It is evident that the inclination angles corresponding maximum of energy intake are different for each month of the year being greater in winter season and smaller in the summer, especially in June-July, reflecting the position of the sun.

Month	a	b	c	Angle
January	0,0004	0,052	1,9596	65
February	0,0005	0,051	2,8297	51
March	0,0006	0,0453	4,1992	37,8
Aprill	0,0005	0,0253	5,2694	25,3
May	0,0005	0,007	6,6069	7
June	0,0005	0,0051	7,6585	5,1
July	0,0006	0,0011	7,7402	0,9
August	0,0007	0,0239	6,6623	17,1
September	0,0007	0,0456	5,0898	32,6
October	0,0005	0,0528	3,4242	52,8
November	0,0004	0,0488	2,0939	61
December	0,0003	0,0422	1,5745	70,3
Annual	0,0005	0,0324	4,6021	32,4

Table 3: *Coefficients of characteristics curves and values of inclination angles corresponding to maximum of energy intake, for the city of Vlora*

B. Loss in Efficiency of Solar System due to Inclination Angle

Another interesting estimation in our study is calculation of lost in solar energy intake if we use a fixed inclination angle equal to that corresponding to annual maximum of energy intake compared with energy intake in the case of monthly change of inclination angle to value corresponding monthly maximum of energy intake.
At first, solar energy values were obtained for each month, taking the maximum angle of the respective month. While for the whole year, the amount of energy will be calculated for the 32,4° angle value. Table 4shows the average daily solar energy values produced by each unit of area of solar collector in each month of the year, if it is inclined at the optimal inclination angle of the respective months.

Month	Angle 0	Average Daily Insolation (kWh/m^2/d)	Nr. of days	Monthly Insolation (kWh/m^2)
January	65	3,6	31	111,61
February	51	4,19	28	117,52
March	37,8	5,11	31	158,52
Aprill	25,3	55,59	30	167,56
May	7	6,62	31	205,18
June	5,1	7,59	30	227,64
July	0,9	7,67	31	237,79
August	17,1	6,89	31	213,71
September	32,6	5,9	30	176,87
October	52,8	4,71	31	146,08
November	61	3,56	30	106,86
December	70,3	2,92	31	90,48
Annual	32,4	5,12	365	1868,27

Table 4: *Monthly and annual energy intake, corresponding to inclination angles of maximum daily energy intake per unit area for Vlora city*

Annual energy intake for every square meter of solar system in case of monthly change of inclination angle is 1959,82kWh/m^2 compared with 1868,8 kWh//m^2 in case of fixed inclination angle or 4.9% more. In the case of fixed inclination angle efficiency of solar system decrease for inclination angle different from angle corresponding maximum of energy intake with average rate of 0.33 % per degree. However, it must be mention that for small differences of inclination angles the decrease rate is much smaller.
Inclination angles for which the annual solar energy intake in case of fixed position facing south has a maximum in region of Vlora is ~32.5° degrees, Annual gain of energy intake for every square meter of solar system in case of monthly change of inclination angle compared with case of fixed inclination angle are 4.88

IV. CONCLUSIONS

Inclination angle of a solar system with horizon is an important parameter influencing the efficiency of solar energy intake. Its influence on solar energy intake depends not only on inclination angle but also on regional yearly distribution of solar insolation. However always there is an inclination angle typical for each region which maximize yearly or monthly solar energy intake. In this paper firstly, solar energy values were obtained for each month, taking the maximum angle of the respective month, while for the whole year, the amount of energy was calculated for the ~**32.5°** angle value. Annual energy intake for every square meter of solar system in case of monthly change of inclination angle is 1959,82kWh/m^2 compared with 1868,8 kWh/m^2 in case of fixed inclination angle or 4.9% more.

It was also shown that efficiency of solar system decreases for inclination angles different from above angles with an average rate of 0.33 % per degree.

However, it must be mention that for small differences of inclination angles the decrease rate is much smaller, minimizing in a way importance of inclination angle.

In the case of monthly change of inclination angle of solar system to values corresponding maximum of monthly intake of solar energy intake was defined an increase of efficiency compared with the case of fixed inclination angle of 4.88%.

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