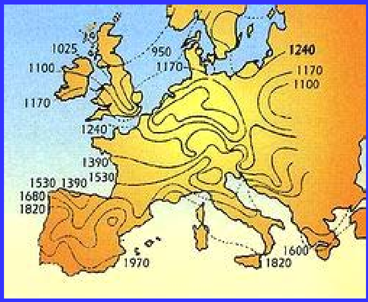
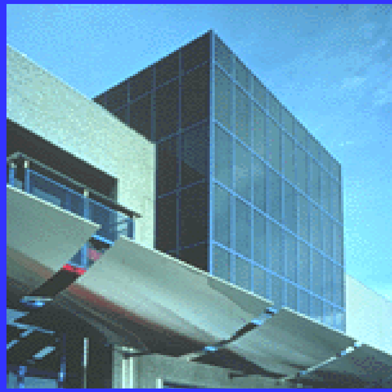
LECTURES ON RENEWABLES ENERGY SYSTEMS





TECHNOLOGY OF PV-SYSTEMS AND APPLICATIONS

Prof. Dr. Socrates Kaplanis

Erwin Schrodinger
(1887 - 1961)
Nobel Laureate in Physics in 1933 - "The formalism of the quantum mechanics"

Chapter III

PV-GENERATOR SYSTEMS AND COMPONENTS

3.1 Types of PV-generators or systems

a. Autonomous – Stand Alone PV-system

A general simple block diagram for stand alone PV-system is shown below.

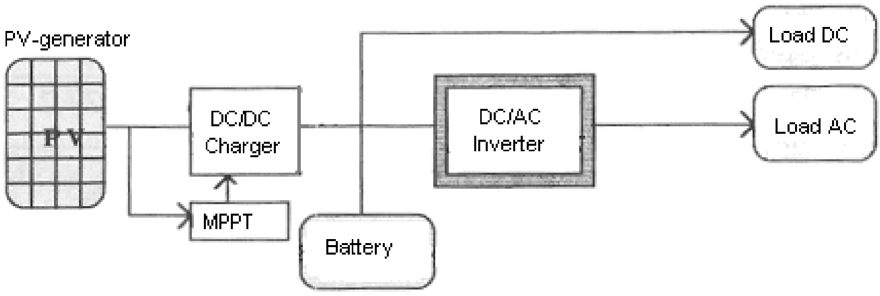


Figure 3.1.a: *Block diagram of a stand-alone PV-system to feed DC and AC loads. Energy storage (batteries) and an MPPT device are included to let for energy independence for a time period and to increase system's efficiency, respectively.*

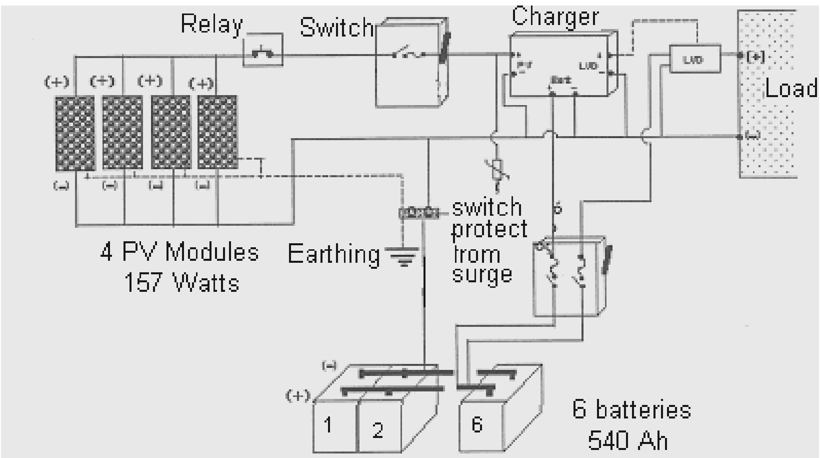


Figure 3.1.b: *4 PV-panels connected in parallel to meet load. The charge along with a protection device store energy in 6 batteries with capacity 540 Ah.*

