PERFORMANCE QUALITY SAFETY

PQS solar autonomy calculation method

March 2011

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- University of Southampton Solar Autonomy Calculation Tool - final report
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RI*f*I Number:	**08/MT/00505/C**
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1. Introduction

This report describes work carried out under subcontract AID-1233-13-07789-CRT, with the aim to develop a solar autonomy calculation tool to be used for determining the number of days of autonomy suitable for solar powered vaccine refrigerators with either batteries or cold storage.

The methodology used for this purpose is based on a technique developed in the Solar Energy Laboratory at Southampton University which provides a rigorous link between observed solar radiation data and the number of days of autonomy. Details of the methodology are described in Sec. 3. This section also contains the description of a system model based on energy balance on which the autonomy tool is based.

A significant part of the work has been devoted to the search for a satisfactory database of solar radiation data and an analysis of its suitability for the project. The overview of solar radiation databases and their assessment are given in Sec. 4.

Results of the work are presented in Sec. 5 and on an accompanying CD-ROM which contains the following Microsoft Excel files:

- Autonomy_Tool.xls
- Days_of_Autonomy.xls
- A folder with 97 Excel files (henceforth referred to as the station files), each with the title of an individual station followed by the underscore “_” .

2. Abbreviations

A:L ratio	Array to Load Ratio, used synonymously with Array Oversize Factor
CA	Array Oversize Factor, used synonymously with A:L ratio
DoA	Days of Autonomy
LOLP	Loss of load Probability
MTBF	Mean Time Between Failures
PV	Photovoltaic
WRDC	World Radiation Data Centre

3. Methodology used in this work

3.1 Determination of the Days of Autonomy

The procedure for the determination of the Days of Autonomy (DoA) which was used in this project is based on a standard model of PV system operation as a function of time (see, for example, [1-3] and references therein). Focusing on the daily energy balance within the PV system, the energy contained in the energy storage (for example, the state of charge of the battery) is portrayed as a series of climatic cycles. The climatic cycle with the maximum energy deficit gives the required size of the energy storage that would guarantee continuous operation. Only the most significant cycles need be brought into the analysis, making it possible to obtain a rigorous sizing procedure in terms of a small subset of what maybe a large amount of solar radiation data. Which cycles are significant is determined by modelling, as described in Sec. 3.2.

3.2 The system model

The system model determines the amount of energy in the energy storage on a daily basis, and is shown schematically as a flow chart in Fig. 1. For each day, the procedure determines the energy input into the system by the PV array (*energy_in*), the energy *balance* after the *load* is supplied, and the *shortfall*, including the energy available in the energy store. For convenience, all energy quantities are normalised to the daily energy load. The procedure then determines the amount of energy left in the energy store at the end of the day. By virtue of the normalization, the energy in the energy store is equal to the appropriate Days of Autonomy required for that particular day. The minimum of all the Days of Autonomy for all the days in the times series of data then gives the required Days of Autonomy for the system to supply power to the load without interruption.

No system losses are included in the model but are taken into account by an appropriate increase of the array size (or equivalently, decreasing the load) with the use of an Array Oversize Factor CA (also called the Array to Load Ratio, A:L), as described in Sec. 3.3.

3.3 Array Oversize Factor

The terms “Array Oversize Factor” and “Array to Load Ratio” are used synonymously in this report. IEEE standard 1562 defines the Array to Load Ratio, A:L as: “The average daily photovoltaic ampere hours (Ah) available divided by the average daily load in ampere hours. The average daily PV ampere hours is calculated by taking the average daily solar resource for the month of interest in kilowatt hours per square meter (kW/m^2) *(sic)* times the array current at its maximum power point (Imp) under standard test conditions (STC).“ In other words, an array corresponding to A:L ratio of unity will supply the load exactly if solar radiation is equal to the mean value during the “worst month” (the month with the lowest value of solar radiation), and there are no system losses.

An Array Oversize Factor greater than unity is employed to accommodate any system losses, which may include dust on the array, Coulombic efficiency losses in the battery, losses from a charge controller or inverter if not included in the average daily load, etc. [4,5]. The total magnitude of these losses lies typically between 10% and 20%.

The procedure used in this project includes a consideration of an additional increment in the Array Oversize Factor, above the requirement to accommodate system losses. It is well established [1,3] that a higher value of the Array Oversize Factor has a beneficial effect on system operation, by improving the continuity (or reliability) of supply which is sometimes quantified in terms the so-called Loss of Load Probability (LOLP).

It has been shown in these studies that if a measure of the reliability of supply is considered as a fixed parameter (described in more detail in Sec. 3.4), an increase of the Array Oversize Factor can be used to reduce the number of days of autonomy in the system, but otherwise achieving a similar performance. The Array Oversize Factor discussed in this report refers to this part of the Array Oversize Factor – in other words, no attempt has been made to quantify possible system losses, such as defined more fully in reference [4].

3.4 Statistics of climatic cycles and the continuity of supply

The continuity or reliability of supply is an important characteristic of the photovoltaic power system operation, and its quantitative analysis has been carried out as part of the project. The reliability of supply is sometimes characterised by the Loss of Load Probability (LOLP) which is equal to the fraction of time when the PV power system cannot supply the load due to lack of solar radiation.

Recommended values of LOLP are not always generally agreed upon, particularly in high-reliability applications where the objective for the PV power system is to supply power without any shedding of the load. For this reason, this project has replaced LOLP by a frequency based measure similar to Mean Time Between Failures (MTBF). The MTBF concept is often used by engineers in the design of structures based on extreme value analysis (for example, 50 year wind, 100 year flood, etc.). Based on an analysis of the requirements of the project, the durability of PV system components and discussions within the project team, the reference time scale for supply continuity without shedding load has been set at 20 years.

Only 38 stations among the 97 selected for analysis contain a time series longer than 20 years, and provide a direct basis for the determination of the Days of Autonomy with the required continuity of supply. To allow stations with a shorter time series of data to be used, we have analysed the frequency of climatic cycles based on the available solar energy data, initially by using locations with data series in excess of 20 years. We have found that the data for all theses stations fit the following empirical relationship between the frequency of climatic cycles (interpreted as MTBF) and the Days of Autonomy:

$$\log(MTBF) = a * DoA + b \qquad \text{Equation (1)}$$

where *a* and *b* are constants - the slopes and intercepts of the fitted lines (see Fig. 2a).

This result is useful for several reasons. In the first instance, it makes it possible to estimate the impact of using shorter time series of data than 20 years. These data can simply be fitted to equation (1) to obtain the required constants a and b, which are then used to calculate the required Days of Autonomy from

$$DoA = \frac{1.301 - b}{a} \qquad \text{Equation (2)}$$

since log(20) = 1.301.

In a different setting, Eq. (1) was applied to several datasets to minimize the effects of possible errors in the data series on account of missing data. Equation (1) which embodies the statistics pertaining to several climatic cycle then removes the uncertainty with respect to the accuracy of data referring to individual climatic cycles. The validity of relation (1) was also taken as an indicator of internal consistency of the data series, and is reflected in data shown in bold figures for the Days of Autonomy in Table 1.

4. Solar radiation data

The results produced by the autonomy tool reflect the accuracy of the solar energy data on which they are based. A comprehensive analysis of the three most readily available sources of solar radiation was carried out as part of the project, including:

- Meteonorm software-generated data
- NASA database of satellite-based data
- WRDC database of data from ground-based measurements

Results of this analysis are presented in Secs. 4.1- 4.3.

4.1 Meteonorm data

METEONORM software package (marketed by Meteotest of Switzerland, www.meteotest.ch) offers a comprehensive climatological database for solar energy applications at a wide range of locations of the globe. It is also a computer program for climatological calculations, capable of producing monthly means of solar radiation on arbitrarily orientated surfaces. “Synthetic” time series of daily or hourly global solar radiation can also be generated, based on the method of Markov transition matrices [6]. The latest version of Meteonorm (version 6) can generate up to five years of synthetic data, by choosing five different random seeds to initiate the generation algorithm.

Meteonorm (which can also provide ambient temperature data) is used extensively by designers of solar energy systems, and was the original choice of solar radiation data for the project. We have evaluated the suitability of Meteonorm solar radiation data as an be input into the procedure set out in Sec. 3. To this end, results for the Days of Autonomy using Meteonorm were compared with the results based on WRDC ground based data. This comparison was carried out for 10 stations with a long time series of daily solar radiation where we had good confidence in the accuracy of the ground based data. Figure 3, where each point corresponds to one station, shows the results of this analysis in the form of DoA values obtained using Meteonorm plotted against the corresponding DoA results based on WRDC data. Points where the two methods are in good agreement lie close to the dotted line.

It is clear that the DoA results generated by Meteonorm do not agree well with the results obtained with the use of WRDC data. For all the stations examined, Meteonorm seriously underestimates the required Days of Autonomy. Based on an application of the method discussed in Sec. 3.4 one can estimate that a system with the Days of Autonomy designed with the use of Meteonorm data would display supply continuity of less than five years. Clearly, this is insufficient for the purposes of this project. This conclusion was discussed with Jan Remund of Meteotest who confirmed that Meteonorm was designed with the prime purpose of generating mean monthly values of solar radiation; little analysis has been carried out as to the suitability of the Meteonorm algorithm to reproduce faithfully the extreme sequences of daily solar radiation which are required for the present application.

Despite this apparent unsuitability of Meteonorm to determine the Days of Autonomy, it remains desirable to use Meteonorm to generate values of solar radiation which are needed by the system designers alongside the Days of Autonomy. To this end, we have compared the mean daily solar radiation values during the worst month generated by Meteonorm with the corresponding values obtained using the WRDC database. The results are shown in Fig. 4. It is observed that, with the exception of one station (Lodwar), the two sets of results agree well. The agreement or disagreement between the worst monthly solar radiation values was later extended to cover all stations that were analysed in this project, and is shown in Table 1 as part of the results. The overall conclusion is that Meteonorm is a valuable accompanying instrument and source of data, alongside the Days of Autonomy results presented in this project.

4.2 NASA satellite data

The NASA website http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi provides, among other parameters, a time series of daily solar radiation values. According to the information at this web site, the surface solar insolation from satellite observations is inferred with the use of a radiative transfer model consisting of a modeled atmosphere and a mathematical model and/or parameterization of the scattering and absorption processes. Available for all locations on a 1 degree longitude by 1 degree latitude grid and extending from 1st July 1987 to 31st December 2005, this database satisfied the requirements of both geographical coverage and length of the time series. The web site gives an extensive assessment of the accuracy of this method but, as with the Meteonorm data, there appears to be no documented evidence of the accuracy of these data in application to the Days of Autonomy for photovoltaic systems.

An assessment of the time series produced by this method was therefore carried out in order to assess its suitability for the purposes of this project. In this instance, we have compared the Array Oversize Factor obtained using WRDC and NASA data for 3 and 5 Days of Autonomy (Fig. 5). These data were obtained by using the respective monthly average values – in other words, modelling WRDC data with the WRDC worst month average, and NASA data with the appropriate NASA average. Figure 5 shows that a correlation exists in some 50% of the sites but agreement is poor in the remaining cases. We have further compared the monthly means of daily solar radiation values for the worst month between NASA and Meteonorm (Fig. 6). It is seen that, in about 50% of the sites, there is a significant disagreement between the two data sources.

It therefore appears that the agreement between the NASA and WRDC data (and/or Meteonorm, in the case of mean daily values) is not universal. In about half of the cases, the statistics of the NASA time series of solar radiation data does appear to agree with the WRDC and Meteonorm data, but there is no clear procedure to identify these data with any degree of confidence. One cannot therefore recommend the NASA database as the main source of data for the project.

4.3 WRDC database

The World Radiation Data Centre (WRDC) database contains archive data obtained from ground based measurements at more than 1200 stations across the world. WRDC was established in 1964 under the auspices of the World Meteorological Organisation, and is located in St. Petersburg at the Main Geophysical Observatory of the Russian Federal Service for Hydrometeorology and Environmental Monitoring. The database is currently managed in cooperation with the National Renewable Energy Laboratory of the U.S. Department of Energy, and can be accessed without charge through the internet at http://wrdc-mgo.nrel.gov/html/get_data-ap.html. Altogether, 384 stations were identified as containing daily solar radiation data pertaining to latitudes between 30N and 30S. Different amount of data is available for each station ranging from no data at all to a complete time series of global daily radiation extending from the beginning of 1964 to the end of 1993.

Following an initial assessment of the relevant sites in the tropics from the WRDC network with respect to the total and the missing number of data, a detailed comparison was made with the time series generated by Meteonorm and the NASA satellite derived data (discussed above in Secs. 4.1 and 4.2). The WRDC database was then chosen as the most suitable to provide data for the present project.

4.4 Processing of data

The data in the WRDC database are subject to the usual constraints on the accuracy of ground based measurements. Whilst missing data are readily apparent, errors due to lack of calibration, maintenance, numerical errors etc. are usually difficult to identify with any degree of certainty. According to the Surface meteorology and Solar Energy website http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi, the World Climate Research Program estimated in 1989 that “most routine-operation ground sites had ‘end-to-end’ uncertainties from 6 to 12%. Specialized high quality research sites are hopefully more accurate by a factor of two.”

A standard procedure therefore had to be established to cope with the missing data within the time series. Whilst the time series for some locations are almost free from missing data, the time series for other sites may have substantial numbers of data missing. This may not be particularly serious if the missing data occur during parts of the year with high solar radiation but may have a critical effect on the results if falling within a significant climatic cycle. Three measures were taken to deal with the missing data, and to minimise the effect on the results:

i. Single isolated values (non-sequential) of missing daily solar radiation were replaced by the average of the adjacent days

ii. Two or more adjacent days of missing data were replaced by a high value of solar radiation (10 kWh/m^2). This has the effect that missing data do not produce a spurious climatic cycle. At the same time, of course, the size of a climatic cycle where such occurrence may fall is likely to be reduced.

iii. To minimise the effect of several adjacent missing data (ii), we have sought to deduce the final result from several climatic cycles, by a procure discussed in Sec. 3.4. This can, of course, only be done for a time series with sufficient length of data but appears to be successful for several sites in India.

5. Results and Deliverables

The Days of Autonomy for 97 locations are summarized in Table 1, together with supplementary data for each station (Table 1b). Explanatory notes to this Table are given in Table 1a. Table 1 is also presented separately as a spreadsheets Days_of_Autonomy.xls on an accompanying CD ROM. Results from four locations (Calcutta, Maputo, Nairobi and Pretoria) are based on an analysis of two nearby stations for each location.

97 Microsoft Excel files (on CD ROM), with the names of individual stations followed by the underscore "_" (referred to as the station files) give further details for each station. Table 2 gives a detailed explanation of each worksheet in these files.

Spreadsheet Autonomy_Tool.xls (on CD ROM) contains a program which determines the number of Days of Autonomy from a user supplied series of daily solar radiation data and the mean value during the worst month of the year. The instructions for use are given in the spreadsheet.

6. Conclusions

This project has been successful in the development of a solar autonomy calculation tool to be used for determining the number of days of autonomy suitable for solar powered vaccine refrigerators with either batteries or cold storage. The methodology used in the project is discussed in Sec. 3; the solar radiation databases and the reasons for the resulting choice which was used in this work are discussed in Sec. 4.

The results include a Microsoft Excel spreadsheet Autonomy_Tool.xls which allows the determination of the Days of Autonomy from user supplied solar radiation data. Results of calculations by the Autonomy Tool are presented for 92 stations in the tropics for Array Oversize Factors (Array to Load Ratios) of 1.0, 1.1 and 1.25. Four further stations were incorporated in the calculation in the analysis of nearby locations. The quality of data for five stations proved to be unusable for the purposes of Autonomy Tool calculations.

The results also include values of the Days of Autonomy extrapolated to 20 year supply continuity for selected locations, obtained by an exponential fit to intervals of supply continuity determined on the basis of the Autonomy Tool. Considering that this extension of the methodology is purely empirical, the fit of data to this equation has been found to be surprisingly widespread but further work is required to substantiate this augmented procedure in more detail.

The table of results (presented as Table 1 and in the spreadsheet Days_of_Autonomy.xls) also includes the full coordinates of all stations, and the monthly means of daily solar radiation for the "worst month" , both from WRDC data and using Meteonorm database. Further details of the solar radiation and PV system operation at each of the locations as a function of time are given in 97 station files which present also the Meteonorm values of the monthly means of daily solar radiation and of the ambient temperature.

