PHOTOVOLTAIC POWER GENERATION MODELING

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ABSTRACT

The solar power is an interesting developing energy source that has different types of useful applications. The purpose of this paper was to present a model that can estimate the hourly energy produced by a solar module in different sunshine conditions. The output power of a solar module is mainly dependent on solar radiation, temperature of the solar cell, and the technical properties of the module. The most complex of these to estimate was the solar radiation and how it changes in real sky conditions and what is the real hourly average solar irradiationobtained by the module. To model the solar radiation in southern Finland area, measuredhourly long term radiation and sunshine data was obtained from the Finnish Meteorological Institution. With these data a regression model for solar irradiation was constructed and used for the power generation model. The solar irradiation model manages to estimate the irradiation quite well especially for a horizontal surface. The power output model though can not be verified because lack of measured data of such device and therefore must be taken as a rough estimation.

INTRODUCTION

The rising concern on carbon dioxide emissions has affected the interest in different renewable and non-polluting energy sources like solar and wind energy. One of the main flaws in these energy sources is that they can not produce the amount of power that is wanted at the certain time because their power is dependent on factors we can not affect. It is only possible to estimate the approximate long term energy or a short time forecast with weather reports. When a consumer is considering buying solar modules, he wants to know how much he can realistically expect it to produce daily. Also consumers and the electric utilities might want to know the produced energy on hourly basis.

A solar module has a nominal power value on its nameplate but it is rare that the module would produce that high power rates at any time of day. The solar radiation received by the module is dependent mostly on the angle of incidence of the direct solar irradiance which varies during the day. Also it is very likely that the sun is behind clouds and therefore only some diffused radiation will be received by the module. This probability varies monthly and is essential when trying to construct a model to realistically estimate the power of solar module. In this paper it is presented how one type of hourly regression model is constructed from measured data and then applied to estimate produced solar power easily.

BASICS

Theoretical solar irradiance

There are many theoretical models for estimating the hourly clear sky solar irradiance but their complexity and results vary depending on e.g. the place of observation. These models usually estimate the three different types of radiation that constitute the total radiation: direct, diffuse, and reflected. The direct solar radiation is the one that comes straight from the sun and it is the most significant component of the total radiation. The diffuse radiation is the radiation that has scattered from the clouds and atmosphere thus even on cloudy days with no sunshine the receiver gets some radiation. The reflected radiation is reflected from nearby ground and other objects. Its amount is usually quite low and it is difficult to estimate right so that is why it has been omitted in this work. All the models use the information about the position of the sun relative to the location of the observer. These can easily be calculated but the differences arise when the models try to estimate how much the solar radiation attenuates in the atmosphere.

In this paper a model presented byRigollier et al. [1] was chosen. It is relatively simple to use and it has only one variable that is not very easy to define. The model begins by calculating the position of the sun with the knowledge of the coordinates of the observer, and it needs a variable named Linke turbidity factor to estimate the solar irradiance. The Linke turbidity factor is a dimensionless coefficient that represents the clearness of the atmosphere. In summer time the factor is usually higher than in winter e.g.because of the amount of water vapour in the air. In this work the monthly average values for the Linke turbidity factor were obtained from the SoDa service [2] maintained by Armines / MINES ParisTech, Centre Energétique et Procédés (CEP) because of no better knowledge of such variable. These monthly averages were then interpolated to get daily values so the variable would be more continuous and would not dramatically change between months.

This theoretical model is good enough to roughly estimate the hourly solar radiation that is available on clear days, but as the most of the time, the sunshine is blocked by clouds. This model can not estimate these kinds of conditions and therefore measured data is essential to produce a useful model.

Power generation model

The power produced by a solar module is dependent mostly on solar radiation, temperature of the solar cell, and the technical properties of the modules that are for different crystalline silicon modules quite the same. In this paper it is assumed that the solar modules work on their maximum power point as they usually do when they are connected to an inverter. The low transmittance of the sun radiationon very high angles of incidence is also ignored.

The estimation of power generated from a solar module is done with a simple equation that uses the standard test conditions (STC) and normal operating cell temperature (NOCT) values provided by the manufacturer. Mattei et al. [3] have presented the equation of solar module efficiency in a form of

$$\eta = \eta_{\mathrm{STC}}(1 - \beta_{\mathrm{P}}(T_{\mathrm{c}} - T_{\mathrm{STC}}) + \gamma log G) \tag{1}$$

whereη_{STC} is the solar cell efficiency in STC, T_c the solar cell temperature, β_P solar cell power temperature coefficient and G the solar irradiance. Mattei et al. say the equation is mostly used with γ=0 and this is also done here. The solar cell temperature can be estimated with equation

$$T_c = T_a + (T_{NOCT} - 20°C)\frac{G}{800 W/m^2} \quad (2)$$

whereT_a is the ambient temperature. Because we are usually more interested in power, the equation 1 is changed to give power instead of efficiency

$$P = \frac{G}{1000 W/m^2} P_{STC}(1 - \beta_P(T_c - T_{STC})) \quad (3)$$

whereP_{STC} is the nominal power of the solar module.