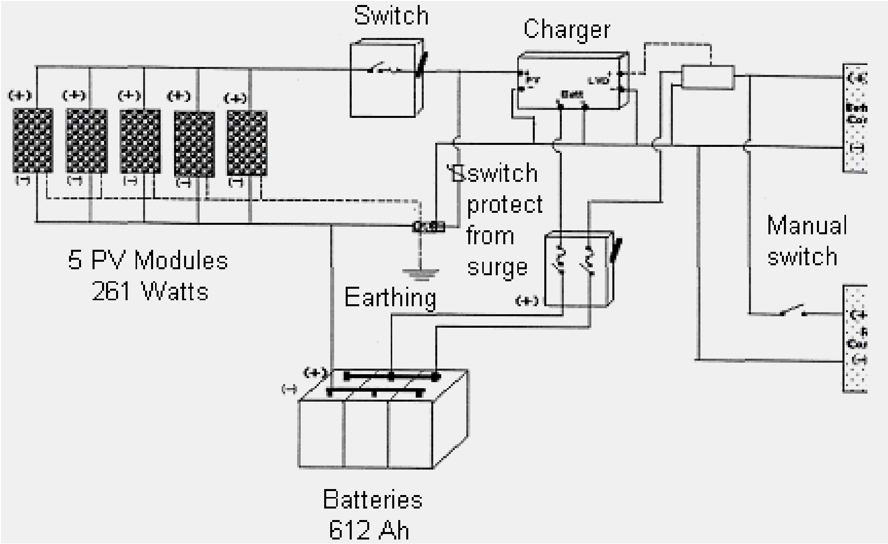


Figure 3.1.c: *5 PV-panels connected in parallel to meet **DC** load. The charge store energy in batteries with capacity 612 Ah.*

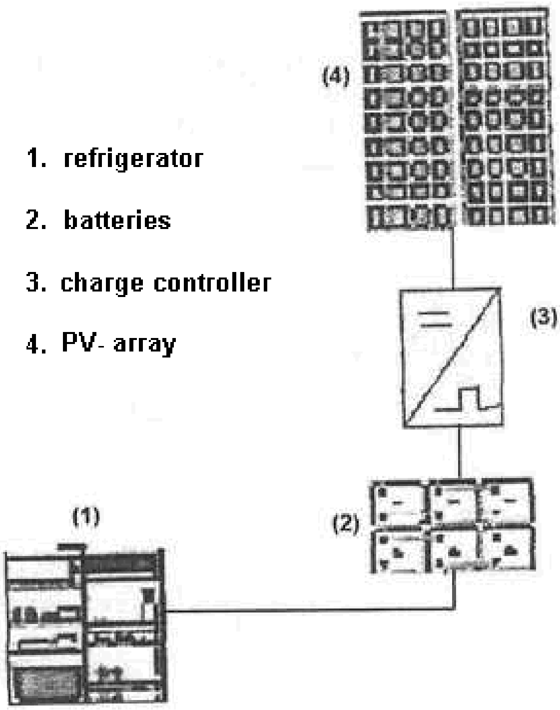


Figure 3.1d: *A bloc diagram of the PV stand alone refrigerating system, as design and construct in the solar Laboratory of T.E.I. Patras*

b. Other types: Hybrid ones and PV-systems connected to the grid

1. One may design **hybrid** systems: i.e. **PV** + **Wind** and/or **Hydro** and/or **Diesel**, see figs. 3.3 and 3.4 Similarly,
2. One might design a PV connected to the grid. A simple block diagram is shown in fig. 3.2.a, b, c, d.

Exercise: one may search the web to find many PV-system designs and applications.
Please, provide detailed configurations for PV-systems, as the above mentioned, and details concerning the elements which constitute the system; see the block diagrams in figs. 3.1-3.4 .

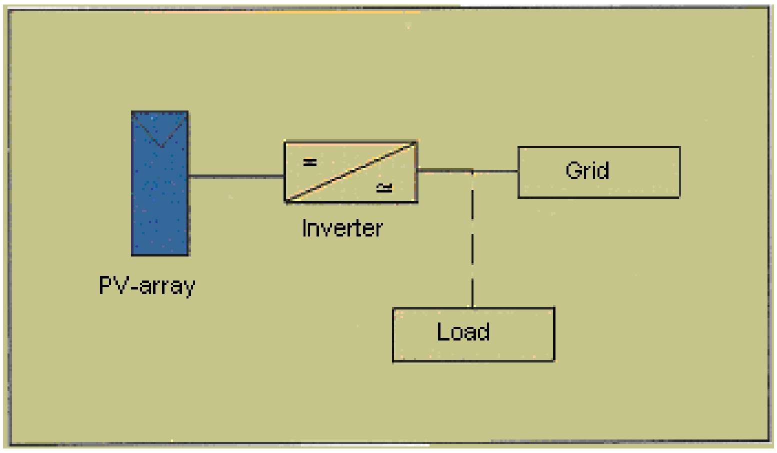


Figure 3.2a: *Simple schematic diagram of a PV generator connected to the grid. Using battery charging for partial storage is another possibility.*