7. References

1. T. Markvart, K. Fragaki and J.N. Ross, PV system sizing based on observed time series of solar radiation, *Solar Energy*, Vol. 80, pp. 46-50, 2006
2. T. Markvart et al, Battery charge management for minimum cost PV systems, *Proc. 17th European Photovoltaic Solar Energy Conference*, Munich, Germany, 2001.
3. E. Lorenzo, *Solar Electricity: Engineering Photovoltaic Systems,* Progensa, Seville, 1994.
4. Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems, IEEE Standard 1562, 2007.
5. L. Castañer et al, Chapters IIIa1-3 in: T. Markvart and L. Castañer (eds), *Practical Handbook of Photovoltaics: Fundamentals and Applications*, Elsevier, Oxford (2003).
6. R. Aguiar et al, A simple procedure for generating sequences of daily solar radiation values using a library of Markov transition matrices, *Solar Energy*, Vol. 40, pp. 269, 1988.

8. Tables

WRDC No.[1]	Country	Station name	Lat	Long	Alt	Worst month[2]	W. Month average[3]		Days of autonomy[4]: directly derived[5]			Days of autonomy[4]: extrapolated / other[6]			Comment (met.data)[7]	No. of WRDC data[8]
							WRDC	Meteon	1.0	1.1	1.25	1.0	1.1	1.25		
603900	ALGER	DAR EL BEIDA	36.72	3.25	25	dec, jan	2.10	2.10	9.1	5.2	3.4					1948
661520	ANGOLA	DUNDO	-7.40	20.82	775	aug	4.10	4.10	5.4	2.3	1.8	5.7	2.7	1.9		4079
661600	ANGOLA	LUANDA	-8.85	13.23	74	aug	3.47	4.06	9.4	6.0	3.1				15%,S	4320
662850	ANGOLA	LUENA / LUSO	-11.78	19.92	1357	mar	4.85	5.06	*10.5*	2.8	1.4				dec,D	3316
963150	BRUNEI	BRUNEI ARPT	4.93	114.93	22	dec	4.63	4.61	*6.0*	*2.8*	*1.5*					2374
655010	BURKINA FASO	DORI	14.03	-0.03	276	dec	5.19	5.29	4.6	1.7	1.3					3559
655220	BURKINA FASO	GAOUA	10.33	-3.18	333	aug	4.69	4.74	6.1	4.2	1.8					3469
854060	CHILE	ARICA	-18.35	-70.33	55	jul	2.92	3.77	7.1	3.7	1.2				P, 23%	2828
854700	CHILE	COPIAPO	-27.30	-70.42	290	jun	2.89	3.03	5.9	2.4	1.8					2767
854880	CHILE	LA SERENA	-29.92	-71.20	146	jun	2.35	2.40	6.1	4.1	2.7				P	2677
854062	CHILE	PARINACOTA	-18.20	-69.27	4392	jun	4.51	----	3.4	2.0	1.1					2129
562940	CHINA	CHENGDU	30.67	104.02	508	dec	1.14	1.35	12.4	9.9	7.6				15%	2006
592870	CHINA	GUANGZHOU	23.13	113.32	8	mar	1.77	2.41	18.3	13.7	11.3				feb, 27%	1975
567780	CHINA	KUNMING	25.02	102.68	1892	oct	2.61	3.26	9.9	8.1	6.9				20%	2006
802220	COLOMBIA	BOGOTA /	4.7	-74.13	2547	jun	3.98	3.81	6.0	2.1	1.0				may	2012
802410	COLOMBIA	GAVIOTAS	4.55	-70.92	165	jun	3.99	3.83	5.3	1.9	1.1					2012
783250	CUBA	HAVANA /	23.17	-82.35	50	dec	3.38	3.39	7.0	4.8	2.7	8.7	4.9	3.0		3620
631250	DJIBOUTI	DJIBOUTI	11.55	43.15	13	jan	4.75	5.13	*12.2*	*7.6*	*4.8*				dec, 7%,D	2162
973900	EAST TIMOR	DILLI ARPT	-8.57	125.57	6	jan	4.83	4.94	*u*	*u*	*5.1*					3923
623710	EGYPT	CAIRO	30.08	31.28	33	dec	2.87	3.03	**9.4**	**5.2**	**2.5**	8.9	4.4	2.0		9125
624350	EGYPT	EL KHARGA	25.45	30.53	78	dec	4.15	4.45	4.0	2.4	1.3				7%	8183
786622	EL SALVADOR	AHUACHAPAN	13.95	-89.87	725	sep	4.75	4.83	4.7	2.6	2.0	4.8	3.0	2.1		3224
786720	EL SALVADOR	LA UNION	13.33	-87.88	95	nov	4.77	4.50	*3.0*	*2.8*	*2.3*				dec, 6%,D	3224
786621	EL SALVADOR	NUEVA CONCEP	14.13	-89.28	320	dec	4.74	4.84	4.1	2.2	1.9					3132
786620	EL SALVADOR	S. SALVADOR	13.72	-89.20	698	sep	3.50	4.57	*u*	*u*	*u*				23%	5656
634500	ETHIOPIA	ADDIS ABABA	8.98	38.80	2324	aug	3.63	3.84	8.5	5.9	4.4				jul	6115
916900	FIJI	SUVA /	-18.05	178.57	5	jun	3.21	3.20	9.6	5.3	3.7					2950
654420	GHANA	KUMASI	6.72	-1.60	287	aug	3.35	3.48	**10.6**	**4.3**	**2.0**					8735
654010	GHANA	NAVRONGO	10.9	-1.10	201	aug	4.94	4.84	7.7	2.9	1.5					2314
788970	GUADELOUPE	LE RAIZET	16.27	-61.52	11	dec	4.30	4.00	*10.0*	*5.2*	*4.2*				7%	7514
814050	GUIANA	CAYENNE /	4.83	-52.37	9	jan	3.84	3.84	**12.9**	**7.2**	5.4	11.8	6.6	3.9		5962
617660	GUINEA-BISSAU	BISSAU ARPT	11.88	-15.65	39	dec	4.64	4.45	*10.4*	*2.6*	*1.5*					3770
617690	GUINEA-BISSAU	BOLAMA	11.58	-15.48	18	dec	4.53	4.32	11.3	7.2	4.7					2037
785010	HONDURAS	CISNE ISLS	17.4	-83.93	9	dec	4.24	4.13	8.8	4.3	3.0				P	4139
426470	INDIA	AHMADABAD	23.07	72.63	55	dec	4.41	4.45	11.9	9.1	6.6					10432
430030	INDIA	BOMBAY /	19.12	72.85	8	jul	3.86	3.84	*10.8*	*7.4*	*6.1*					8364
428070	INDIA	CALCUTTA /	22.53	88.33	5	dec	3.87	3.94	7.6	4.6	3.0	**6.1**	**4.2**	**3.0**		5352 + 4623
423390	INDIA	JODHPUR	26.3	73.02	217	dec	4.22	4.16	5.8	3.4	2.1				P	9281
433390	INDIA	KODAIKANAL	10.23	77.47	2339	oct	4.45	4.20	6.6	4.8	3.1	6.4	4.2	2.5	jun, 6%,S	9674
432790	INDIA	MADRAS /	13	80.18	10	dec	4.08	4.16	9.8	7.7	5.1					10462
428670	INDIA	NAGPUR /	21.1	79.05	308	aug	4.07	4.26	8.1	5.3	4.7					10401
421820	INDIA	NEW DELHI /	28.58	77.20	211	dec	3.66	3.71	5.1	3.3	2.2					10157
636120	KENYA	LODWAR	3.12	35.62	506	jul	6.19	4.80	*u*	*u*	*u*				apr, 29%	10007
637410	KENYA	NAIROBI /	-1.32	36.92	1624	jul	3.69	3.81	13.4	10.1	7.3					10766
637370	KENYA	NAROK	-1.13	35.83	1890	jul	4.62	----	15.0	7.1	5.1					9796
450110	MACAU	MACAU	22.2	113.53	57	feb	2.68	4.87	*33.7*	*26.5*	*18.3*				jun, P, 45%	9459
670830	MADAGASCAR	ANTANANARIVO	-18.80	47.48	1279	jun	3.28	4.70	*u*	*u*	*u*				30%	4958
670090	MADAGASCAR	DIEGO-SUAREZ	-12.35	49.30	114	jun	4.15	4.81	7.0	5.6	3.7				jul, P, 14%,S	2039

Table 1 (continued on p. 10). The principal results of this work. For detailed explanation see text and Table 1a.

486150	MALAYSIA	KOTA BHARU /	6.17	102.28	5	dec	3.49	3.32	11.2	8.0	6.3					6510
486470	MALAYSIA	KUALA LUMPUR	3.12	101.55	27	dec	4.08	4.06	17.0	9.5	4.0					7634
762250	MEXICO	CHIHUAHUA UN	28.63	-106.08	1435	dec	3.82	3.81	7.3	5.1	3.0					3009
762252	MEXICO	CIUDAD UNIV.	19.33	-99.18	2268	dec	4.18	3.84	9.7	7.7	5.6				9%	9672
762251	MEXICO	ORIZABITA	20.58	-99.20	1745	dec	4.82	----	7.4	4.3	2.2	7.5	4.2	2.3		8767
672950	MOZAMBIQUE	CHIMOIO	-19.12	33.47	731	jun	4.31	4.33	10.0	**5.1**	**2.1**	7.8	4.3	1.9		10157
673411	MOZAMBIQUE	MAPUTO	-25.97	32.60	70	jun	3.73	3.73	**8.4**	**4.4**	**3.1**	7.7	3.7	2.7		10615
672370	MOZAMBIQUE	NAMPULA	-15.10	39.28	438	jun	4.52	4.70	*21.5*	*15.0*	*8.3*	*13.3*	*7.4*	*4.1*		9672
683120	NAMIBIA	KEETMANSHOOP	-26.53	18.12	1067	jun	4.27	4.33	2.1	1.2	1.1	2.3	1.3	1.1		4228
681100	NAMIBIA	WINDHOEK	-22.57	17.10	1728	jun	4.87	4.97	2.8	2.2	1.6					4258
652290	NIGERIA	BENIN CITY	6.32	5.60	79	aug	3.47	3.55	**12.6**	**7.9**	**3.1**	11.4	6.2	3.0		10375
417800	PAKISTAN	KARACHI ARPT	24.9	67.13	21	dec	3.96	4.06	9.8	5.9	3.7					8640
416750	PAKISTAN	MULTAN	30.2	71.43	122	dec	3.04	3.06	*17.5*	*13.9*	*8.6*	*12.8*	*7.3*	*3.0*		8482
416610	PAKISTAN	QUETTA /	30.27	66.92	1620	dec	3.53	3.32	*14.9*	*10.8*	*5.2*				jan, 6%,D	10708
940350	PAPUA NEW GUIN	PORT MORESBY	-9.43	147.22	28	jun	4.93	4.74	6.6	2.9	2.3				jul	2552
847520	PERU	AREQUIPA	-16.32	-71.55	2524	jun	5.45	5.50	7.5	3.6	2.0					2524
847521	PERU	HUANCAYO	-12.12	-75.33	3380	jun	5.84	6.03	*10.2*	2.9	0.7					1459
984300	PHILIPPINES	SCIENCE GARD	14.63	121.02	45	dec	3.58	3.77	*u*	*16.8*	*6.2*	*16.0*	*10.5*	*5.9*		10280
684420	RSA	BLOEMFONTEIN	-29.10	26.30	1351	jun	3.75	3.73	3.7	2.6	2.0	3.8	2.6	2.2		4258
682621	RSA	PRETORIA / F	-25.73	28.18	1330	jun	3.85	3.97	4.5	3.1	2.5					3620
616410	SENEGAL	DAKAR / YOFF	14.73	-17.50	27	dec	4.56	4.71	9.3	4.0	3.1					9185
616270	SENEGAL	LINGUERE	15.38	-15.12	20	jan	4.77	4.29	*4.3*	*2.5*	*1.8*				dec, P, 11%	2312
616870	SENEGAL	TAMBACOUNDA	13.77	-13.68	49	dec	3.90	3.81	6.5	2.4	1.7					2040
486980	SINGAPORE	SINGAPORE /	1.37	103.98	5	nov	3.88	3.93	11.8	5.6	4.4					10249
434660	SRI LANKA	COLOMBO	6.9	79.87	7	dec	4.74	4.57	*6.1*	*3.2*	*2.3*				jun, P,S	4196
627950	SUDAN	ABU NA'AMA	12.73	34.13	445	dec	5.75	5.81	*9.7*	*6.0*	*1.1*					9666
628400	SUDAN	MALAKAL	9.55	31.65	387	jul	4.85	5.00	*22.6*	*9.3*	*2.2*					7513
627230	SUDAN	SHAMBAT OBS.	15.67	32.53	380	dec	5.51	5.74	7.5	2.2	1.5					10309
626710	SUDAN	TOKAR	18.43	37.73	19	jan	3.18	----	*11.4*	*7.4*	*2.5*					3166
638940	TANZANIA	DAR ES SALAA	-6.87	39.20	55	apr	3.88	3.93	*u*	*9.2*	*2.4*					4195
638620	TANZANIA	DODOMA	-6.17	35.77	1119	may	5.38	5.13	*u*	*6.6*	*0.6*				apr	4137
638160	TANZANIA	SAME	-4.08	37.72	872	may	3.69	4.06	11.3	5.8	2.7	12.5	7.7	2.7	jul, 9%,S	2797
639620	TANZANIA	SONGEA	-10.68	35.58	1067	jul	3.79	----	12.0	6.5	4.6					3010
483270	THAILAND	CHIENG MAI	18.78	98.98	312	aug	4.30	4.26	*10.8*	5.2	3.8					2402
637050	UGANDA	ENTEBBE ARPT	0.05	32.45	1155	jul	4.29	4.53	*4.0*	*2.8*	*1.6*					4745
636300	UGANDA	GULU	2.75	32.33	1104	jul	4.30	4.45	*12.4*	6.2	2.1					4656
636820	UGANDA	JINJA	0.45	33.18	1175	jul	4.36	----	9.1	5.6	1.6	9.5	5.0	1.8		3895
636740	UGANDA	KASESE	0.18	30.10	959	jul	4.35	4.45	7.9	5.8	3.1	10.3	4.9	2.5		4502
636540	UGANDA	MASINDI	1.68	31.72	1146	jul	4.80	4.94	*u*	*u*	*u*					4683
804130	VENEZUELA	MARACAY	10.25	-67.65	436	dec	4.29	4.45	*u*	*6.5*	*2.8*					10522
804570	VENEZUELA	PUERTO AYACUCH	5.6	-67.50	73	jun	3.60	3.77	*15.5*	3.6	1.9				P	10338
804620	VENEZUELA	S. ELENA	4.6	-61.12	907	jun	4.28	4.57	*u*	*u*	*u*				nov, 6%	9942
804530	VENEZUELA	TUMEREMO	7.3	-61.45	180	dec	3.91	3.9	14.3	4.3	0.8					10430
641800	ZAIRE	BUKAVU	-2.52	28.85	1612	nov	4.60	4.70	**5.7**	**3.3**	**2.3**	6.3	2.9	1.8		5962
640400	ZAIRE	KISANGANI	0.52	25.18	415	jul	4.02	4.06	**4.0**	**2.4**	**1.3**	4.9	2.4	1.3		5137
640050	ZAIRE	MBANDAKA	0.05	18.27	345	jul	3.96	4.03	9.3	3.6	1.7				jun,P,D	9037
676660	ZAMBIA	LUSAKA CITY	-15.42	28.32	1280	feb	4.94	4.84	10.2	4.7	2.1				jan,S	2037
679640	ZIMBABWE	BULAWAYO /	-20.15	28.62	1343	jun	4.63	4.70	6.4	5.4	4.7					10738
677740	ZIMBABWE	HARARE /	-17.83	31.02	1471	jun	4.68	4.80	**6.3**	**3.8**	**3.2**	6.0	4.0	2.8		8365

Table 1 (continued from p. 9). The principal results of this work. For detailed explanation see text and Table 1a.