OBSERVATION DATA AND THE MODEL

To be able to produce a model that would rather realistically estimate the solar irradiation, large amounts of observation data from the Finnish Meteorological Institution were obtained. [4] Observation data were mostly hourly for global and diffuse solar irradiation, sunshine hours, and temperature and they were measured at the Helsinki-Vantaa airport (60˚ 19' N, 24˚ 57' E, 53 m above sea level) between 1st January 1981 and 10th July 2011.

The solar irradiation model was decided to be produced using the theoretical solar irradiance values and the measured sunshine hour values. First the theoretical values were calculated with the model of Rigollier et al. as previously presented. The Linke turbidity values were taken from the SoDa service Linke turbidity maps with the coordinates of the observation site. These monthly average values were then interpolated to get a ninth degree polynomial fitting for daily values.The regression model of the solar irradiation was fitted to the measured data with the tilt angles of 0˚, 42˚ and 90˚ from the horizontal surface. Because the measured direct and diffuse irradiation data were for horizontal surface, they were manipulated to correspond with tilted measurements by following two equations [5]:

$$H_{b,T} = H_{b,H}\frac{\cos\theta_i}{\sin\alpha_s} \quad (4)$$

and

$$H_{d,T} = H_{d,H}\frac{1+\cos\beta}{2} \quad (5)$$

In the former equation for tilted direct irradiation, θ_i is the angle of incidence and α_s the sun altitude. In the latter equation for tilted diffuse irradiation, β is the tilt angle of the surface.
Naturally this method does increase the inaccurateness of the tilted surface model and must be noted when used. The Figures1-3 show how the regression models follows the measured data in the case of horizontal, 42˚ tilted and vertical surface when the sunshine conditions vary.

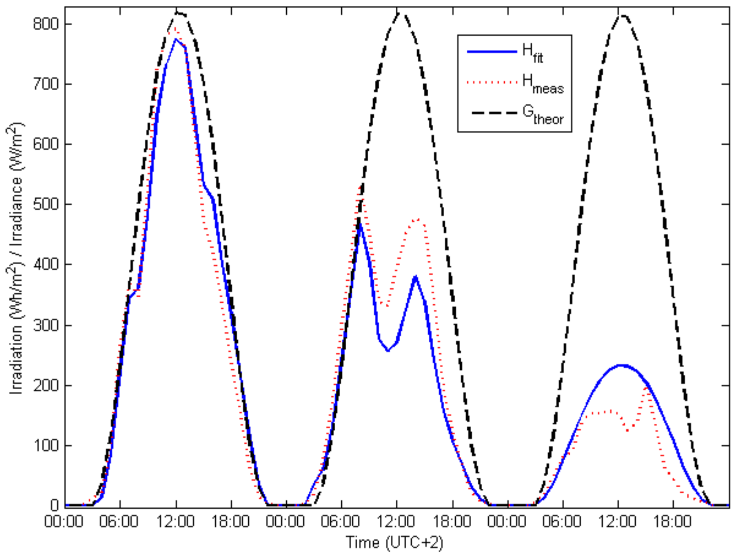

Figure 1:Solar irradiation and irradiance on horizontal surface in July 2003.

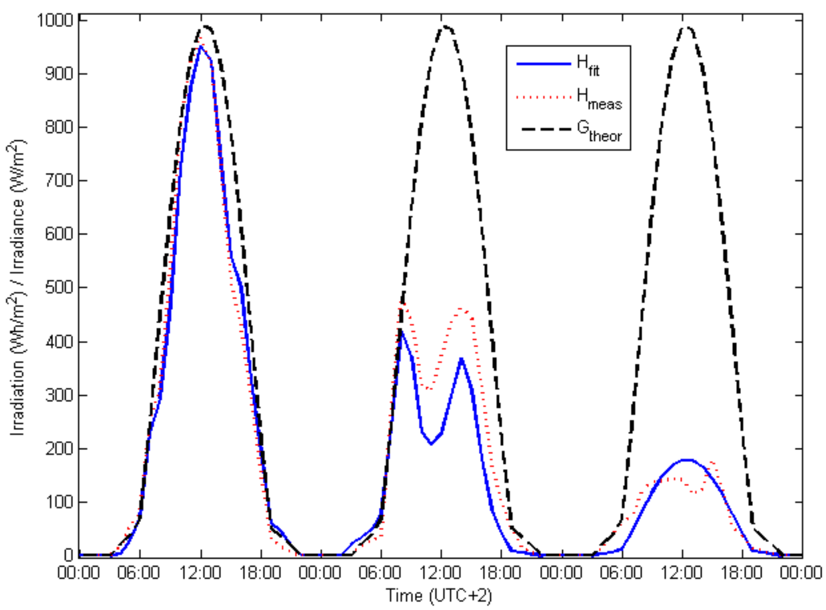

Figure 2: Solar irradiation and irradiance on 42˚ tilted surface in July 2003.