Examples of PV-hybrid systems:

In general, three categories of DC/AC inverters are used in PV-systems:
a. **Variable frequency inverters**; are used for stand-alone drive/shaft power applications, almost exclusively in PV-pumping systems
b. **Self-commutating fixed frequency inverters**; able to feed an isolated distribution grid
c. **Line commutated fixed frequency inverters;** able to feed the grid, only where the grid frequency is defined by another power source connected in parallel.
In several designs, PV-systems use the grid as energy storage, instead of a battery. The latter has limited time life, as the number of cycles (charge-discharge) is limited; about 1200 cycles.
Batteries overall characteristics make the PV-system usually costy.
For medium-large PV-systems **line-commutated inverters equipped with an MPPT** are used.

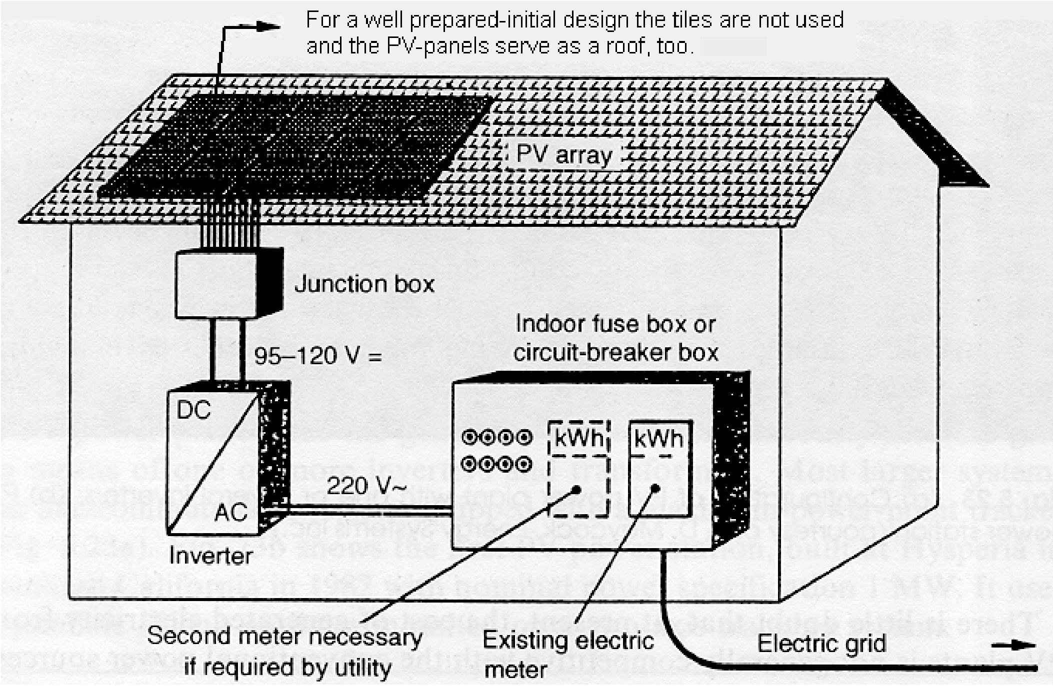


Figure 3.2b: *Roof-top grid-connected PV-system. (Solar Electricity, Tomas Markvart)*