1	Station number in WRDC classification
2	Month with the lowest mean daily solar radiation according to WRDC data
3	Mean daily solar radiation for the worst month, in kWh/m2
4	Results for Days of Autonomy for specific CA (=A:L) values, as indicated. Results in bold come from what appear to be particularly reliable data ((see Sec. 3.4 of the Report). Values in italics indicate results with uncertain accuracy. Numbers at the bottom of the heading indicate the Array Oversize Factors CA.
5	DoA values obtained for the climatic cycles with the lowest value for the period of WRDC data. u indicates data too unreliable to obtain meaningful results
6	Wherever meaningful, results obtained by procedure described in Sec. 3.4. Extrapolated results shown in bold recommended as likely to be more reliable than the corresponding directly derived values.
7	A month, when given, corresponds to the “worst month” according to Meteonorm, where this is different from the WRDC worst month.
	"P" refers to Meteonorm message “Use of precalculated radiation map based on satellite and ground information due to low density of network” issued with the data.
	“D” signifies a discrepancy between several monthly mean solar radiation values given by Meteonorm and calculated from WRDC data (see the appropriate station file for more detail)
	“S” signifies a significant difference between monthly mean solar radiation values given by Meteonorm and calculated from WRDC data (see the appropriate station file for more detail).
	A percentage, when given, indicates the discrepancy between the W. Month average values according to Meteonorm and WRDC (only specified if greater than 5%).
8	Total number of data, including any missing values within the time series.

Table 1a. Notes to headings of Table 1.

ABU NA'AMA	Results omit two very large climatic cycles, with data of uncertain accuracy.
ADDIS ABABA	Excluded from the analysis are the short stretches of data and several climatic cycles on account of missing data.
ANTANANARIVO	Two disparate segments of data. One segment gives apparent overestimate in DoA, one an underestimate. No reliable results are possible.
AREQUIPA	Two segments of data with a shift between them.
BISSAU ARPT	DoA results come from a single climatic cycle near 1974. It is unclear whether this is a real effect. If not included DoA for CA=1.0 would be reduced substantially, with a smaller reduction for CA=1.1 and 1.25.
BOMBAY	Large number of missing data (particularly near the largest climatic cycle which has been omitted) make it difficult to make an reliable assessment of accuracy.
CALCUTTA /	Results obtained by a combination of data for two sites. Despite a long series of data, it is difficult to assess the accuracy of results due to large number of missing data. Extrapolated results possibly more accurate
CHIENG MAI	Accuracy of DoA for CA=1.0 uncertain on account of missing data.
CISNE ISLS	Meteonorm data for Swan Island.
COLOMBO	Data in several segments which do not seem to agree. Accuracy difficult to judge.
COPIAPO	Data in two segments with a shift which has some effect on DoA
DAR ES SALAA	Data for CA=1.0 and 1.1 show a large climatic cycle which can be ascribed to a prominent dip in solar radiation data, lasting for several years, with uncertain accuracy
DILLI ARPT	A large climatic cycle due to an interval with a sudden shift towards low solar radiation data which may not be very reliable.
DJIBOUTI	A pronounced shift in solar radiation data towards the end of the time series giving the reported climatic cycles
DODOMA	Data for CA=1.0 and 1.1 show a large climatic cycle which can be ascribed to a prominent dip in solar radiation data with uncertain accuracy.
ENTEBBE ARPT	A change in the pattern of solar radiation data in the autumn of 1972. DoA results take into account only climatic cycles prior to this time.
GULU	A pronounced climatic cycle due to a dip in solar radiation data in 1968-69 lasting for almost one year
HUANCAYO	Two segments of data with some shift between them.
LA UNION	A shift in solar radiation data in second half of the time series gives rise to large climatic cycles, of uncertain reliability. Reported results based on the first 6 years of data.
LE RAIZET	A pronounced shift in solar radiation data after the first 7 years may explain the high worst month average in comparison with Meteonorm
LINGUERE	A short data series, of uncertain accuracy
LODWAR	A pronounced shift in the radiation data during the last 5-10 years towards higher values which may explain, at least partially, the very high WRDC worst month average. Results do not appear reliable enough to report.
LUANDA	Best estimate based on available data

Table 1b (continued on p. 13). Notes to table 1 on individual stations

MACAU	I am at a loss to explain these very high DoA values, especially as they come from a long series of solar radiation data. Perhaps the Meteonorm monthly mean data for Hong Kong in the station file will provide a clue ?
MALAKAL	Large DoA values for CA=1 and CA=1.1 uncertain due to missing data
MASINDI	A sudden change in solar radiation data in mid 1969, giving an unreliable value of the worst month average and the resulting DoAs. Results too unreliable to report.
MULTAN	Accuracy of data resulting in the most significant climatic cycle suspect. Values in extrapolated/other column give results if this cycle is omitted.
NAMPULA	Data of uncertain accuracy. Values in extrapolated/other column give results if the most significant climatic cycle is omitted.
ORIZABITA	Climatic cycles at the end of the time series of data omitted due to suspect solar radiation data.
PRETORIA / F	Results based on data from Pretoria Forum which, although generally consistent with data from Pretoria, give slightly larger DoA values
PUERTO AYACUCHO	Results for CA=1.0 due to one large climatic cycle, of uncertain accuracy
QUETTA /	All significant climatic cycles due to a decrease of solar radiation data after mid 1987.
S. SALVADOR	Two disparate segments of data. One segment gives an apparent overestimate in DoA, one an underestimate. No reliable results possible.
SCIENCE GARD	DoA values in "directly derived" column are from a large climatic cycle at the end of 1969, due to data of uncertain accuracy. DoA values in "extrapolated" column (possibly more credible) if this climatic cycle is excluded.
TOKAR	A large climatic cycle due to suspect solar radiation data. DoA results given are with this climatic cycle omitted.
TUMEREMO	Gradual shift in solar radiation data. Accuracy of results uncertain.

Table 1b (continued from p. 12). Notes to table 1 on individual stations.

Tab	Explanation
data	DoA data, plotted in charts CA=1.0, CA=1.1, and CA=1.25, as follows: Column A: Date, in a fraction of year format (i.e. each day corresponds to 1/365 = 0.0274. For example, 64.236 corresponds to day 86 = 365 * 0.236 in 1964) Columns B-D: DoA values for CA=1.0, CA=1.1, and CA=1.25 Column E: Missing data indicator, as follows: 1 = a single missing day 2 = several missing days in succession
CA=1.0, CA=1.1, CA=1.25	Charts of the DoA values for the corresponding Array Oversize Factor CA. The minima of graphs give the Days of Autonomy, plotted against the dates when they occur. Points at the bottom of graphs indicate missing data (see Fig 7). Additional, more detailed, DoA graphs may also be present to enable closer analysis, when needed. Such tabs are denoted by dates or as cc1, cc2, etc.
c cycles	A list of the most significant climatic cycles, together with the date of minimum in the cycle (maximum energy deficit), and the total length of the cycle, in days. Colour highlights indicate cycles that have been omitted (yellow) or included (green). Green highlight is not always indicated explicitly. See comments against station in Days_of_Autonomy.xls spreadsheet or Table 1b for more detail.
radiation data	Column A: Date, in fraction of year format (see “data” tab above). Column B: Daily solar radiation, in kWh/m^2. Number 10 indicates more than one missing day, in succession. Column C: Constant equal to the mean daily solar radiation during the worst month, as determined by the WRDC data.
rad chart	Plot of radiation data. Other plots may also be present to show a particular period of data in more detail. Such sheets may be denoted by, for example, radn 80-83.
meteonorm	Mean monthly solar radiation and ambient temperature data from Meteonorm. In the case of disagreement between monthly means of daily solar radiation given by Meteonorm and WRDC, an additional column gives the WRDC mean daily solar radiation values, in kWh/m^2.

Table 2. Notes for worksheets with details of 97 station files.

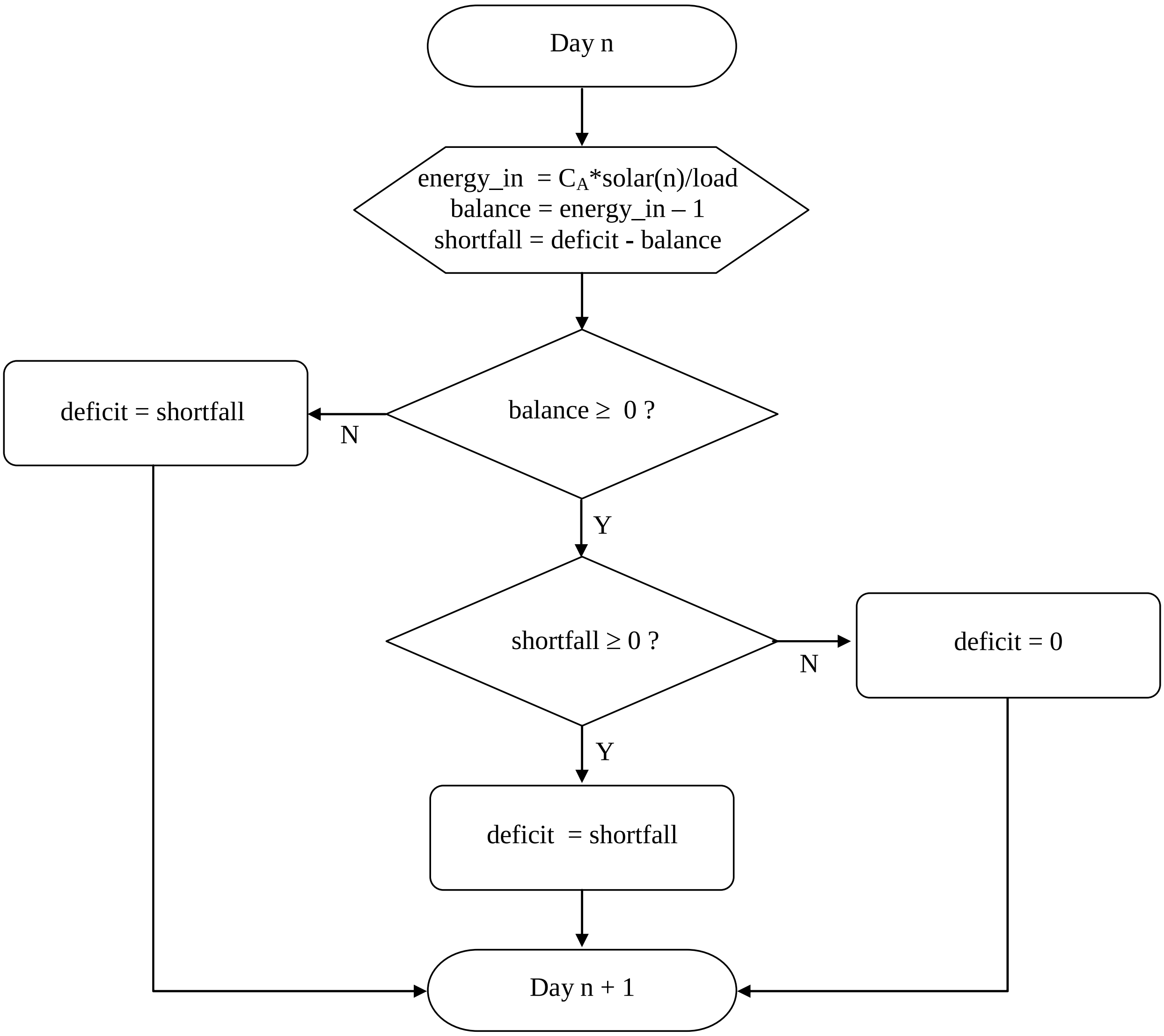


Fig. 1. The system model flow chart. © University of Southampton

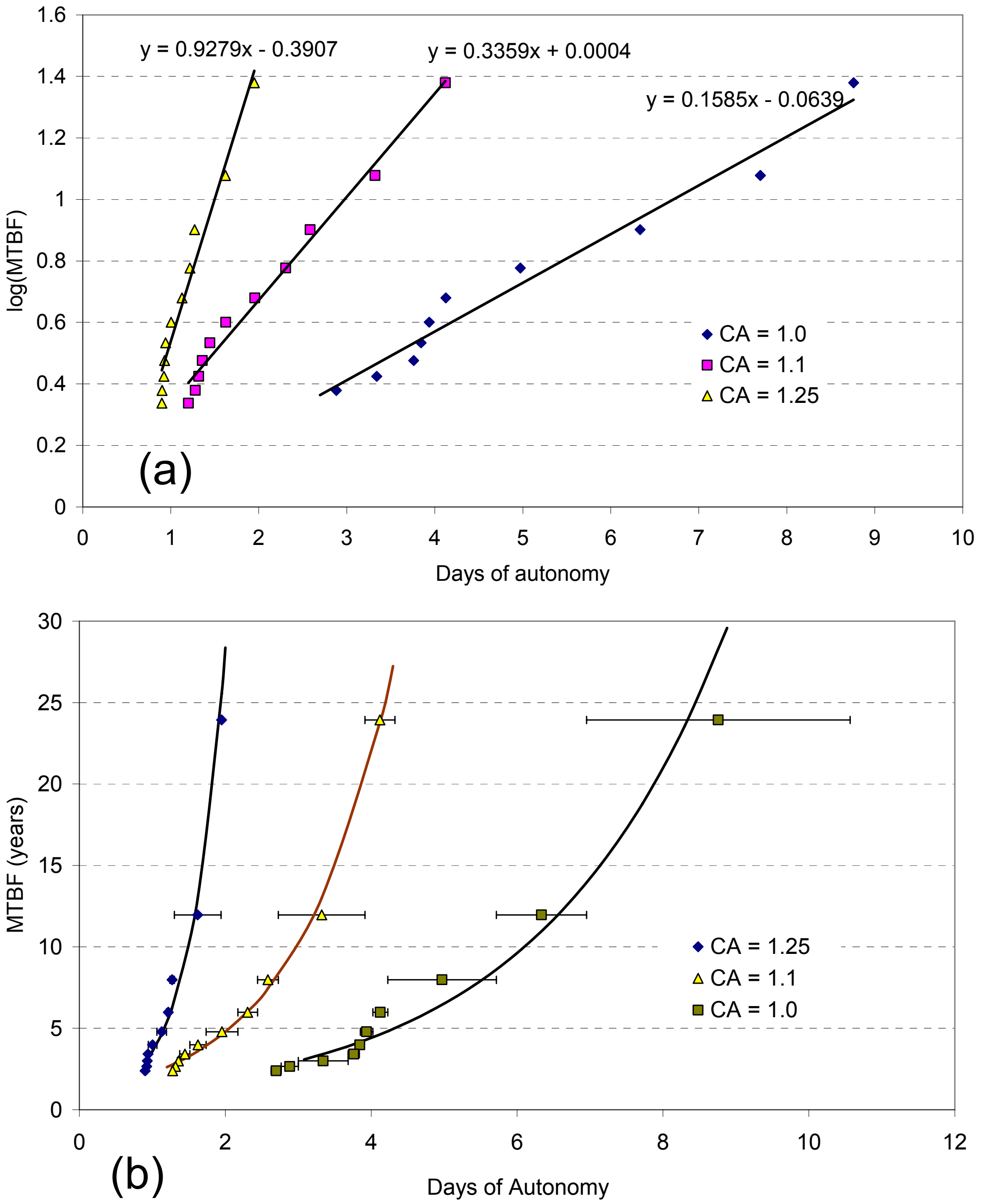
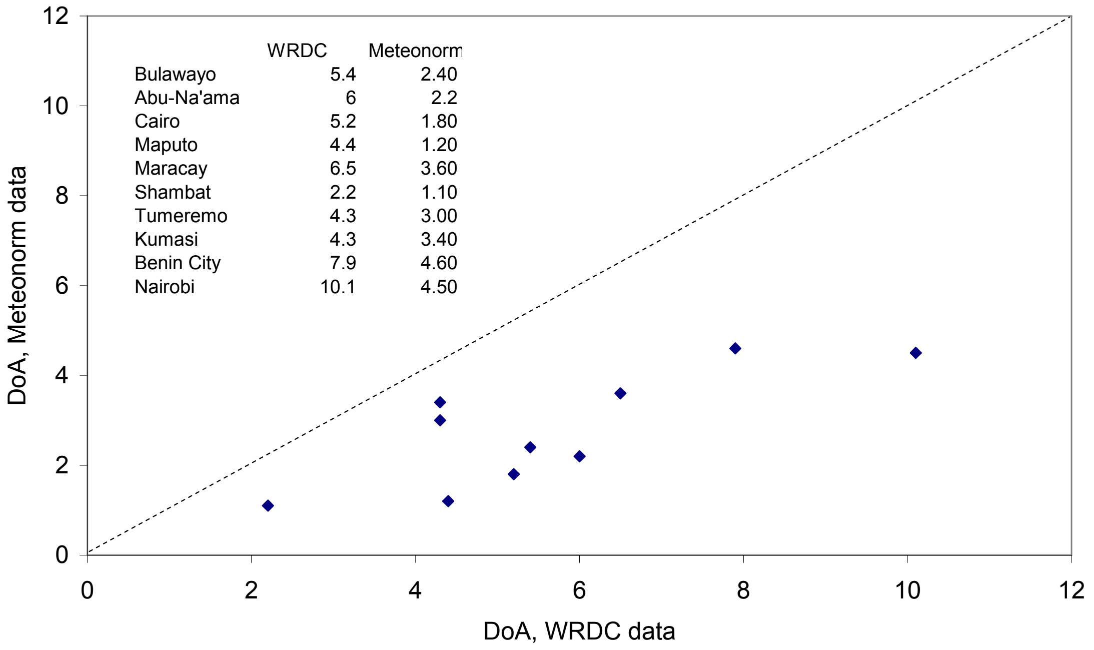
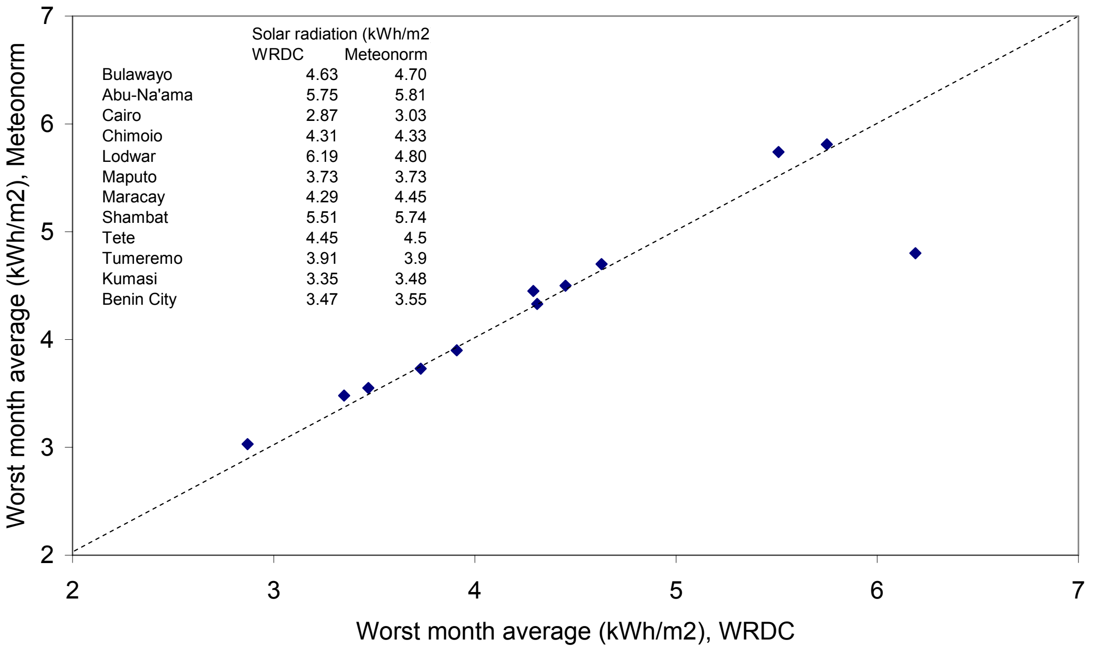