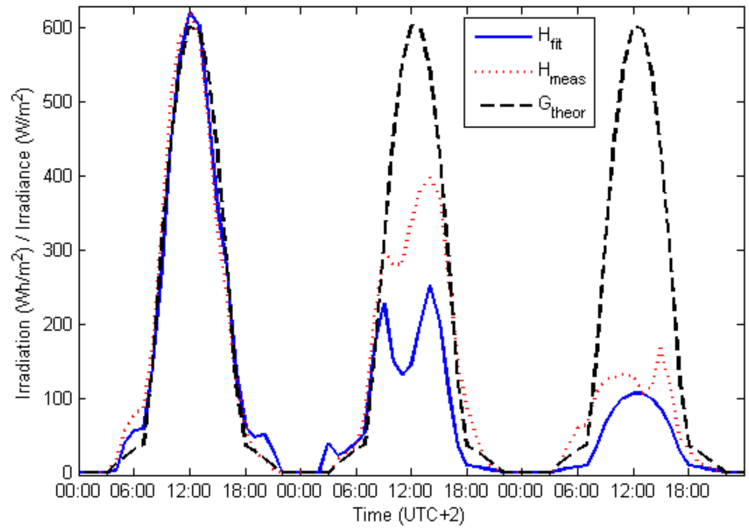

Figure 3: Solar irradiation and irradiance on vertical surface in July 2003.

The measured data of sunshine hours were also interesting because it shows quite well how the probabilities of clouds affect the solar irradiation during a year. For each month, a distribution of sunshine hour values was calculated. From the measured data, the sunshine hour values were taken into account only when the theoretical model suggested that the center of the sun is above horizon. In every month the most probable sunshine hour values are 0 and 1 and all the other values are quite uniformly distributed between them. For example this can be seen from the distribution of daytime sunshine hours in August in Figure 4. From these monthly distributions, an average value for each month could be calculated and these are presented in Table 1.

With the mean sunshine values for each month, irradiation of the whole year was calculated and it was noticed that the approximately the same energy result would be achieved if a sunshine hour value of 0.437 was used for every month. This naturally gives too optimistic solar energy values for winter months and too pessimistic for the summer. These average sunshine hour values give a solar irradiance 985 kWh/m^2 for a whole year. When comparing this value to the measured year energies, it can be noticed that it is on average 3.6 % higher than the measured year energies in the case of a horizontal surface. The Figure 5 shows the daily irradiation values of one year with different tilt angles and sunshine hour values.

Table 1: The probabilities of no sunshine t_{ssh}=0 and constant direct sunshine t_{ssh}=1 for each month, and the monthly weighted mean value of sunshine hour.

Month	t_{ssh}=0	t_{ssh}=1	Mean value of t_{ssh}
January	70.3 %	7.9 %	0.179
February	54.9 %	15.7 %	0.297
March	46.7 %	20.4 %	0.366
April	34.3 %	23.9 %	0.452
May	24.7 %	27.2 %	0.518
June	26.3 %	22.4 %	0.490
July	21.7 %	23.0 %	0.526
August	25.2 %	16.4 %	0.456
September	35.8 %	13.4 %	0.375
October	53.1 %	11.2 %	0.273
November	71.5 %	6.9 %	0.165
December	75.2 %	5.6 %	0.142

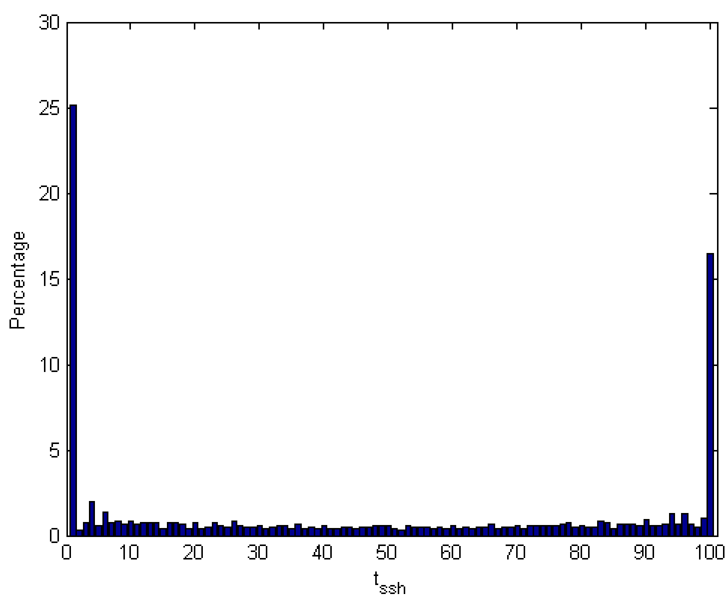

Figure 4: Distribution of daytime sunshine hours in August.