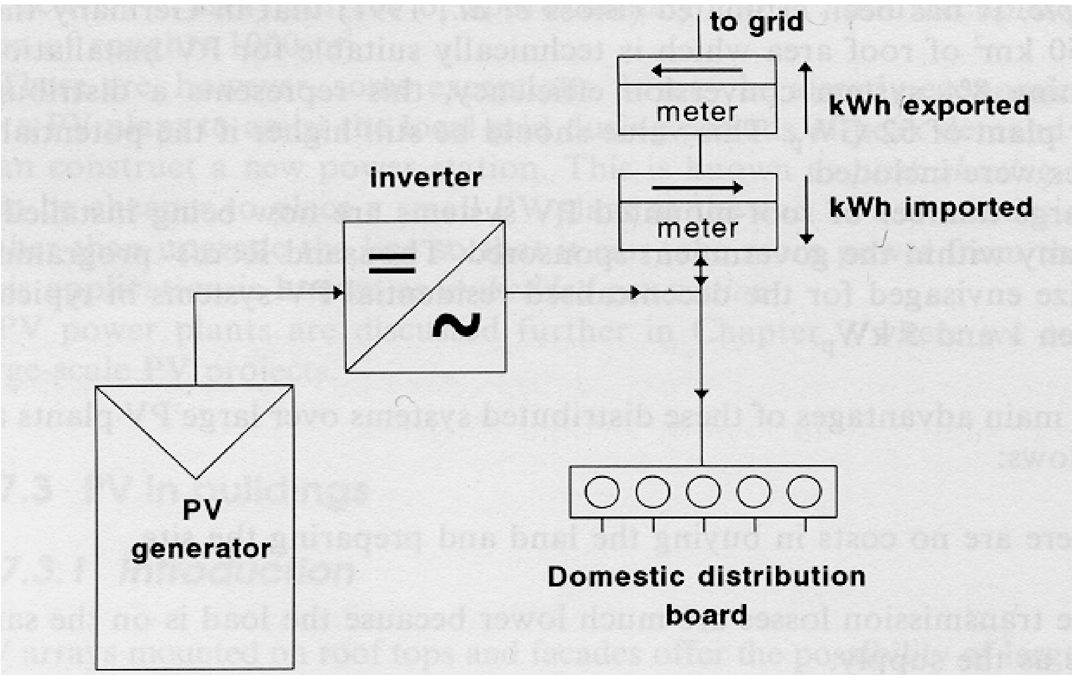


Figure 3.2c: *Configuration of a residential grid-connected system. (Solar Electricity, Tomas Markvart)*