Fig. 2. An illustration of the method for fitting the dependence between the frequency of climatic cycles (interpreted as MTBF) and the required number of Days of Autonomy, on the example of WRDC data for Kumasi (Ghana). (a) The log-linear dependence, used to obtain the coefficient of the fit (Eq. (1)). (b) Actual dependence.



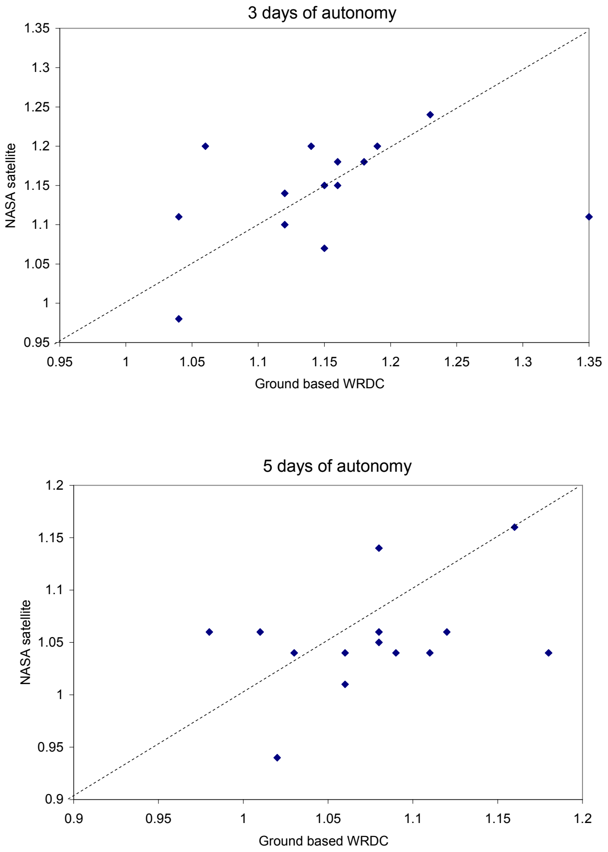
	WRDC	Meteonorm
Bulawayo	5.4	2.40
Abu-Na'ama	6	2.2
Cairo	5.2	1.80
Maputo	4.4	1.20
Maracay	6.5	3.60
Shambat	2.2	1.10
Tumeremo	4.3	3.00
Kumasi	4.3	3.40
Benin City	7.9	4.60
Nairobi	10.1	4.50

Fig. 3. Comparison between DoA values obtained using Meteonorm and WRDC data for ten stations in the tropics.



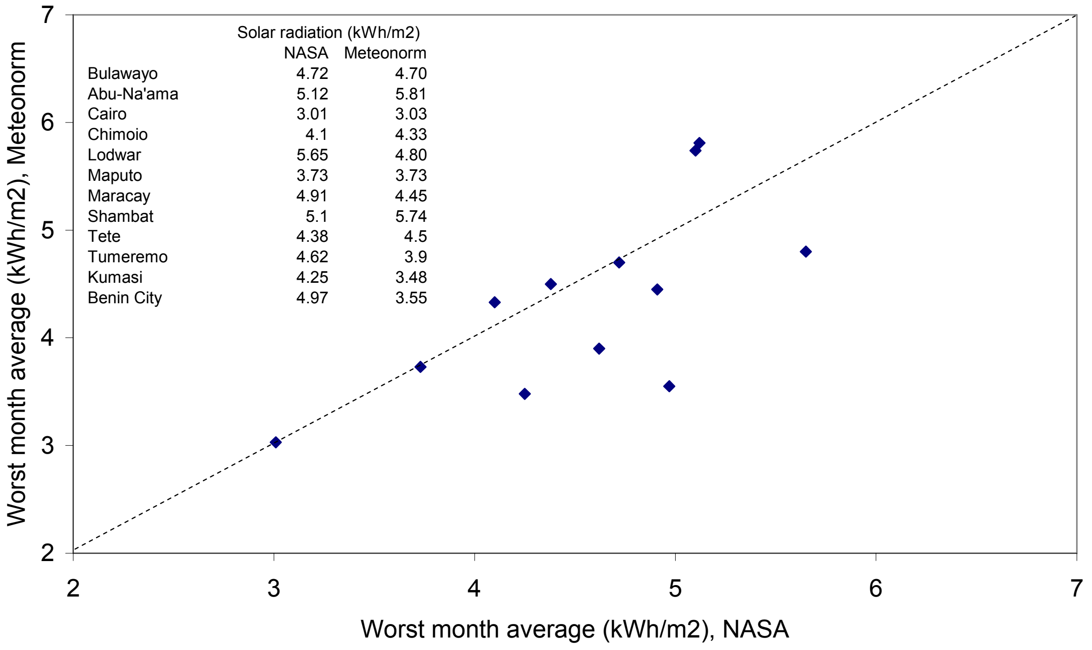
	Solar radiation (kWh/m2	
	WRDC	Meteonorm
Bulawayo	4.63	4.70
Abu-Na'ama	5.75	5.81
Cairo	2.87	3.03
Chimoio	4.31	4.33
Lodwar	6.19	4.80
Maputo	3.73	3.73
Maracay	4.29	4.45
Shambat	5.51	5.74
Tete	4.45	4.5
Tumeremo	3.91	3.9
Kumasi	3.35	3.48
Benin City	3.47	3.55

Fig. 4. Comparison of the mean daily solar radiation during the worst month according to Meteonorm and WRDC for 12 stations in the tropics.



	WRDC		NASA	
	5 days	3 days	5 days	3 days
Bulawayo	1.03	1.12	1.04	1.14
Abu-Na'ama	1.12	1.19	1.06	1.2
Boende	0.98	1.04	1.06	1.11
Cairo	1.08	1.14	1.14	1.2
Chimoio	1.06	1.16	1.04	1.18
Lodwar	1.16	1.23	1.16	1.24
Maputo	1.06	1.16	1.01	1.15
Maracay	1.11	1.18	1.04	1.18
Narok	1.18	1.35	1.04	1.11
Shambat	1.02	1.04	0.94	0.98
Tete	1.01	1.06	1.06	1.2
Tumeremo	1.08	1.12	1.06	1.1
Kumasi	1.09	1.15	1.04	1.07
Benin City	1.08	1.15	1.05	1.15

Fig. 5. Comparison between the Array Oversize Factor for 14 stations produced using WRDC and NASA satellite based data for 3 and 5 days of autonomy.



	Solar radiation (kWh/m2)	
	NASA	Meteonorm
Bulawayo	4.72	4.70
Abu-Na'ama	5.12	5.81
Cairo	3.01	3.03
Chimoio	4.1	4.33
Lodwar	5.65	4.80
Maputo	3.73	3.73
Maracay	4.91	4.45
Shambat	5.1	5.74
Tete	4.38	4.5
Tumeremo	4.62	3.9
Kumasi	4.25	3.48
Benin City	4.97	3.55

Fig. 6. Comparison of the worst month average daily solar radiation according to Meteonorm and NASA data for 12 sites in the tropics.

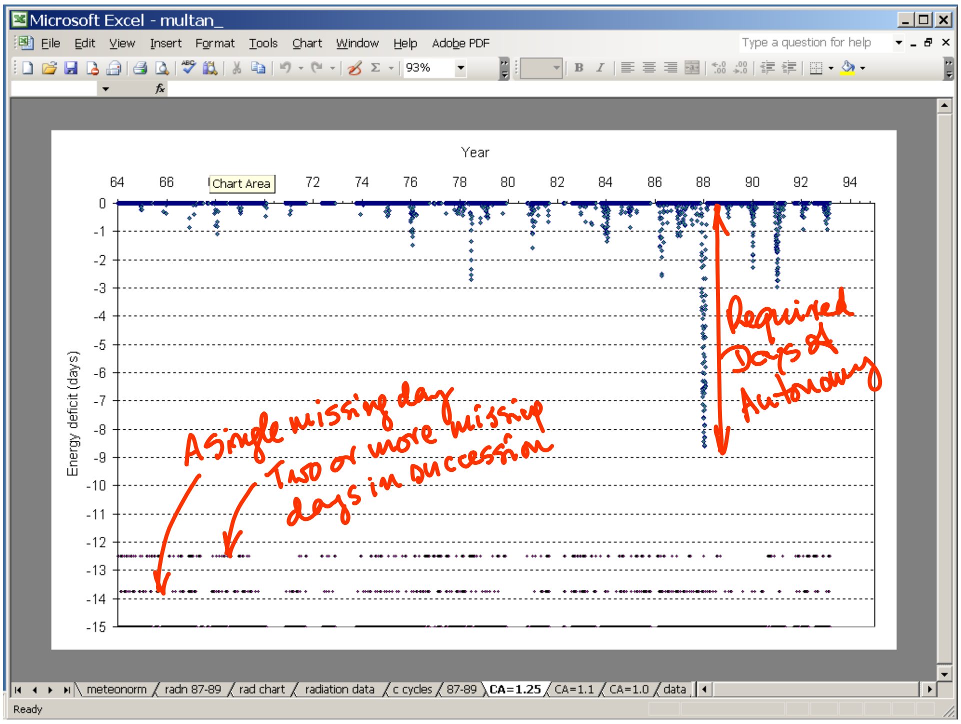


Fig. 7. A worksheet in a station file depicting the determination of the Days of Autonomy from the graph, and the dates of the missing solar radiation values

Solar Energy Consulting

Days of solar autonomy for 132 tropical locations

Prepared for: World Health Organisation / Programme for Appropriate Technology in Health (PATH)

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1. Introduction

This report describes work carried out under the work order 01568.WKO to determine the required number of days of autonomy for a high-reliability stand-alone photovoltaic system operating in the tropics.

The methodology used to determine the Days of Autonomy in this report is based on a technique developed in the Solar Energy Laboratory at Southampton University [1] which provides a rigorous link between observed solar radiation data and the number of days of autonomy. Details of this procedure and data analysis can be found in a previous report [2]. The method builds on broader features of stand-alone PV system operation as described in the IEEE standard [3] which should be consulted for the context and background information.

2. Abbreviations

A:L ratio	Array to Load Ratio, used synonymously with Array Oversize Factor
CA	Array Oversize Factor, used synonymously with A:L ratio
DoA	Days of Autonomy
PV	Photovoltaic
WRDC	World Radiation Data Centre

3. Work carried out

138 sites in the WRDC database within the tropics have been analyzed to determine the required number of Days of Autonomy required by an autonomous solar vaccine refrigeration system. These sites were selected principally on the rationale that the minimum length of the time series of daily solar radiation data to produce adequate accuracy for the Days of Autonomy is 5 years (nominally 1826 days). The sites in this report thus effectively complete the locations in the tropics where these data are available in the WRDC database. Eleven other stations (Table 1) were added due to their importance for WHO/PATH work. Six other stations (Table 2), with data marginally fewer than the 1826 required, were added for completeness by the authors of this report.

Results of the work are presented in Tables 3 - 5 and on an accompanying CD-ROM which contains the following Microsoft Excel files:

- DaysOfAutonomy-Project_2.xls. The information contained in this spreadsheet is identical to that given in Tables 3-5.
- A folder with 138 Excel files (referred to as the station files), each with the title of an individual station followed by “_f” .

Table 3 gives the number of Days of Autonomy determined in this work, geographical information for the stations, and other information that may be relevant to the users, as detailed in Table 4. Table 5 gives notes to the various stations where difficulties were encountered in processing the data. Individual station files give the daily solar radiation data, more detailed information about the climatic cycles leading to the results in Table 3, and monthly means of daily solar radiation and temperature as given by Meteonorm 6.0, when this information is available.

References

1. T. Markvart, K. Fragaki and J.N. Ross, PV system sizing based on observed time series of solar radiation, *Solar Energy*, Vol. 80, pp. 46-50, 2006

2. H. Toma and T. Markvart, Report 08/MT/00505/C: Solar Autonomy Calculation Tool, Research Institute for Industry, University of Southampton (2008).