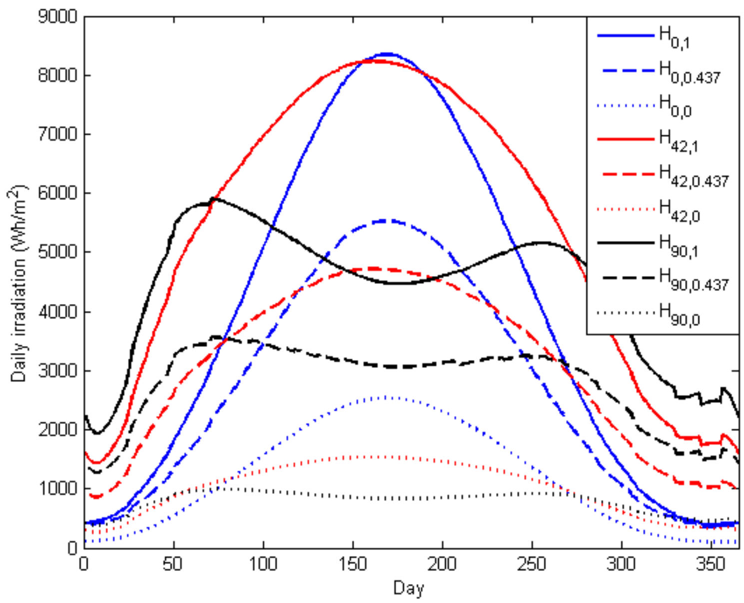

Figure 5: Daily irradiation with different tilt angles and sunshine hours.

With the regression model for the hourly solar irradiation, only the outside temperature and few solar module parameters had still to be defined. An average temperature for each hour of a year was calculated from the observation data. The temperature data was measured every 3 hours till the year 2001 and the missing temperature data were replaced with the previous value. Because the cell temperature will most probably not change very fast, a moving average of 3 from the average hourly temperatures were taken. The needed parameters of the power equation were chosen to be quite typical values found from the technical information of the manufacturers. The normal operating cell temperature was chosen to be 47 ˚C and the power temperature coefficient 0.45 %/˚C. The standard test condition temperature is 25 ˚C.

The power values were calculated for three different tilt angles and with three different sunshine values. The tilt angles were horizontal 0˚, 42˚ and vertical 90˚. The sunshine hours were 0, 1, and the average for each month. The Figures 6-8 show how the monthly energy varies in different months on average and in a case where there would be no clouds for a whole month. The Figure 9 shows yearly energy of a solar module with different tilt angles and with a sunshine hour value of 1 and with the monthly average values. The Figure 10 shows the comparison of average yearly and monthly energies to the nominal energy of the solar module.

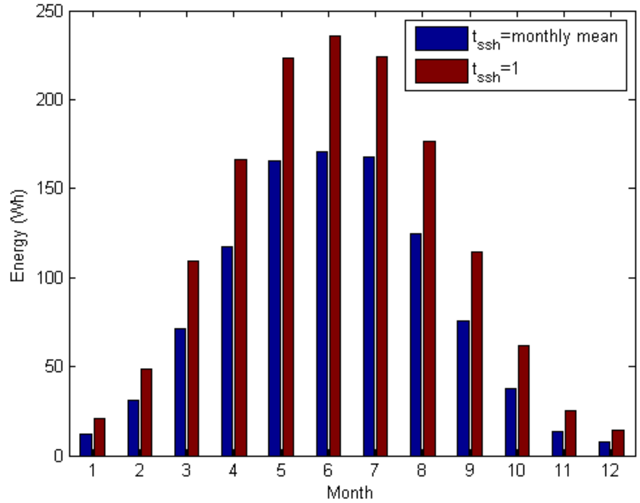

Figure 6: Monthly energy with tilt angle of 0˚ and nominal power of 1 W in different months.

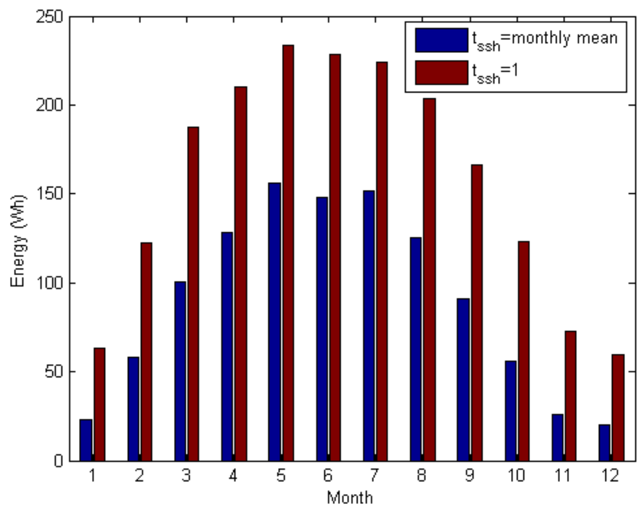

Figure 7: Monthly energy with tilt angle of 42˚ and nominal power of 1 W in different months.