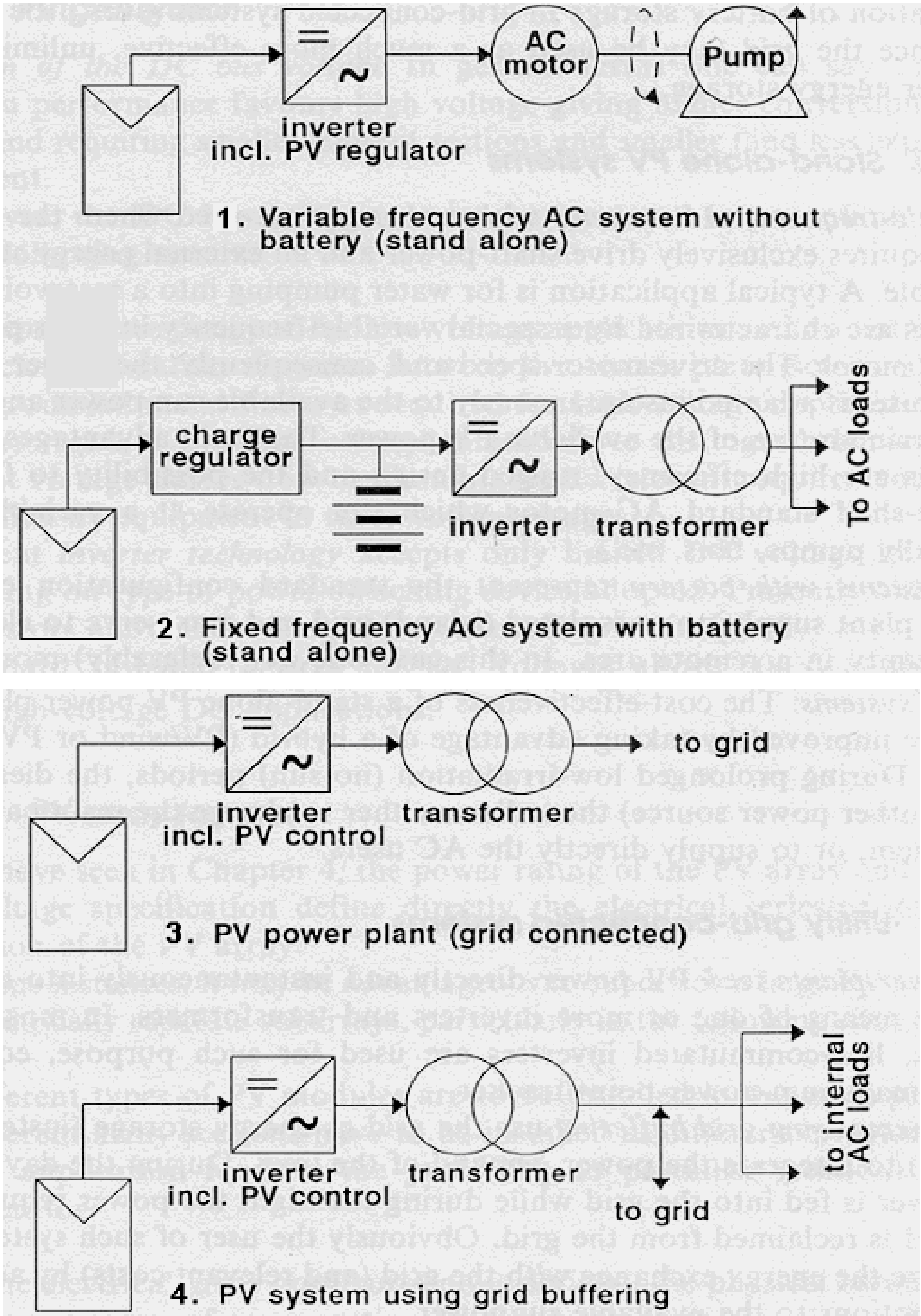


Figure 3.2d: *Different types of large PV-systems. (Solar Electricity, Tomas Markvart)*

- **PV – hybrid systems**

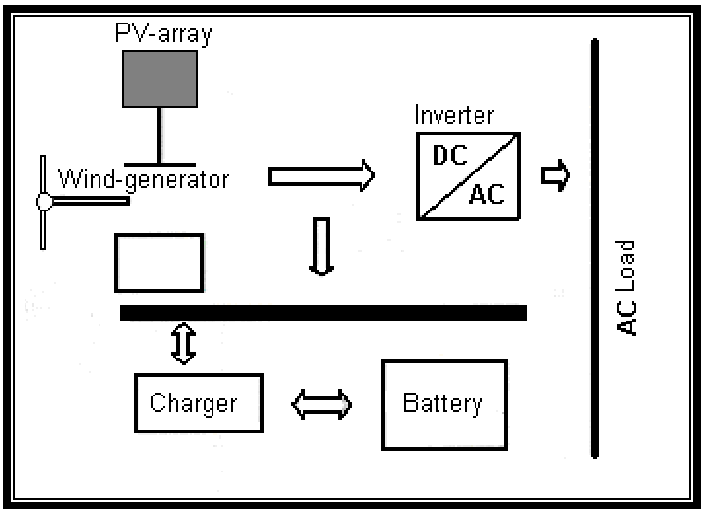


Figure 3.3: *A PV-hybrid system made up by a PV-array and a Wind generator. There is no back –up system except for the battery. In fig 3.4 below the back-up system consists of a Diesel, too.*