WRDC no.	Country	Station	No. of data
605710	ALGER	BECHAR	1307
419230	BANGLADESH	DHAKA	1185
419770	BANGLADESH	CHITTAGONG	1618
967450	INDONESIA	JAKARTA OBS.	973
967451	INDONESIA	BANDUNG	761
610430	NIGER	TAHOUA	914
652020	NIGERIA	LAGOS / OSHO	760
844010	PERU	PIURA	1399
847522	PERU	PAMPA DE MAJES	1095
607150	TUNISIA	TUNIS / CARTHAGE	1460
488200	VIETNAM	HANOI	1095

Table 1. Stations included with significantly fewer data than 5 years

WRDC no.	Country	Station	No. of data
664100	ANGOLA	MENONGUE	1795
617810	GUINEA-BISSAU	BAFATA	1822
671610	MADAGASCAR	TULEAR	1796
964130	MALAYSIA	KUCHING	1705
964710	MALAYSIA	KOTA KINABALU	1766
637910	TANZANIA	KILIMANJARO ARPT	1764

Table 2. Stations included with marginally fewer data than 5 years

WRDC No.[1]	Country	Station name	Lat	Long	Alt	Worst month[2]	W. Month average[3]		Days of autonomy[4]						No. of WRDC data[8]	Comment (met.data)[7]
									directly derived[5]			extrapolated / other[6]				
							WRDC	Meteon	1.0	1.1	1.25	1.0	1.1	1.25		
605710	ALGER	BECHAR	31.62	-2.23	773	dec	3.50	3.45	3.1	1.7	1.1	4.6	2.6	1.4	1307	
606800	ALGER	TAMANRASSET	22.78	5.52	1378	dec	4.45	4.58	2.6	2.3	1.7	3.8	3.1	2.4	1883	
662150	ANGOLA	MALANGE	-9.55	16.37	1139	aug	4.63	4.97	*9.3*	*2.5*	*1.3*	cannot reliably fit			3224	jul
662851	ANGOLA	NOVA LISBOA	-12.73	15.83	1700	apr	5.02	5.13	4.1	2.7	1.7	5.6	3.4	2.0	2010	
663900	ANGOLA	LUBANGO /	-14.93	13.57	1758	mar	5.23	No Met	5.7	3.4	1.9	8.0	3.8	2.1	1856	
664100	ANGOLA	MENONGUE /	-14.65	17.68	1348	jun	5.21	No Met	7.8	2.3	1.1	9.5	2.6	1.4	1795	
664220	ANGOLA	MOCAMEDES	-15.20	12.15	43	jul	3.40	3.58	4.6	3.2	2.1	cannot reliably fit			3650	
419230	BANGLADESH	DHAKA	23.77	90.38	8	jan	4.08	4.19	5.2	2.5	2.0	6.7	3.9	2.4	1185	
419770	BANGLADESH	CHITTAGONG /	22.35	91.82	33	jan	4.35	4.42	4.8	3.7	2.9	7.9	5.2	3.5	1618	
789550	BARBADOS	HUSBANDS	13.15	-59.62	113	nov	4.44	4.63	3.1	2.2	2.0	3.6	2.9	2.1	3616	
655030	BURKINA FASO	OUAGADOUGOU	12.35	-1.52	316	dec	5.33	5.42	3.9	1.6	1.3	5.1	1.8	1.3	3255	
655070	BURKINA FASO	FADA N'GOURM	12.03	0.37	308	aug	5.19	5.29	**4.6**	**2.2**	**1.5**	**4.6**	**2.2**	**1.4**	3497	
655100	BURKINA FASO	BOBO-DIOULAS	11.17	-4.32	460	aug	5.35	5.45	7.3	4.8	3.2	cannot reliably fit			2617	
85850	CAPE VERDE	MINDELLO	16.88	-25.00	2	dec	4.26	no Met	*6.3*	*2.9*	*1.6*	*8.4*	*3.3*	*1.6*	3649	
85890	CAPE VERDE	PRAIA	14.90	-23.52	27	dec	4.13	no Met	*2.8*	*1.8*	*1.2*	*4.1*	*2.4*	*1.8*	3678	
854690	CHILE	PASCUA IS.	-27.17	-109.43	69	jun	2.33	2.50	*6.4*	*2.3*	*2.1*	cannot reliably fit			2009	
854860	CHILE	VALLENAR	-28.60	-70.77	526	jun	2.74	2.87	4.7	3.0	2.3	not fitted			2770	
574940	CHINA	WUHAN	30.62	114.13	23	jan	1.64	2.00	30.6	25.2	17.1	35.6	29.8	21.7	2006	P-Met, 18%
623450	EGYPT	TAHRIR	30.65	30.70	16	dec	3.05	3.03	*8.0*	*4.4*	*1.8*	*5.4*	*3.1*	*1.4*	10830	
623690	EGYPT	BAHTIM	30.13	31.25	17	dec	3.02	3.00	**6.5**	**3.6**	**1.8**	**6.2**	**3.2**	**1.6**	9431	
623920	EGYPT	ASYUT	27.20	31.17	52	dec	3.53	3.90	5.1	3.8	2.8	4.8	3.4	2.5	5110	10%
624140	EGYPT	ASWAN	23.97	32.78	192	dec	4.31	4.77	2.5	2.0	1.7	2.6	2.0	1.7	5110	10%
786623	EL SALVADOR	S. TECLA	13.68	-88.28	965	sep	1.94	No Met	data unreliable - unable to process						4531	
786624	EL SALVADOR	S. CRUZ	13.43	-88.82	30	jun	2.33	No Met	*3.1*	*2.0*	*1.6*	*3.2*	*2.2*	*2.0*	4653	
916800	FIJI	NANDI	-17.75	177.45	13	jun	3.80	3.90	*12.7*	*7.4*	*4.2*	not fitted			9944	
654180	GHANA	TAMALE	9.50	-0.85	168	aug	4.24	4.42	*9.3*	*3.0*	*1.1*	*8.6*	*3.5*	*1.3*	4626	
654531	GHANA	TAFO	6.25	-0.38	195	aug	3.34	3.39	8.3	4.7	3.1	9.0	5.9	3.7	2312	
654600	GHANA	AKUSE	6.10	0.12	17	jul	4.04	4.00	**4.1**	**1.7**	**0.9**	**5.4**	**2.0**	**1.0**	2279	jan
654670	GHANA	TAKORADI	4.88	-1.77	5	aug	4.00	4.23	10.4	5.2	2.8	9.3	4.5	3.2	6236	
654720	GHANA	ACCRA	5.60	-0.17	68	jul	3.70	4.32	data unreliable - unable to process						4807	15%
617810	GUINEA-BISSAU	BAFATA	12.18	-14.67	42	aug	3.79	3.52	9.2	2.5	1.5	11.2	4.1	2.2	1822	8%
450040	HONG KONG	KING'S PARK	22.32	114.17	65	mar	2.55	2.27	22.3	14.8	11.4	not fitted			7300	feb, 12%
425160	INDIA	SHILLONG	25.57	91.88	1598	sep	3.78	3.87	8.8	5.9	4.3	7.5	5.5	4.0	9246	
428380	INDIA	BHAUNAGAR	21.75	72.20	5	aug	4.27	4.26	**6.7**	**5.4**	**4.5**	**6.0**	**5.0**	**4.0**	9002	
430630	INDIA	POONA	18.53	73.85	555	aug	4.39	4.48	6.5	4.2	2.6	6.8	4.6	2.8	10161	
431490	INDIA	VISHAKHAPATN	17.72	83.23	3	jul	4.62	4.68	6.8	5.1	4.5	6.3	4.4	3.6	10067	
431920	INDIA	GOA / PANJIM	15.48	73.82	58	jul	3.95	3.74	*9.5*	*6.4*	*4.5*	*7.1*	*5.0*	*3.6*	10004	
433710	INDIA	TRIVANDRUM	8.48	76.95	60	nov	4.81	4.43	8.5	6.9	5.1	8.4	5.8	4.1	10494	jun, 8%
967450	INDONESIA	JAKARTA OBS.	-6.18	106.83	8	may	3.34	4.23	4.9	3.0	1.8	not fitted			973	P-Met, dec, 21%
967451	INDONESIA	BANDUNG /	-6.83	107.62	1310	may	3.30	3.84	4.6	2.6	1.6	6.0	4.1	2.7	761	P-Met, dec, 14%
636240	KENYA	MANDERA	3.93	41.87	230	jul	4.41	4.45	*9.6*	*4.7*	*2.3*	*8.2*	*4.1*	*1.8*	9521	
636610	KENYA	KITALE	1.02	35.00	1890	jul	5.34	4.52	8.1	3.4	2.1	8.0	3.8	2.0	9735	P-Met, 18%
636860	KENYA	ELDORET	0.53	35.28	2120	jul	5.24	4.39	12.4	6.2	2.9	cannot reliably fit			7299	P-Met, 19%
636861	KENYA	NANYUKI	0.02	37.07	1947	nov	4.44	No Met	5.8	3.1	1.7	8.6	4.1	2.2	2769	

Table 3. Days of Autonomy - part 1

637080	KENYA	KISUMU	-0.10	34.75	1157	jul	5.78	4.74	*4.0*	*2.3*	*1.5*	cannot reliably fit			9366	P-Met, 22%
637140	KENYA	NAKURU	-0.27	36.10	1901	jul	5.65	4.10	*4.3*	*2.6*	*1.5*	not fitted			9218	P-Met, 38%
637230	KENYA	GARISSA	-0.47	39.63	138	jul	5.45	5.23	*8.3*	*1.9*	*1.1*	not fitted			10674	
637371	KENYA	MUGUGA	-1.22	36.63	2096	jul	3.67	3.90	6.8	4.3	2.2	10.6	4.8	2.6	2524	
637720	KENYA	LAMU	-2.27	40.90	30	jun	4.82	4.93	6.2	3.3	2.1	7.0	3.7	2.5	3010	
637930	KENYA	VOI	-3.40	38.57	579	aug	4.27	4.23	9.0	3.8	1.4	8.2	3.5	1.3	8851	
637990	KENYA	MALINDI	-3.23	40.10	20	may	4.58	4.63	13.4	4.9	2.9	cannot reliably fit			8154	jun
638200	KENYA	MOMBASA /	-4.03	39.62	57	jul	4.44	4.63	10.1	4.4	2.4	11.4	5.2	2.5	8272	jun
671610	MADAGASCAR	TULEAR	-23.38	43.73	8	jun	2.99	4.17	*5.8*	*2.0*	*1.2*	cannot reliably fit			1796	P-Met, 28%
486010	MALAYSIA	PINANG /	5.30	100.27	3	oct	4.54	4.45	21.3	13.2	4.7	19.7	10.4	4.0	6571	
964130	MALAYSIA	KUCHING	1.48	110.33	27	jan	3.44	3.52	5.2	3.7	2.9	8.9	6.1	3.5	1705	
964710	MALAYSIA	KOTA KINABALU	5.93	116.05	3	dec	5.09	4.23	6.4	4.3	2.6	7.9	5.2	2.9	1766	P-Met, 20%
789250	MARTINIQUE	LE LAMENTIN	14.60	-61.00	5	nov	4.44	4.43	*9.5*	*4.2*	*3.6*	cannot reliably fit			7180	
672150	MOZAMBIQUE	PEMBA	-12.97	40.50	49	jun	4.83	4.83	*8.4*	*3.9*	*2.9*	*8.6*	*4.9*	*3.8*	6781	
672170	MOZAMBIQUE	LICHINGA	-13.28	35.25	1364	jun	4.65	4.80	**12.6**	**5.8**	**3.2**	**11.8**	**4.8**	**2.7**	6633	apr
672371	MOZAMBIQUE	GURUE	-15.47	36.98	734	jun	4.01	4.06	**7.4**	**3.2**	**2.3**	**7.3**	**3.4**	**2.2**	4195	jul
672410	MOZAMBIQUE	LUMBO	-15.03	40.67	10	jun	4.38	4.23	8.1	5.0	4.1	not fitted			7543	
672610	MOZAMBIQUE	TETE	-16.18	33.58	123	jun	4.45	4.50	5.8	2.9	2.1	5.3	2.5	1.7	8608	
672650	MOZAMBIQUE	MOCUBA	-16.83	36.98	134	jun	3.86	3.90	9.4	4.7	1.7	cannot reliably fit			5411	
672970	MOZAMBIQUE	BEIRA	-19.80	34.90	10	jun	4.21	4.23	**6.5**	**3.7**	**2.1**	**5.2**	**3.0**	**2.1**	9857	
673080	MOZAMBIQUE	CHICUALACUAL	-22.08	31.68	452	jun	4.07	4.07	8.7	5.5	2.8	cannot reliably fit			3620	
673230	MOZAMBIQUE	INHAMBANE	-23.87	35.38	14	jun	3.71	3.47	6.8	3.1	1.9	6.9	2.6	2.0	8001	7%
673231	MOZAMBIQUE	CHOKWE	-24.52	33.00	33	jun	3.57	3.47	5.8	2.3	1.6	cannot reliably fit			10432	
673232	MOZAMBIQUE	MANIQUENIQUE	-24.73	33.53	13	jun	3.49	3.50	5.3	2.5	2.1	5.5	2.2	1.7	7723	
673412	MOZAMBIQUE	UMBELUZI	-26.05	32.38	12	jun	3.11	No Met	*13.4*	*4.7*	*2.2*	not fitted			7392	
915770	NEW CALEDONIA	KOUMAC	-20.57	164.28	23	jun	3.66	3.63	**7.2**	**4.3**	**3.3**	**7.4**	**4.8**	**3.0**	4840	
610430	NIGER	TAHOUA	14.90	5.25	386	dec	5.08	4.52	1.7	0.8	0.8	not fitted-only 2 years data			914	P-Met, 12%
652020	NIGERIA	LAGOS / OSHO	6.55	3.35	19	jul	3.57	3.65	4.4	2.6	1.8	cannot reliably fit			760	P-Met, aug
844010	PERU	PIURA	-5.18	-80.60	49	jul	4.76	4.77	4.3	1.7	0.9	6.9	2.0	1.1	1399	
847522	PERU	PAMPA DE MAJES	-16.35	-72.17	1440	may	4.42	No Met	data unreliable - unable to process						1095	
619800	REUNION	ST-DENIS /	-20.88	55.52	21	jun	3.97	3.97	7.0	4.6	4.1	6.1	4.0	3.4	6537	
682881	RSA	ROODEPLAAT	-25.58	28.35	1164	jun	3.84	3.90	**3.9**	**2.6**	**2.2**	**3.3**	**2.7**	**2.4**	4197	
684060	RSA	ALEXANDER BAY	-28.57	16.53	21	jun	3.50	3.57	**3.4**	**1.5**	**1.2**	**3.4**	**1.6**	**1.1**	3955	
684240	RSA	UPINGTON	-28.40	21.27	836	jun	3.73	3.77	**3.2**	**2.0**	**1.4**	**2.7**	**1.8**	**1.4**	4138	
685880	RSA	DURBAN /	-29.97	30.95	8	jun	3.04	3.07	**5.0**	**2.8**	**2.4**	**4.9**	**3.4**	**2.6**	4258	
619310	SAN TOME&PRINS	S. TOME	0.38	6.72	8	jan	3.93	3.90	*3.1*	*1.6*	*1.1*	not fitted			3770	dec
616120	SENEGAL	PODOR	16.65	-14.97	6	jan	4.06	4.29	4.9	3.5	2.3	6.4	4.6	2.9	2194	P-Met, dec
616121	SENEGAL	LOUGA	15.62	-16.22	38	jan	4.19	no Met	*4.8*	*2.7*	*1.8*	cannot reliably fit			3008	
616300	SENEGAL	MATAM	15.65	-13.25	15	dec	4.27	4.42	6.3	3.1	2.3	6.2	3.4	2.6	2831	P-Met
616411	SENEGAL	BAMBEY	14.70	-16.47	20	dec	4.39	4.84	5.7	2.8	2.4	6.2	4.3	3.0	2097	9%
616950	SENEGAL	ZIGUINCHOR	12.55	-16.27	26	dec	4.18	4.71	data unreliable - unable to process						4256	aug, 11%
626410	SUDAN	PORT SUDAN	19.58	37.22	3	dec	4.03	4.10	*12.3*	*8.6*	*4.2*	*13.5*	*9.2*	*4.7*	7603	
626500	SUDAN	DONGOLA	19.17	30.48	226	dec	5.07	5.45	*5.0*	*2.0*	*0.9*	*4.2*	*2.2*	*1.3*	6076	7%
626820	SUDAN	HUDEIBA	17.57	33.93	350	dec	4.87	5.42	data unreliable - unable to process						5900	10%
627220	SUDAN	AROMA	15.83	36.15	430	dec	4.35	5.58	*7.5*	*1.3*	*0.8*	*7.6*	*1.4*	*0.9*	4080	P-Met, 22%
627350	SUDAN	SHOWAK	14.22	35.85	511	dec	5.20	4.84	*5.6*	*1.2*	*0.7*	*5.9*	*1.4*	*0.8*	3804	7%
627510	SUDAN	WAD MEDANI	14.40	33.48	408	dec	5.82	5.87	9.1	2.3	0.9	7.7	1.6	0.8	10279	