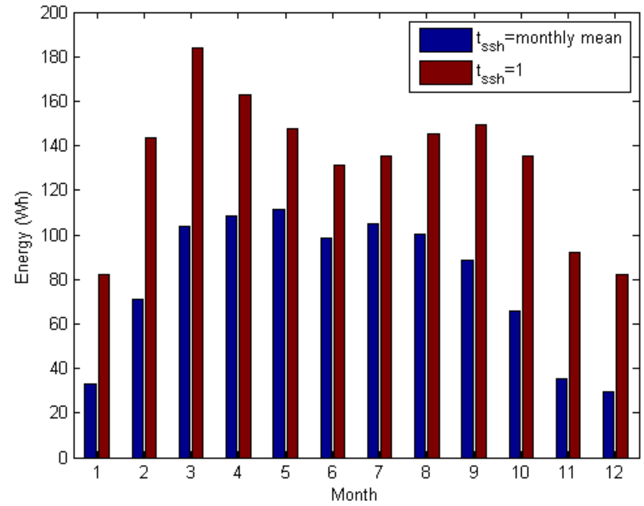

Figure 8: Monthly energy with tilt angle of 90˚ and nominal power of 1 W in different months.

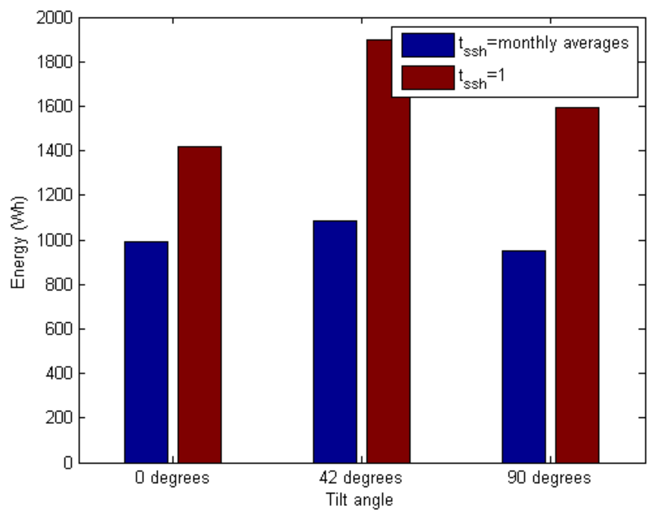

Figure 9: Yearly energy obtained with 1 W module with different tilt angles.

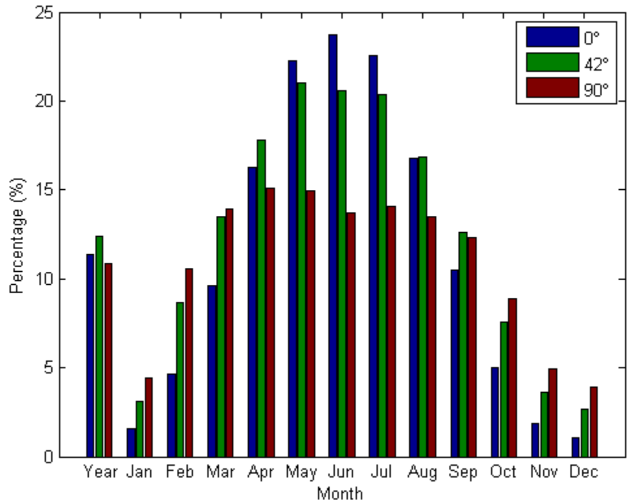

Figure 10: Average solar module energies compared to the nominal energy of the module.

To be easily able to estimate the average hourly power produced by solar modules, monthly average hours were calculated.The values of an hour are presented as a value of p_{index} which can then be applied to an equation

$$P_{\text{h}} = \eta_{\text{eff}} P_{\text{STC}} \frac{p_{\text{index}}}{1000} \quad (6)$$

whereη_{eff} is the inverter efficiency.The values of p_{index} are presented in Tables 2-10 in Appendix A for different sunshine hour and tilt angle values and they are presented in the normal time of Finland (UTC+2).

CONCLUSIONS

This paper presenteda method to estimate the hourly solar irradiance and solar module power in southern Finland. The model used the measured observation data of the Finnish Meteorological Institute to produce a model for global irradiation with different sunshine hour values. The solar irradiation model gives quite good estimates at least for the horizontal surface as could previously be seen. The power output model on the other hand probably has some weaknesses because of its simplicity. It does not take into account for example the low transmittance of solar radiation on great angles of incidence and the cooling effect of wind. Also when the module is installed e.g. on roof, the cell temperature will increase compared to the situation where it is mounted and airflow can go under it.The lack of measured solar module power data prevents us from verifying the final results.