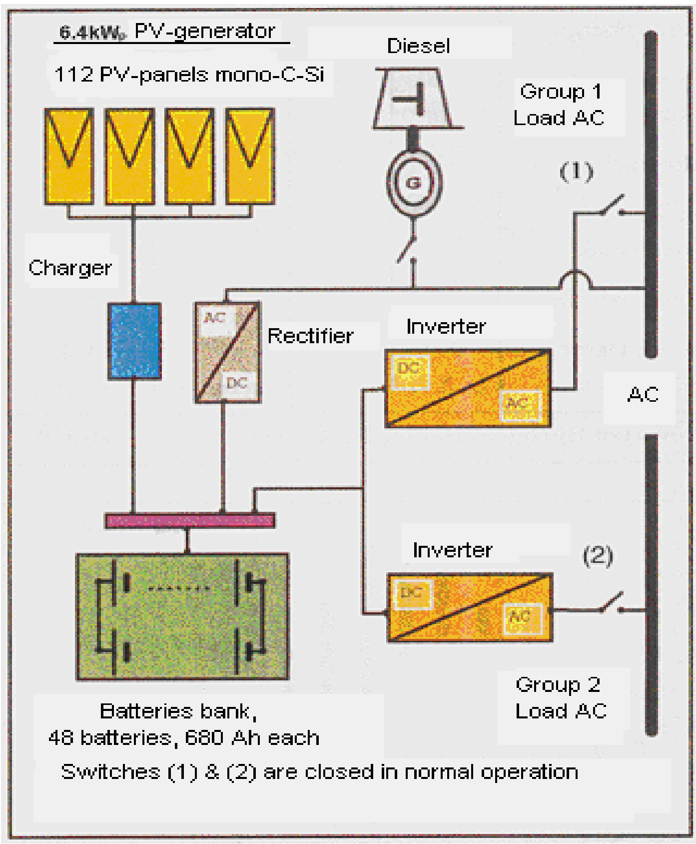


Figure 3.4: *A PV hybrid system used in a Hotel "Elounda" in Crete. The system is split in two DC/AC inverters for flexibility and effectiveness reasons. A Diesel is used to feed with power, when the PV system does not produce enough power. Then, the Diesel may charge batteries, too. For this reason a rectifier is used.*

Table 3.1: *Appliances & Loads for the Hotel Elounda in Crete, Greece*				
Appliances	Power/unit. (W)	Number of units	Operation h/day	Load/day (Wh/day)
Internal Lighting	30	110	1	3300
Outside Lighting	25	30	6	4500
Refrig. in rooms	100	11	6	6600
1 Big Central Refrigerator.	400	3	11	13200
2 Big Central Refrig.	300	1	11	3300
Long waves cooker	1200	1	1	1200
Pump	750	1	2	1500
Biological cleaning	400	1	2	800
Traps for flying insects	20	15	5	1500
Others	200	22	1	4400
Total Daily Load				**40300Wh/day**

Problem 3.1

Estimate some other details for the PV-system shown in fig. 3.4. What is the Peak Power installed?

Details of the PV-system shown in fig.3.4 are given in the following:

a. In this figure a hybrid system consists of a PV-generator of 6.4 kW_p, with 112 PV-panels, mono-c-Si of 57 W_p each $\Rightarrow 112\times 57W_p/each=6.4kW$.

b. The PV-inclination is $\beta=30^0$. Why such a low inclination?

The designer put two DC/AC inverters of 685 kWA each (voltage output 220 Volts, voltage input 48 Volts). So, there is a requirement of 48 Volts.

c. This 48 Volts come from the 24 batteries in series, because there are two series of batteries in parallel $\Rightarrow$ 24 batteries $\times$ 2 Volts = 48 Volts.

The typical loads for a Hotel to be taken into account, as fig.3.4 shows, are given in Table 3.1.

Remark:

Total Daily Load: 40300Wh = 40.3kWh [Energy]

PV- power installed 6.4 kW [Power]

Question: How this power was estimated?

Answer: This has to do with the quantity called Peak Solar Hour (PSH) to be studied in §3.2. If ones estimates PSH for this day of the month for the inclination of the PV-array and multiplies with the PV-power (W_p), then the product just meets the Daily Load.

⇒ Another hybrid PV-system, which consists of a PV-generator and a Diesel, with batteries as a storage system for short back up periods, is shown in fig.3.5.
The PV-system components are clearly shown and are self-explanatory.

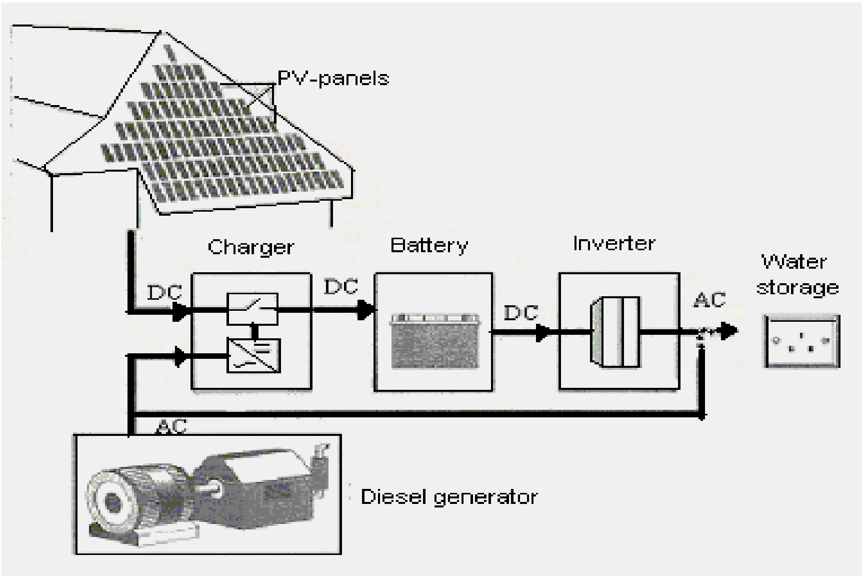


Figure 3.5: *A PV-generator of 4 kW$_p$ at Monte-Negro (Germany) coupled to a Diesel.*

A Simple Problem 3.2, for a PV-panel power output.