Table 3. Days of Autonomy - part 2

627600	SUDAN	EL FASHER	13.62	25.33	733	dec	5.70	5.74	*13.4*	*5.1*	*1.2*	cannot reliably fit			8421	P-Met
627601	SUDAN	ZALINGEI	12.90	23.48	900	aug	5.50	5.61	7.3	1.5	0.8	cannot reliably fit			3043	
628080	SUDAN	GHAZALA GAWA	11.47	26.45	481	dec	5.63	6.00	data unreliable - unable to process						7845	
628090	SUDAN	BABANUSA	11.33	27.82	453	oct	3.98	5.81	data unreliable - unable to process						2154	P-Met, aug, 31%
628100	SUDAN	KADUGLI	11.00	29.72	499	aug	4.58	5.68	*4.3*	*3.1*	*2.2*	not fitted			4135	jul, 19%
629410	SUDAN	JUBA	4.87	31.60	460	jul	5.02	5.06	9.7	4.4	1.9	9.5	3.9	1.8	8727	
67000	SWITZERLAND	GENEVE	46.25	6.13	416	dec	0.79	0.81	**11.1**	**10.1**	**8.4**	**12.6**	**10.8**	**8.3**	4745	
637290	TANZANIA	BUKOBA	-1.33	31.82	1137	may	4.27	4.00	15.0	6.1	3.6	16.3	6.6	3.2	4137	dec
637560	TANZANIA	MWANZA	-2.47	32.92	1139	dec	5.19	4.71	12.6	3.9	2.8	cannot reliably fit			4195	10%
637910	TANZANIA	KILIMANJARO ARPT	-3.42	37.07	891	jun	3.82	4.23	8.7	5.8	3.4	14.6	8.8	4.5	1764	10%
638010	TANZANIA	KIGOMA	-4.88	29.63	882	nov	4.13	3.73	*11.3*	*9.3*	*6.4*	cannot reliably fit			1946	11%
638320	TANZANIA	TABORA ARPT	-5.08	32.83	1181	nov	5.39	4.94	*19.8*	*7.8*	*4.7*	cannot reliably fit			3892	dec, 9%
638700	TANZANIA	ZANZIBAR /	-6.22	39.22	15	apr	4.32	4.37	**4.3**	**2.2**	**1.1**	**5.1**	**2.1**	**1.3**	3922	
638870	TANZANIA	IRINGA	-7.67	35.75	1426	feb	5.84	5.71	*20.3*	*7.3*	*2.3*	*19.8*	*8.1*	*2.6*	4135	dec
639710	TANZANIA	MTWARA	-10.27	40.18	113	apr	4.18	4.70	7.1	3.0	2.0	9.4	3.2	2.7	2585	P-Met, jun, 11%
484550	THAILAND	BANGKOK	13.73	100.57	2	sep	4.30	4.13	26.1	10.4	3.9	14.3	5.6	3.8	9855	oct
789700	TRINIDAD&TOBAG	PIARCO INT.	10.62	-61.35	12	nov	3.97	4.00	3.7	3.1	2.7	cannot reliably fit			2370	
607150	TUNISIA	TUNIS / CARTHAGE	36.83	10.23	5	dec	2.05	2.42	3.2	1.7	1.5	4.0	2.3	1.9	1460	15%
607151	TUNISIA	SIDI BOUZID	36.87	10.35	127	dec	2.19	2.48	**7.0**	**4.8**	**3.2**	**6.7**	**3.9**	**2.8**	9275	P-Met, 12%
636020	UGANDA	ARUA	3.05	30.92	1204	jul	4.56	4.71	4.4	2.3	1.4	6.5	2.5	1.6	1947	
636800	UGANDA	KAMPALA	0.32	32.62	1144	jul	4.59	4.26	7.5	3.6	2.1	8.5	4.4	2.2	2313	8%
636840	UGANDA	TORORO	0.68	34.17	1170	jul	4.67	No Met	*9.6*	*3.6*	*1.7*	cannot reliably fit			3864	
636841	UGANDA	NAMULONGE	0.53	32.62	1148	jul	4.34	4.35	**5.9**	**2.7**	**1.5**	**6.7**	**3.1**	**1.7**	3620	
637020	UGANDA	MBARARA	-0.62	30.65	1412	jul	5.03	4.94	data unreliable - unable to process						4380	
727930	USA	SEATTLE	47.45	-122.30	130	dec	0.72	0.71	**12.1**	**8.5**	**5.1**	**11.9**	**8.3**	**5.2**	7604	
804030	VENEZUELA	CORO	11.42	-69.68	16	dec	4.89	5.26	*8.0*	*4.5*	*3.6*	not fitted			10461	
804050	VENEZUELA	LA ORCHILA	11.80	-66.18	3	dec	3.87	3.81	5.4	2.7	1.8	not fitted			4809	
804070	VENEZUELA	MARACAIBO /	10.57	-71.73	66	nov	3.63	3.83	*16.9*	*7.1*	*2.1*	*11.1*	*7.0*	*2.1*	10430	
804100	VENEZUELA	BARQUISIMETO	10.07	-69.32	613	dec	4.75	5.16	data unreliable - unable to process						10491	8%
804150	VENEZUELA	CARACAS /MAIQUET	10.60	-66.98	43	dec	4.39	4.35	6.7	3.9	2.7	4.9	3.0	2.3	10491	
804190	VENEZUELA	BARCELONA	10.12	-64.68	7	dec	4.35	4.60	*23.7*	*5.0*	*2.0*	cannot reliably fit			10399	nov
804230	VENEZUELA	GUIRIA	10.58	-62.32	13	dec	4.06	4.35	data unreliable - unable to process						8966	
804350	VENEZUELA	MATURIN	9.75	-63.18	65	dec	3.95	3.81	*8.3*	*3.3*	*1.3*	cannot reliably fit			10461	
804380	VENEZUELA	MERIDA	8.60	-71.18	1479	nov	4.68	4.67	*6.9*	*4.8*	*1.9*	not fitted			10429	
804440	VENEZUELA	CIUDAD BOLIV	8.15	-63.55	43	dec	4.13	4.26	*9.7*	*2.6*	*1.6*	*7.9*	*2.4*	*1.1*	9942	
804470	VENEZUELA	S. ANTONIO	7.85	-72.45	377	dec	3.57	3.53	*10.5*	*6.8*	*3.3*	not fitted			10522	nov
804500	VENEZUELA	S. FERNANDO	7.90	-67.42	47	jun	4.65	4.77	data unreliable - unable to process						10035	dec
488200	VIETNAM	HANOI	21.03	105.85	5	jan	2.28	2.32	16.2	10.2	5.3	9.8	9.8	7.1	1095	P-Met
912450	WAKE IS.	WAKE IS.	19.28	166.65	4	dec	4.51	No Met	6.9	6.5	5.9	not fitted			4563	
640340	ZAIRE	BUTA	2.78	24.78	450	jul	3.99	4.03	**4.4**	**2.4**	**1.7**	**4.7**	**2.5**	**1.9**	3740	
640770	ZAIRE	BUNIA / RUAMPARA	1.57	30.22	1285	jul	4.57	4.77	5.6	3.0	1.8	5.9	3.3	2.2	2920	aug
641150	ZAIRE	INONGO	-1.97	18.27	300	jul	3.70	No Met	6.1	2.0	1.3	cannot reliably fit			3191	
641260	ZAIRE	BOENDE	-0.22	20.85	375	jul	3.92	4.00	**5.2**	**2.5**	**1.8**	**5.1**	**2.5**	**1.7**	7573	
641550	ZAIRE	KINDU	-2.95	25.92	497	jul	3.80	3.84	9.2	5.2	1.8	7.2	4.0	1.9	6630	
642200	ZAIRE	KINSHASA / BINZA	-4.37	15.25	445	jul	3.23	3.52	*10.2*	*5.2*	*3.5*	cannot reliably fit			9336	8%
642350	ZAIRE	KANANGA	-5.88	22.42	654	aug	3.55	4.03	7.2	2.8	1.9	7.4	3.0	1.5	7632	P-Met, jul, 12%
643700	ZAIRE	LUBUMBASHI	-11.65	27.47	1260	feb	4.57	4.60	*16.3*	*6.1*	*1.9*	*7.3*	*3.5*	*1.6*	3772	

Table 3. Days of Autonomy - part 3

1	Station number in WRDC classification
2	Month with the lowest mean daily solar radiation according to WRDC data
3	Mean daily solar radiation for the worst month, in kWh/m2
4	Results for Days of Autonomy, for specific CA (= A:L) values, as indicated. Results in bold come from what appear to be particularly reliable data (see Sec. 3.4 of the Report for the first part of the project). Values in italics indicate results with uncertain accuracy.
5	DoA values obtained for the climatic cycles with the lowest value for the period of WRDC data.
6	Wherever meaningful, results obtained by procedure described in Sec. 3.4. Extrapolated results shown in bold recommended as likely to be more reliable than the corresponding directly derived values.
7	A month, when given, corresponds to the “worst month” according to Meteonorm, where this is different from the WRDC worst month.
	"P" refers to Meteonorm message “Use of precalculated radiation map based on satellite and ground information due to low density of network” issued with the data.
	A percentage, when given, indicates the discrepancy between the W. Month average values according to Meteonorm and WRDC (only specified if greater than 7%).
8	Total number of WRDC data, including any missing values within the time series. Yellow highlight indicates a time series (significantly) shorter than 5 years

Table 4. Notes to Table 3

ACCRA	Wide variability of solar radiation data resulting in meaningless DoA results
AROMA	Low accuracy data.
BABANUSA	A wide drift in solar radiation data. Impossible to analyse.
BAFATA	Suspect variability in a short series of solar radiation data. Accuracy of results uncertain.
BARCELONA	Data around the two dominant climatic cycles not credible and have been ignored. DoA given is due to the third most significant cc around 1990-91, with uncertain accuracy, particularly for CA=1.0.
BARQUISIMETO	A wide shift of data - data unusable
CHOKWE	A pronounced dip in solar radiation data between 1979 and 1984 due to data of suspect accuracy. These data have been omitted from analysis.
CIUDAD BOLIV	A shift in data after 1984 when all the dominant climatic cycles occur, resulting possibly in an overestimate of DoA, particularly for CA=1.0.
CORO	A suspicious shift in data after mid 1991. Data after this point ignored.
DONGOLA	Data with a wide range of variability. Best guess at a dominant climatic cycle.
EL FASHER	Accuracy of dominant climatic cycle uncertain.
GARISSA	A shift in the early part of the data series making the data in the present form unusable. Results correspond to analysis using data from 1974 only
GHAZALA GAWA	Several sharp breaks in data (around 1973 and after 1980). Impossible to analyse.
GOA / PANJIM	Data giving rise to the dominant climatic cycle of uncertain accuracy.
GUIRIA	Wide swings in the data - data unusable
HANOI	A short time series of data giving results with low accuracy.
HK - KING'S PARK	Very large DoA but solar radiation data appear OK. Similar to Macau ?
HUDEIBA	Wide variability of solar radiation data resulting in meaningless DoA results
IRINGA	Accuracy of data uncertain
JAKARTA OBS.	A short series of data; data responsible for a large climatic cycle near 72.2 are suspect and have been omitted from analysis.
KADUGLI	A shift in data after 81.5. Later data ignored.
KIGOMA	A short series of data with some drift. Accuracy uncertain
KINSHASA / BINZA	Solar radiation data responsible for the dominant climatic cycle of uncertain accuracy although other data appear quite good.
KISUMU	Two dips in solar radiation data which give rise to very large DoA values have been omitted from analysis.
KITALE	Dominant climatic cycle around 67.8 due to suspect radiation data and has been omitted.
KOTA KINABALU	Last few days in the time series suspect and have been omitted from analysis
LA ORCHILA	Data suspect after 1976. These data ignored.
LAGOS / OSHO	Data series too short to meaningfully fit
LE LAMENTIN	A shift in data prior to 1980 making the accuracy of results (particularly for CA=1.0) suspect.
LOUGA	Solar radiation data prior to mid 1981 significantly lower that other data and omitted from analysis
LUBUMBASHI	One large cc which does not fit with others but data appear reasonable. Omitted from extrapolated only
MALANGE	Dominant cycle for CA=1.1 and 1.25 due to data of suspect accuracy and has been omitted
MANDERA	Some shift in solar radiation data. Accuracy uncertain.

Table 5. Notes on stations (part 1)

MARACAIBO /	Climatic cycle around 1992 not credible and ignored. DoA for CA=1.0 and 1.1 due to a climatic cycle near 1985 with data of uncertain accuracy
MATURIN	Data after 89 show a systematic shift and have been ignored. Other sharp shifts in data make the accuracy of results uncertain.
MBARARA	Large shift in solar radiation data in 1969. Data unusable.
MERIDA	Substantial swings in the data making accuracy of results uncertain. DoA for CA=1.0, in particular, does not seem credible.
MINDELLO	Two dominant climatic cycles due to data of uncertain accuracy
MOCAMEDES	Data before 1967 unreliable and have been ignored
MOMBASA /	Data giving rise to dominant climatic cycle suspect. Cycle omitted from analysis.
NAKURU	Data in two parts, with a distinct shift between them. Unusable in the present form. Results corresponds to analysis using data from 1970 only.
NANDI	Results due to a small number of climatic cycles. The largest - probably due to a systematic shift of data - has been ignored. Accuracy of the remaining results for CA=1.0 and Ca=1.1 uncertain.
PAMPA DE MAJES	A very short series of data which lack consistency. No reliable results possible.
PASCUA IS.	Wide swings in radiatin data. Accuracy or results uncertain.
PEMBA	Data near 79 giving rise to a climatic cycle for CA=1.1 and 1.25 appear suspect and have been omitted from analysis for these values of CA.
POONA	A short sequence of data after 1993 of suspect accuracy has been omitted from analysis
PORT SUDAN	Data after 1982 suspect and omitted from analysis. Accuracy of data responsible for the dominant climatic cycle around 1971 (included) is also uncertain
PRAIA	An initial sequence of data to 65.16 of suspect accuracy. The climatic cycle in this range has been omitted from analysis.
S. ANTONIO	Very deep climatic cycles between mid 1974 and mid 1977 due to data of uncertain accuracy. There is also a shift in data after 1989. Results represent the best estimate using remaining data.
S. CRUZ	Data of similar form as for S. Teckla. Sudden change in solar radiation data at 74.4. Later data omitted.
S. FERNANDO	Wide swings in the data - data unusable
S. TECLA	Strange data. Most days barely reach 3kWh/m^2. Large DoA values due to drift in the data - data series not credible.
S. TOME	A dip in the first half of the data series, leading to unrealistic DoA values. Results correspond to analysis using data from 1969 only.
SHOWAK	A gradual shift in solar radiation data making the accuracy of results uncertain.
TABORA ARPT	Accuracy uncertain
TAHRIR	Drift towards the end of the time series of solar radiation data producing climatic cycles responsible for the DoA results. Accuracy uncertain.
TAMALE	Data between 73.5 and 77 not credible and omitted from analysis
TORORO	A dip in the middle of the solar radiation data. Accuracy uncertain.
TULEAR	Accuracy uncertain
UMBELUZI	Accuracy uncertain due to suspect data prior to 1984. Use data for Maputo ?
VALLENAR	Two separate sequences of data, with a considerable shoft between them. Only data after 1989 used in the analysis.
WAKE IS.	A sudden shift in solar radiation data around 1967. Data prior to this not used. Results due to an unusual, very short but deep, climatic cycle.
WUHAN	A wide variation in data. Accuracy uncertain.
ZIGUINCHOR	Wide variability of solar radiation data resulting in meaningless DoA results

Table 5. Notes on stations (part 2)

Instructions for autonomy calculation

(For Solar Vaccine Refrigeration Systems per the WHO PQS)

Summary: The following methods are used to determine the days of autonomy (i.e. energy storage) for solar vaccine refrigeration systems. These systems may be either:

1. Battery driven (see PQS E03/RF04);
2. Direct solar driven (see PQS E03/RF05); or
3. Direct solar driven with ancillary battery (see PQS E03/RF06).

Battery based autonomy can be increased or decreased by providing a greater or lesser battery capacity. Direct drive autonomy is typically fixed by the amount of thermal storage included in the refrigerator. For direct drive systems PQS test results are used to determine the days of autonomy for a given temperature zone (i.e. moderate +27ºC, temperate +32º or hot +43°C).