References

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APPENDIX A

Table 2: The values of p_{index} in the case of horizontal surface and witht$_{ssh}$=0.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
J	0	0	0	0	0	0	0	0	0	0.94	16.0	32.4	42.4	42.2	32.0	15.6	1.50	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	2.86	25.8	56.9	81.8	95.3	96.0	83.8	60.2	29.6	4.45	0	0	0	0	0	0
M	0	0	0	0	0	0	0.15	11.7	45.7	86.5	121	145	157	156	143	119	84.2	43.7	9.82	0	0	0	0	0
A	0	0	0	0	0	3.46	26.0	66.2	110	148	177	196	205	202	189	166	134	93.8	50.9	15.1	0.50	0	0	0
M	0	0	0	0	6.64	31.6	70.2	113	152	185	210	225	232	229	217	196	167	131	90.8	50.3	17.9	1.68	0	0
Jn	0	0	0	0	17.7	47.6	86.1	127	163	194	217	232	238	236	226	208	181	148	110	71.2	35.7	11.2	0	0
Jl	0	0	0	0	9.48	33.8	69.8	110	147	179	202	218	226	224	215	197	171	138	101	62.4	28.7	6.89	0	0
A	0	0	0	0	0	7.96	35.0	73.6	113	148	175	192	200	198	188	168	139	103	64.3	28.3	5.61	0	0	0
S	0	0	0	0	0	0	4.83	30.4	67.9	104	133	152	159	156	142	118	85.3	48.2	15.6	1.10	0	0	0	0
O	0	0	0	0	0	0	0	2.18	21.2	50.8	78.1	96.2	103	98.0	81.8	56.2	26.6	4.75	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0.16	11.0	30.7	46.6	53.0	48.5	34.0	14.6	0.74	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	11.0	25.2	32.8	30.4	18.8	3.06	0	0	0	0	0	0	0	0

Table 3: The values of p_{index} in the case of a horizontal surface and with the monthly averages of t_{ssh}.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	4.62	42.1	64.2	77.6	77.3	63.4	41.5	6.66	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	14.2	70.7	120	159	180	181	162	124	76.2	19.8	0	0	0	0	0	0
M	0	0	0	0	0	0	1.33	41.7	112	182	242	284	304	303	280	237	177	108	38.1	0	0	0	0	0
A	0	0	0	0	0	19.8	85.2	160	243	316	373	411	427	422	397	351	288	211	131	60.4	4.48	0	0	0
M	0	0	0	0	38.5	100	177	264	345	413	465	498	512	505	480	436	375	300	218	136	71.8	13.9	0	0
Jn	0	0	0	0	70.5	128	203	283	357	420	468	499	512	508	486	447	393	326	250	173	104	57.0	0	0
Jl	0	0	0	0	51.9	104	176	257	334	401	451	486	501	498	477	439	384	316	238	160	92.6	42.5	0	0
A	0	0	0	0	0	38.6	100	173	248	315	367	402	418	414	393	353	297	229	155	87.1	29.2	0	0	0
S	0	0	0	0	0	0	24.6	84.8	149	213	264	297	310	304	279	236	179	115	52.3	7.19	0	0	0	0
O	0	0	0	0	0	0	0	11.2	59.5	105	147	174	185	177	152	113	67.5	18.5	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0.83	30.2	59.2	80.1	88.6	82.6	63.5	38.0	3.46	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	30.8	48.8	58.6	55.4	40.7	14.2	0	0	0	0	0	0	0	0

Table 4: The values of p_{index} in the case of a horizontal surface and witht$_{ssh}$=1.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	6.04	66.7	115	144	143	113	65.6	8.9	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	14.9	95.4	186	259	299	301	265	196	106	21.6	0	0	0	0	0	0
M	0	0	0	0	0	0	1.07	46.9	153	273	376	447	482	480	442	368	266	147	41.2	0	0	0	0	0
A	0	0	0	0	0	17.3	95.4	213	341	455	544	601	627	619	580	510	412	293	168	61.3	3.36	0	0	0
M	0	0	0	0	32.4	111	224	350	468	567	641	689	708	699	663	600	512	404	284	165	70.6	10.3	0	0
Jn	0	0	0	0	70.5	157	270	390	500	593	662	708	728	721	689	633	553	454	341	226	122	51.0	0	0
Jl	0	0	0	0	44.5	117	222	339	450	545	617	665	687	683	654	599	521	424	313	200	101	34.8	0	0
A	0	0	0	0	0	35.8	121	233	350	453	533	586	610	605	572	511	426	320	206	101	26.3	0	0	0
S	0	0	0	0	0	0	23.6	107	217	324	410	465	488	478	436	364	268	159	60.3	6.31	0	0	0	0
O	0	0	0	0	0	0	0	12.0	81.0	168	247	301	321	306	258	183	96.7	21.8	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	1.11	48.5	109	155	174	161	119	62.2	4.77	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	52.1	93.3	116	108	74.6	21.2	0	0	0	0	0	0	0	0