There are three options to specify Autonomy, defined as *"time in days that a solar refrigerator, or combination refrigerator and icepack freezer, can maintain the vaccine load within the acceptable temperature range under low solar radiation conditions"*. In all cases minimum autonomy will be no less than 3 days and there is no maximum.

Options 1 and 2 are performance-based and are derived from measured long term, daily solar radiation. Daily sequences of extraordinarily low solar radiation are used to define the autonomy required to sustain operation of the refrigerator through historic low solar radiation time periods. Option 3 is a prescriptive standard of 5 days autonomy as used in past WHO PIS requirements for batteries.

The Solar Array Oversize or excess capacity impacts the days of autonomy. A solar power system with oversized power capacity can recharge a depleted energy storage system more quickly than a solar array with no excess capacity. Solar array oversizing has the effect of reducing the days of autonomy required to sustain refrigerator operation. The PQS PV01.2 requires that the solar array capacity be capable of powering the load plus system losses x 1.25 (i.e. solar array oversize capacity of 25%).

To establish the autonomy required for a proposed site begin with Option 1 and select the most accurate of the 3 options below.

Option 1. The first method is to match the proposed site with one of the listed sites in Table 1 - Autonomy. Table 1 is an edited version of the Tables used to develop the PQS PV01 normative reference ***Solar Autonomy Calculation Tool***, Toma and Markvart, University of Southampton, UK (2009) included with these instructions. Only use Table 1-Autonomy sites for Option 1.

If a proposed site is known to have similar climate conditions as a listed site it is possible to use Table 1 to estimate autonomy for that proposed site. If listed sites from Table 1 cannot be used for a proposed site but measured long term daily solar radiation is available for the proposed site then go to Option 2. If Table 1 cannot be used for the proposed site and representative measured long term daily solar radiation is not available then go to Option 3.

Option 2. The second method is to estimate the days of autonomy from a measured set of accurate long term daily solar radiation values using the method detailed in the technical paper ***Solar Autonomy Calculation Tool****,* H. Toma and T.Markvart, University of Southampton, UK (2009). Long term data is defined as a record with a minimum of 5 years (1826 days) of recorded daily solar radiation.

Option 3. If Option 1 or Option 2 cannot be used then the final method is to provide a minimum of 5 days of autonomy.

Table 1 instructions:
For Option 1 use Table 1 to either 1.) select a listed site; or 2.) match a proposed site to a listed site found in Table 1 only if the proposed site has a similar climate.

Do not use Table 1 to estimate autonomy for proposed sites in unknown locations or if a proposed site will differ from a listed site in any of these three climate criteria: 1.) PQS temperature zone; 2.) solar radiation reference period; and 3.) climate classification or microclimate. If all 3 climate criteria are met then proceed to Table 1 and select the Days of Autonomy. This autonomy (or greater) can be input in manual calculations and/or used in computer assisted design methods. If a proposed site is near more than one listed site and all sites are in a similar climate then it is recommended to select the listed site with an elevation closest to the proposed site.

Solar designers have access to long term data including measured temperature and solar radiation. Remote sites often do not have these databases and interpretation of available data is required to establish the design temperature and solar radiation reference period.

Direct verification of microclimate or climate classification will not always be possible. To determine if a proposed site could use the same autonomy as a listed site comparison and interpretation of site data may be necessary. Two comparable sites would ideally have similar elevation, temperature, solar radiation, precipitation and climate classification. Another method to determine if a proposed site is in a similar climate as a listed site requires purchaser/specifier to provide local knowledge of climate conditions.

Example 1: Determine the days of Days of Autonomy for a proposed site in Algeria at latitude 22 and longitude 4, elevation 1402 meters.

Table 1 provides two sites in Algeria. Tamanrasset, Algeria is in the same region as the proposed site. Determine if the proposed site would use the same PQS temperature zone to establish energy consumption of the equipment. If yes, proceed to determine if the proposed site could use the same solar radiation reference period as Tamanrasset. Since the elevations of the two sites are similar, no microclimate differences are known and a review of detailed climate classification maps shows both sites are located in the same climate classification zone it is likely that both experience similar climatic conditions.

Using typical solar design methods insure that the solar array has been sized to provide a 1.25 Solar Array Oversize* capacity then the proposed site can use the Table 1-Autonomy listed for Tamanrasset, Algeria.

From Table 1 select 3.0 days of autonomy. The WHO PQS requires a minimum autonomy of 3.0 days for all solar powered refrigerators.

Example 2: What is the autonomy required for Chengdu, China?

Table 1 lists autonomy of 7.6 days. Do not use Option 3 (autonomy = 5 days) because long term measured data supports the need for 7.6 days.

Example 3: Determine the days of Days of Autonomy for Minas Gerais, Brazil (latitude -8.97, longitude – 72.78).

No sites are included in Table 1 for Brazil and there are no other sites near latitude -9 and longitude -73. Option 2 requires a minimum of 5 years of accurately recorded solar radiation data. If sufficient data are found from another reliable source, input these data in the calculation method described in Solar Autonomy Calculation Tool, H. Toma and T.Markvart, 2009. If data are found but are unusable or if no data are found, then the system must be designed to provide 5 days of autonomy (as required by PQS).

Example 4: You are in the early stages of planning a large project in a tropical country with a variety of climates including snow covered mountains, smoky cities, sea coasts, deserts and jungles. Table 1 has 3 locations within the project country and you find requirements for 3, 5 and 7 days of autonomy. The installation sites have not been selected. For all possible sites can you justify a single specification of 5 days of autonomy?

There is not sufficient information to specify a 5 day autonomy. It is recommended that detailed location information be obtained and then used to establish the autonomy and design conditions most likely at each site. If the project will be nationwide then the apparent elevation variations and climatic differences may require the use of two or more design temperatures and would probably require different solar radiation reference periods and different autonomies. While Option 3 requires 5 days of autonomy if the other Options cannot be used special care should be taken in this case because there is data to support the need for 7 days of autonomy in at least one location.

Table 1 – Autonomy (for solar array oversize= 1.25*)

WRDC No.	Country	Station name	Lat	Long	Alt (m)	Worst month	W. m. average kWh/m^2	Length of record (days)	Days of autonomy (C_A=1.25)
603900	ALGERIA	DAR EL BEIDA	36.72	3.25	25	Dec, Jan	2.10	1948	3.4
606800	ALGERIA	TAMANRASSET	22.78	5.52	1378	Dec	4.45	1883	3.0
661520	ANGOLA	DUNDO	-7.40	20.82	775	Aug	4.10	4079	3.0
661600	ANGOLA	LUANDA	-8.85	13.23	74	Aug	3.47	4320	3.1
663900	ANGOLA	LUBANGO /	-14.93	13.57	1758	Mar	5.23	1856	3.0
662850	ANGOLA	LUENA / LUSO	-11.78	19.92	1357	Mar	4.85	3316	3.0
662150	ANGOLA	MALANGE	-9.55	16.37	1139	Aug	4.63	3224	3.0
664220	ANGOLA	MOCAMEDES	-15.20	12.15	43	Jul	3.40	3650	3.0
662851	ANGOLA	NOVA LISBOA	-12.73	15.83	1700	Apr	5.02	2010	3.0
789550	BARBADOS	HUSBANDS	13.15	-59.62	113	Nov	4.44	3616	3.0
655100	BURKINA FASO	BOBO-DIOULAS	11.17	-4.32	460	Aug	5.35	2617	3.2
655010	BURKINA FASO	DORI	14.03	-0.03	276	Dec	5.19	3559	3.0
655070	BURKINA FASO	FADA N'GOURM	12.03	0.37	308	Aug	5.19	3497	3.0
655220	BURKINA FASO	GAOUA	10.33	-3.18	333	Aug	4.69	3469	3.0
655030	BURKINA FASO	OUAGADOUGOU	12.35	-1.52	316	Dec	5.33	3255	3.0
854060	CHILE	ARICA	-18.35	-70.33	55	Jul	2.92	2828	3.0
854700	CHILE	COPIAPO	-27.30	-70.42	290	Jun	2.89	2767	3.0
854880	CHILE	LA SERENA	-29.92	-71.20	146	Jun	2.35	2677	3.0
854062	CHILE	PARINACOTA	-18.20	-69.27	4392	Jun	4.51	2129	3.0
562940	CHINA	CHENGDU	30.67	104.02	508	Dec	1.14	2006	7.6
592870	CHINA	GUANGZHOU	23.13	113.32	8	Mar	1.77	1975	11.3
567780	CHINA	KUNMING	25.02	102.68	1892	Oct	2.61	2006	6.9
802220	COLOMBIA	BOGOTA /	4.7	-74.13	2547	Jun	3.98	2012	3.0
802410	COLOMBIA	GAVIOTAS	4.55	-70.92	165	Jun	3.99	2012	3.0
783250	CUBA	HAVANA /	23.17	-82.35	50	Dec	3.38	3620	3.0
624140	EGYPT	ASWAN	23.97	32.78	192	Dec	4.31	5110	3.0
623920	EGYPT	ASYUT	27.20	31.17	52	Dec	3.53	5110	3.0
623690	EGYPT	BAHTIM	30.13	31.25	17	Dec	3.02	9431	3.0
623710	EGYPT	CAIRO	30.08	31.28	33	Dec	2.87	9125	3.0
624350	EGYPT	EL KHARGA	25.45	30.53	78	Dec	4.15	8183	3.0
623450	EGYPT	TAHRIR	30.65	30.70	16	Dec	3.05	10830	3.0
786622	EL SALVADOR	AHUACHAPAN	13.95	-89.87	725	Sep	4.75	3224	3.0
786720	EL SALVADOR	LA UNION	13.33	-87.88	95	Nov	4.77	3224	3.0
786621	EL SALVADOR	NUEVA CONCEP	14.13	-89.28	320	Dec	4.74	3132	3.0
634500	ETHIOPIA	ADDIS ABABA	8.98	38.80	2324	Aug	3.63	6115	4.4
916800	FIJI	NANDI	-17.75	177.45	13	Jun	3.80	9944	4.2
916900	FIJI	SUVA /	-18.05	178.57	5	Jun	3.21	2950	3.7
654600	GHANA	AKUSE	6.10	0.12	17	Jul	4.04	2279	3.0
654420	GHANA	KUMASI	6.72	-1.60	287	Aug	3.35	8735	3.0
654010	GHANA	NAVRONGO	10.9	-1.10	201	Aug	4.94	2314	3.0
654531	GHANA	TAFO	6.25	-0.38	195	Aug	3.34	2312	3.1

WRDC No.	Country	Station name	Lat	Long	Alt (m)	Worst month	W. m. average kWh/m^2	Length of record (days)	Days of autonomy (C_A=1.25)
654670	GHANA	TAKORADI	4.88	-1.77	5	Aug	4.00	6236	3.0
788970	GUADELOUPE	LE RAIZET	16.27	-61.52	11	Dec	4.30	7514	4.2
814050	GUIANA	CAYENNE /	4.83	-52.37	9	Jan	3.84	5962	5.4
617690	GUINEA-BISSAU	BOLAMA	11.58	-15.48	18	Dec	4.53	2037	4.7
785010	HONDURAS	CISNE ISLS	17.4	-83.93	9	Dec	4.24	4139	3.0
450040	HONG KONG	KING'S PARK	22.32	114.17	65	Mar	2.55	7300	11.4
426470	INDIA	AHMADABAD	23.07	72.63	55	Dec	4.41	10432	6.6
428380	INDIA	BHAUNAGAR	21.75	72.20	5	Aug	4.27	9002	4.5
430030	INDIA	BOMBAY /	19.12	72.85	8	Jul	3.86	8364	6.1
428070	INDIA	CALCUTTA /	22.53	88.33	5	Dec	3.87	9975	3.0
431920	INDIA	GOA / PANJIM	15.48	73.82	58	Jul	3.95	10004	3.3
423390	INDIA	JODHPUR	26.3	73.02	217	Dec	4.22	9281	3.0
433390	INDIA	KODAIKANAL	10.23	77.47	2339	Oct	4.45	9674	3.1
432790	INDIA	MADRAS /	13	80.18	10	Dec	4.08	10462	5.1
428670	INDIA	NAGPUR /	21.1	79.05	308	Aug	4.07	10401	4.7
421820	INDIA	NEW DELHI /	28.58	77.20	211	Dec	3.66	10157	3.0
425160	INDIA	SHILLONG	25.57	91.88	1598	Sep	3.78	9246	4.3
433710	INDIA	TRIVANDRUM	8.48	76.95	60	Nov	4.81	10494	5.1
431490	INDIA	VISHAKHAPATN	17.72	83.23	3	Jul	4.62	10067	4.5
636860	KENYA	ELDORET	0.53	35.28	2120	Jul	5.24	7299	3.0
637230	KENYA	GARISSA	-0.47	39.63	138	Jul	5.45	10674	3.0
637080	KENYA	KISUMU	-0.10	34.75	1157	Jul	5.78	9366	3.0
637720	KENYA	LAMU	-2.27	40.90	30	Jun	4.82	3010	3.0
637990	KENYA	MALINDI	-3.23	40.10	20	May	4.58	8154	3.0
636240	KENYA	MANDERA	3.93	41.87	230	Jul	4.41	9521	3.0
637371	KENYA	MUGUGA	-1.22	36.63	2096	Jul	3.67	2524	3.0
637410	KENYA	NAIROBI /	-1.32	36.92	1624	Jul	3.69	10766	7.3
637140	KENYA	NAKURU	-0.27	36.10	1901	Jul	5.65	9218	3.0
636861	KENYA	NANYUKI	0.02	37.07	1947	Nov	4.44	2769	3.0
637370	KENYA	NAROK	-1.13	35.83	1890	Jul	4.62	9796	5.1
637930	KENYA	VOI	-3.40	38.57	579	Aug	4.27	8851	3.0
450110	MACAU	MACAU	22.2	113.53	57	Feb	2.68	9459	18.3
486150	MALAYSIA	KOTA BHARU /	6.17	102.28	5	Dec	3.49	6510	6.3
486470	MALAYSIA	KUALA LUMPUR	3.12	101.55	27	Dec	4.08	7634	4.0
486010	MALAYSIA	PINANG /	5.30	100.27	3	Oct	4.54	6571	4.7
762250	MEXICO	CHIHUAHUA UN	28.63	-106.08	1435	Dec	3.82	3009	3.0
762252	MEXICO	CIUDAD UNIV.	19.33	-99.18	2268	Dec	4.18	9672	5.6
762251	MEXICO	ORIZABITA	20.58	-99.20	1745	Dec	4.82	8767	3.0
672970	MOZAMBIQUE	BEIRA	-19.80	34.90	10	Jun	4.21	9857	3.0
673080	MOZAMBIQUE	CHICUALACUAL	-22.08	31.68	452	Jun	4.07	3620	3.0
672950	MOZAMBIQUE	CHIMOIO	-19.12	33.47	731	Jun	4.31	10157	3.0
672371	MOZAMBIQUE	GURUE	-15.47	36.98	734	Jun	4.01	4195	3.0
673230	MOZAMBIQUE	INHAMBANE	-23.87	35.38	14	Jun	3.71	8001	3.0
672170	MOZAMBIQUE	LICHINGA	-13.28	35.25	1364	Jun	4.65	6633	3.2
672410	MOZAMBIQUE	LUMBO	-15.03	40.67	10	Jun	4.38	7543	4.1

WRDC No.	Country	Station name	Lat	Long	Alt (m)	Worst month	W. m. average kWh/m^2	Length of record (days)	Days of autonomy (C_A=1.25)
673232	MOZAMBIQUE	MANIQUENIQUE	-24.73	33.53	13	Jun	3.49	7723	3.0
673411	MOZAMBIQUE	MAPUTO	-25.97	32.60	70	Jun	3.73	10615	3.1
672650	MOZAMBIQUE	MOCUBA	-16.83	36.98	134	Jun	3.86	5411	3.0
672150	MOZAMBIQUE	PEMBA	-12.97	40.50	49	Jun	4.83	6781	3.0
672610	MOZAMBIQUE	TETE	-16.18	33.58	123	Jun	4.45	8608	3.0
683120	NAMIBIA	KEETMANSHOOP	-26.53	18.12	1067	Jun	4.27	4228	3.0
681100	NAMIBIA	WINDHOEK	-22.57	17.10	1728	Jun	4.87	4258	3.0
915770	NEW CALEDONIA	KOUMAC	-20.57	164.28	23	Jun	3.66	4840	3.3
652290	NIGERIA	BENIN CITY	6.32	5.60	79	Aug	3.47	10375	3.1
417800	PAKISTAN	KARACHI ARPT	24.9	67.13	21	Dec	3.96	8640	3.7
940350	PAPUA NEW GUINEA	PORT MORESBY	-9.43	147.22	28	Jun	4.93	2552	3.0
847520	PERU	AREQUIPA	-16.32	-71.55	2524	Jun	5.45	2524	3.0
619800	REUNION	ST-DENIS /	-20.88	55.52	21	Jun	3.97	6537	4.1
684060	RSA	ALEXANDER BAY	-28.57	16.53	21	Jun	3.50	3955	3.0
684420	RSA	BLOEMFONTEIN	-29.10	26.30	1351	Jun	3.75	4258	3.0
685880	RSA	DURBAN /	-29.97	30.95	8	Jun	3.04	4258	3.0
682621	RSA	PRETORIA / F	-25.73	28.18	1330	Jun	3.85	3620	3.0
682881	RSA	ROODEPLAAT	-25.58	28.35	1164	Jun	3.84	4197	3.0
684240	RSA	UPINGTON	-28.40	21.27	836	Jun	3.73	4138	3.0
619310	SAN TOME & PRINCIPE	S. TOME	0.38	6.72	8	Jan	3.93	3770	3.0
616411	SENEGAL	BAMBEY	14.70	-16.47	20	Dec	4.39	2097	3.0
616410	SENEGAL	DAKAR / YOFF	14.73	-17.50	27	Dec	4.56	9185	3.1
616270	SENEGAL	LINGUERE	15.38	-15.12	20	Jan	4.77	2312	3.0
616121	SENEGAL	LOUGA	15.62	-16.22	38	Jan	4.19	3008	3.0
616300	SENEGAL	MATAM	15.65	-13.25	15	Dec	4.27	2831	3.0
616120	SENEGAL	PODOR	16.65	-14.97	6	Jan	4.06	2194	3.0
616870	SENEGAL	TAMBACOUNDA	13.77	-13.68	49	Dec	3.90	2040	3.0
486980	SINGAPORE	SINGAPORE /	1.37	103.98	5	Nov	3.88	10249	4.4
629410	SUDAN	JUBA	4.87	31.60	460	Jul	5.02	8727	3.0
626410	SUDAN	PORT SUDAN	19.58	37.22	3	Dec	4.03	7603	4.2
627230	SUDAN	SHAMBAT OBS.	15.67	32.53	380	Dec	5.51	10309	3.0
627510	SUDAN	WAD MEDANI	14.40	33.48	408	Dec	5.82	10279	3.0
627601	SUDAN	ZALINGEI	12.90	23.48	900	Aug	5.50	3043	3.0
637290	TANZANIA	BUKOBA	-1.33	31.82	1137	May	4.27	4137	3.6
639710	TANZANIA	MTWARA	-10.27	40.18	113	Apr	4.18	2585	3.0
637560	TANZANIA	MWANZA	-2.47	32.92	1139	Dec	5.19	4195	3.0
638160	TANZANIA	SAME	-4.08	37.72	872	May	3.69	2797	3.0
639620	TANZANIA	SONGEA	-10.68	35.58	1067	Jul	3.79	3010	4.6
638700	TANZANIA	ZANZIBAR /	-6.22	39.22	15	Apr	4.32	3922	3.0
484550	THAILAND	BANGKOK	13.73	100.57	2	Sep	4.30	9855	3.9
483270	THAILAND	CHIENG MAI	18.78	98.98	312	Aug	4.30	2402	3.8
789700	TRINIDAD & TOBAGO	PIARCO INT.	10.62	-61.35	12	Nov	3.97	2370	3.0
607151	TUNISIA	SIDI BOUZID	36.87	10.35	127	Dec	2.19	9275	3.2
636020	UGANDA	ARUA	3.05	30.92	1204	Jul	4.56	1947	3.0

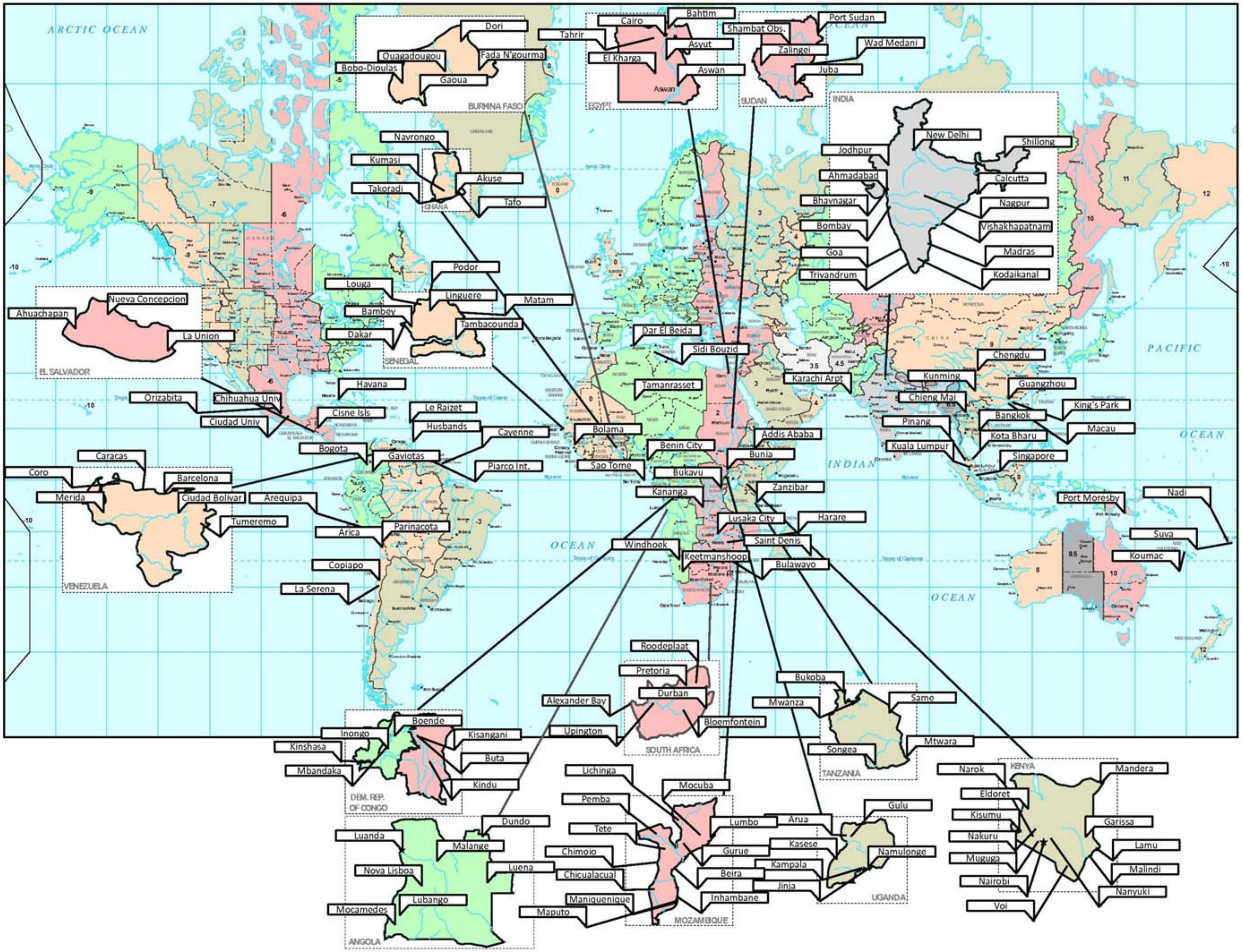
WRDC No.	Country	Station name	Lat	Long	Alt (m)	Worst month	W. m. average kWh/m^2	Length of record (days)	Days of autonomy (C_A=1.25)
636300	UGANDA	GULU	2.75	32.33	1104	Jul	4.30	4656	3.0
636820	UGANDA	JINJA	0.45	33.18	1175	Jul	4.36	3895	3.0
636800	UGANDA	KAMPALA	0.32	32.62	1144	Jul	4.59	2313	3.0
636740	UGANDA	KASESE	0.18	30.10	959	Jul	4.35	4502	3.1
636841	UGANDA	NAMULONGE	0.53	32.62	1148	Jul	4.34	3620	3.0
804190	VENEZUELA	BARCELONA	10.12	-64.68	7	Dec	4.33	10399	3.0
804150	VENEZUELA	CARACAS /MAIQUETIA	10.60	-66.98	43	Dec	4.39	10491	3.0
804440	VENEZUELA	CIUDAD BOLIV	8.15	-63.55	43	Dec	4.13	9942	3.0
804030	VENEZUELA	CORO	11.42	-69.68	16	Dec	4.89	10461	3.0
804380	VENEZUELA	MERIDA	8.60	-71.18	1479	Nov	4.68	10429	3.0
804530	VENEZUELA	TUMEREMO	7.3	-61.45	180	Dec	3.91	10430	3.0
641260	ZAIRE	BOENDE	-0.22	20.85	375	Jul	3.92	7573	3.0
641800	ZAIRE	BUKAVU	-2.52	28.85	1612	Nov	4.60	5962	3.0
640770	ZAIRE	BUNIA / RUAMPARA	1.57	30.22	1285	Jul	4.57	2920	3.0
640340	ZAIRE	BUTA	2.78	24.78	450	Jul	3.99	3740	3.0
641150	ZAIRE	INONGO	-1.97	18.27	300	Jul	3.70	3191	3.0
642350	ZAIRE	KANANGA	-5.88	22.42	654	Aug	3.55	7632	3.0
641550	ZAIRE	KINDU	-2.95	25.92	497	Jul	3.80	6630	3.0
642200	ZAIRE	KINSHASA / BINZA	-4.37	15.25	445	Jul	3.23	9336	3.5
640400	ZAIRE	KISANGANI	0.52	25.18	415	Jul	4.02	5137	3.0
640050	ZAIRE	MBANDAKA	0.05	18.27	345	Jul	3.96	9037	3.0
676660	ZAMBIA	LUSAKA CITY	-15.42	28.32	1280	Feb	4.94	2037	3.0
679640	ZIMBABWE	BULAWAYO /	-20.15	28.62	1343	Jun	4.63	10738	4.7
677740	ZIMBABWE	HARARE /	-17.83	31.02	1471	Jun	4.68	8365	3.2

Table 1 is based on ground station data recorded by the World Radiation Data Centre (www.wrdc-mgo.nrel.gov). Solar Radiation Reference Periods from other databases may be used. Meteonorm has been shown to be in close agreement with WRDC data ***– see Solar Autonomy Calculation Tool,*** Toma and Markvart, 2009

** Oversize Factor: Calculate the capacity of the solar array to power the total load plus system losses and provide an additional 25% capacity. System losses will vary depending on site conditions and equipment component selection. Each component loss factor could be a range of values (e.g. a MPPT control will have a different loss factor than a standard control). System and components will include some of the following losses:*

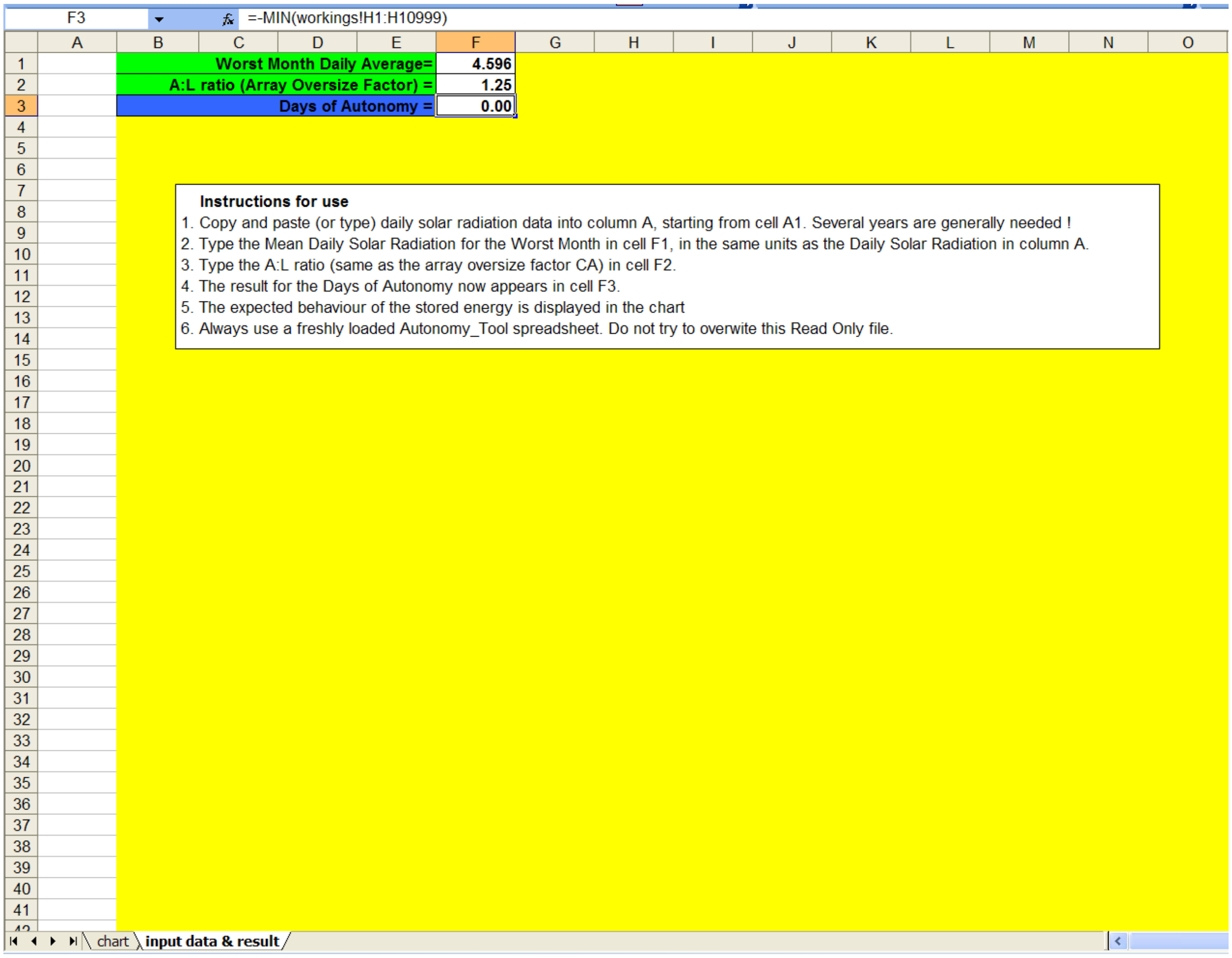
- *PV module nameplate rating differences*
- *PV module mismatch*
- *Soiling/dust*
- *Age*
- *Wiring*
- *Parasitic loss in the control*
- *Coulombic effect of the battery*
- *Starting power requirements (direct drive*

Map of solar reference sites



Introduction to the Excel tool

The image below shows the data entry worksheet for the **Autonomy Tool**. The tool can be downloaded as a read-only file from the PQS website. To use it, open the file, 'Save As' your preferred file name and enter your data as described in the **Instructions for use**. Keep the read-only file for future use.



=-MIN(workings!H1:H10999)

Worst Month Daily Average= 4.596

A:L ratio (Array Oversize Factor) = 1.25

Days of Autonomy = 0.00

Instructions for use

1. Copy and paste (or type) daily solar radiation data into column A, starting from cell A1. Several years are generally needed !
2. Type the Mean Daily Solar Radiation for the Worst Month in cell F1, in the same units as the Daily Solar Radiation in column A.
3. Type the A:L ratio (same as the array oversize factor CA) in cell F2.
4. The result for the Days of Autonomy now appears in cell F3.
5. The expected behaviour of the stored energy is displayed in the chart
6. Always use a freshly loaded Autonomy_Tool spreadsheet. Do not try to overwite this Read Only file.

Guideline revision history

Date	Change summary	Reason for change	Approved
31 Mar 2011	Original version		
28 Oct 2011	Supplementary report added		