Table 5: The values of p_{index} in the case of a 42° tilted surface and with t_{ssh}=0.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	3.42	39.6	68.7	84.4	84.0	67.6	38.4	5.07	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	7.32	52.3	96.2	128	145	146	130	100	57.9	11.1	0	0	0	0	0	0
M	0	0	0	0	0	0	0.05	8.74	47.5	93.3	133	161	175	174	159	130	90.8	45.7	7.08	0	0	0	0	0
A	0	0	0	0	0	0.93	4.7	34.4	76.7	118	152	175	185	182	167	140	103	61.5	21.7	3.21	0.16	0	0	0
M	0	0	0	0	1.72	5.29	13.0	50.7	91.6	129	159	179	188	185	170	144	110	71.3	31.9	6.88	3.67	0.51	0	0
Jn	0	0	0	0	3.87	6.89	15.7	52.5	91.5	127	156	176	185	182	169	146	114	77.1	39.0	8.60	5.77	2.86	0	0
Jl	0	0	0	0	2.59	6.25	11.3	44.9	82.4	118	147	167	177	175	163	141	111	75.2	38.6	8.93	5.60	1.99	0	0
A	0	0	0	0	0	2.23	6.87	34.1	71.2	108	138	159	169	167	154	131	99	62.6	27.1	5.88	1.62	0	0	0
S	0	0	0	0	0	0	1.43	19.8	56.2	94.3	126	148	157	153	137	110	74.5	36.7	7.50	0.36	0	0	0	0
O	0	0	0	0	0	0	0	2.31	28.5	66.7	100	121	129	124	104	73.1	35.5	5.45	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0.38	26.0	63.1	87.4	96.7	90.2	68.5	35.2	1.77	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	45.8	74.9	88.5	84.2	62.6	17.6	0	0	0	0	0	0	0	0

Table 6: The values of p_{index} in the case of a 42° tilted surface and with the monthly averages of t_{ssh}.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	7.93	80.8	131	158	157	129	78.6	11.6	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	22.1	133	229	299	335	336	304	238	145	32.2	0	0	0	0	0	0
M	0	0	0	0	0	0	0.79	35.2	138	251	347	414	447	445	409	340	244	133	30.8	0	0	0	0	0
A	0	0	0	0	0	11.0	36.4	120	238	351	443	505	533	525	484	410	310	195	83.6	29.2	2.66	0	0	0
M	0	0	0	0	21.3	40.0	63.8	179	303	414	502	560	584	574	532	458	358	241	121	44.1	34.3	8.20	0	0
Jn	0	0	0	0	34.3	43.3	69.3	178	291	394	475	530	554	547	510	445	355	249	137	47.7	39.3	30.7	0	0
Jl	0	0	0	0	28.8	42.5	58.3	162	276	382	468	526	554	550	515	450	360	254	142	50.1	39.8	24.3	0	0
A	0	0	0	0	0	21.2	41.5	118	222	323	406	462	489	484	449	386	298	197	98.0	38.1	16.3	0	0	0
S	0	0	0	0	0	0	13.7	70.1	161	255	334	386	408	398	359	293	206	112	34.6	4.17	0	0	0	0
O	0	0	0	0	0	0	0	9.67	76.6	157	226	270	287	275	234	170	91.0	18.3	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	1.01	52.9	117	157	172	162	126	70.1	4.45	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	82.3	128	150	143	109	33.9	0	0	0	0	0	0	0	0

Table 7: The values of p_{index} in the case of a 42° tilted surface and with t_{ssh}=1.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	19.8	214	355	430	428	349	207	29.1	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	42.0	276	486	633	709	712	643	504	303	62.4	0	0	0	0	0	0
M	0	0	0	0	0	0	0.76	54.4	252	472	654	777	838	834	768	641	459	243	45.9	0	0	0	0	0
A	0	0	0	0	0	10.5	39.9	188	392	584	736	835	878	866	799	680	515	319	124	30.2	2.34	0	0	0
M	0	0	0	0	19.3	42.3	81.1	267	461	633	764	848	883	868	806	697	546	364	174	49.8	33.7	6.95	0	0
Jn	0	0	0	0	34.9	50.1	94.0	275	459	622	747	829	865	855	800	701	561	391	208	58.2	44.0	29.4	0	0
Jl	0	0	0	0	26.8	46.7	72.1	238	416	578	705	790	829	823	773	679	545	381	206	59.6	43.0	22.0	0	0
A	0	0	0	0	0	21.5	49.8	185	364	533	668	759	800	792	737	635	492	322	150	44.5	16.3	0	0	0
S	0	0	0	0	0	0	14.9	115	293	473	619	713	752	735	665	543	379	198	49.8	4.30	0	0	0	0
O	0	0	0	0	0	0	0	16.2	158	344	500	599	635	608	519	374	192	33.8	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	2.44	143	327	443	487	456	353	192	11.0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	244	385	449	429	326	97.9	0	0	0	0	0	0	0	0

Table 8: The values of p_{index} in the case of a 90° tilted surface and with t_{ssh}=0.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	6.11	60.8	91.7	105	105	90.3	58.8	8.90	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	12.3	73.3	111	129	136	136	130	113	78.7	18.2	0	0	0	0	0	0
M	0	0	0	0	0	0	0.09	10.1	54.6	94.3	119	132	136	136	130	117	92.1	52.9	8.33	0	0	0	0	0
A	0	0	0	0	0	1.29	5.08	17.5	57.4	90.5	112	123	127	126	119	105	79.5	43.9	8.40	3.81	0.27	0	0	0
M	0	0	0	0	2.35	5.52	7.88	11.0	48.9	80.8	102	113	117	116	108	92.1	66.2	30.7	8.73	6.64	4.27	0.82	0	0
Jn	0	0	0	0	4.44	6.67	8.75	10.5	39.2	71.2	92.9	105	110	109	101	85.8	60.8	26.3	9.69	7.89	5.80	3.64	0	0
Jl	0	0	0	0	3.32	6.18	8.68	10.8	37.9	69.2	90.9	104	109	108	101	87.2	64.0	32.0	10.2	8.10	5.66	2.69	0	0
A	0	0	0	0	0	2.70	6.64	12.5	46.3	76.8	98.0	110	115	114	107	93.3	70.3	39.0	8.86	5.87	2.03	0	0	0
S	0	0	0	0	0	0	1.85	18.6	54.3	86.0	107	118	122	120	112	96.3	70.1	35.6	5.50	0.52	0	0	0	0
O	0	0	0	0	0	0	0	3.76	40.0	79.5	105	118	122	119	107	84.6	47.7	8.21	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0.71	41.2	85.5	106	113	108	90.6	55.0	3.20	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	72.7	102	113	110	90.9	31.0	0	0	0	0	0	0	0	0

Table 9: The values of p_{index} in the case of a 90° tilted surface and with the monthly averages of t_{ssh}.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	14.0	127	184	211	210	181	123	20.1	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	36.7	193	290	350	377	378	353	297	206	52.5	0	0	0	0	0	0
M	0	0	0	0	0	0	1.43	47.7	167	274	356	409	433	432	404	350	267	162	43.2	0	0	0	0	0
A	0	0	0	0	0	18.1	53.6	85.5	194	296	375	426	448	442	409	347	260	155	60.9	45.3	4.61	0	0	0
M	0	0	0	0	33.7	55.5	62.0	70.5	181	285	364	415	436	428	391	326	235	126	63.0	57.3	50.9	13.6	0	0
Jn	0	0	0	0	51.3	57.2	62.7	67.3	147	244	319	368	389	384	352	293	211	110	64.1	59.3	53.8	48.2	0	0
Jl	0	0	0	0	44.4	56.2	63.1	69.0	148	247	325	377	402	398	368	311	229	129	66.3	60.4	53.6	38.1	0	0
A	0	0	0	0	0	33.1	55.7	70.7	161	252	325	372	394	391	362	308	231	140	60.3	52.7	25.9	0	0	0
S	0	0	0	0	0	0	22.7	80.0	167	252	319	361	378	370	339	284	207	119	41.6	7.19	0	0	0	0
O	0	0	0	0	0	0	0	16.5	111	197	261	299	311	301	268	209	127	29.1	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	1.86	85.0	165	205	219	209	174	111	8.00	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	133	184	205	198	164	59.5	0	0	0	0	0	0	0	0

Table 10: The values of p_{index} in the case of a 90° tilted surface and with t_{ssh}=1.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
J	0	0	0	0	0	0	0	0	0	28.4	291	461	545	543	454	282	41.4	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	57.3	357	583	727	797	799	736	601	387	84.8	0	0	0	0	0	0
M	0	0	0	0	0	0	0.47	46.7	258	475	646	757	811	807	748	633	463	249	38.8	0	0	0	0	0
A	0	0	0	0	0	6.64	25.1	81.0	272	454	596	688	728	717	657	546	391	205	39.8	19.1	1.47	0	0	0
M	0	0	0	0	12.1	27.0	37.5	51.3	230	398	527	610	645	632	572	466	319	142	41.2	31.9	21.4	4.36	0	0
Jn	0	0	0	0	22.1	32.1	41.3	49.0	182	345	472	555	591	582	528	430	290	121	45.5	37.4	28.1	18.6	0	0
Jl	0	0	0	0	16.9	29.9	41.0	50.4	176	335	460	545	584	579	530	438	307	148	47.8	38.3	27.5	13.9	0	0
A	0	0	0	0	0	13.6	31.9	58.1	217	377	505	590	630	623	572	476	341	181	41.7	28.4	10.3	0	0	0
S	0	0	0	0	0	0	9.44	86.0	257	428	563	649	685	669	605	493	339	165	26.4	2.71	0	0	0	0
O	0	0	0	0	0	0	0	17.5	187	391	548	642	675	650	566	421	225	37.9	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	3.26	194	425	553	598	566	454	260	14.8	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	352	524	597	575	454	146	0	0	0	0	0	0	0	0