Let some Si PV-panels, have A_p = 0.4 m^2. Let them consist of 40 PV-cells , 100 cm^2 each.
Let, $\mathbf{i_{m(cell)}}$ = 2.5 A , which is a typical value, as discussed in Chapter I, Table 1.2, with $\mathbf{V_m}$ = 0.5 Volts.
Then, the power $\mathbf{P_{m,c}}$ each cell provides at its MPP , $\mathbf{P_{m,c}}$ = 25×0.5A·V= 1.25 W. Hence, the PV-panel produces , $\mathbf{P_{m,panel}}$ = 40×1.25 W = 50 W$_p$

3.2 Peak Solar Hour (P.S.H.)

For convenient calculations concerning the Power and the Energy delivered during a day by a PV-generator, one defines the **P**eak **S**olar **H**our (**P.S.H.**).
To make this term understood, let us take fig.3.6, which shows the solar intensity on the horizontal in Patra, Greece during the14th of July.

One may easily notice that the intensity at horizontal is always less than 10^3 W/m^2, during that day. To estimate the efficiency and the power delivered one, should normalize the intensity to 10^3, due to the **S.T.C**. convention, see §1.2.9.

P.S.H. is defined as the time length (in hours) for a given day, under the assumption that solar insolation is constant to 10^3 W/m^2 during this time length; the **PSH** value should be such that the energy, **E**, estimated under the above assumption **[E=P×(PSH)]** is equal to the real case i.e. the one which is obtained by the integration of the area under the curve in fig.3.6.
This statement is explained graphically in fig 3.6, below.

- **Remark:**

P.S.H. is a number in hours equal to the daily energy (irradiation) in kWh/m^2

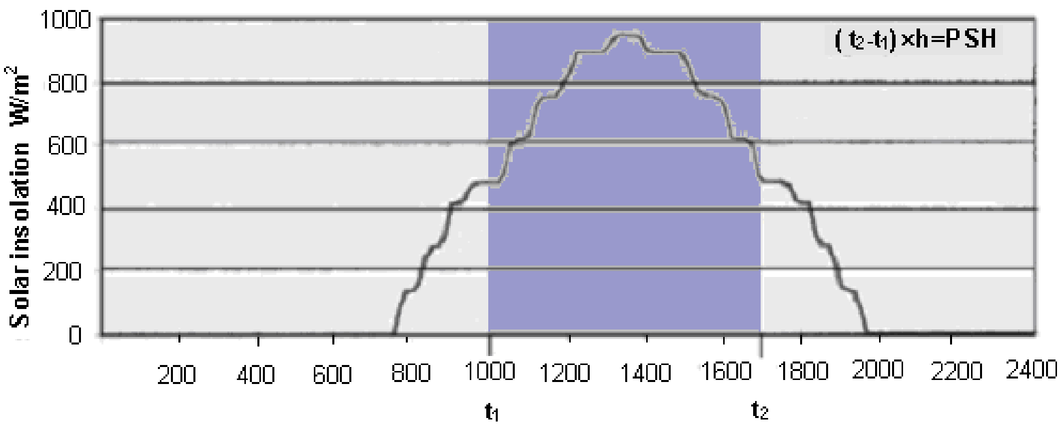


Figure3.6: *Global Solar insolation at horizontal at Patra , Greece (14.07.2001).The shadowed area : having as one side the P.S.H and height equal to 10^3w/m^2 is equivalent to the surface under the insolation curve.*

The figure in the above analysis holds for the horizontal.
However, when we analyze inclined PV-panels, then we have to convert solar insolation to the inclined plane. We do this by multiplying $\mathbf{I_h}$ (solar intensity) or $\overline{\mathbf{H}}_h$ (daily energy) at horizontal by a factor $\overline{\mathbf{R}}$.
$\overline{\mathbf{R}}$ is a conversion factor converting H_{hor} to H_T on the inclined PV-panel.
$\overline{\mathbf{R}}$ is a function of φ (latitude), inclination to horizontal (β), and the month.
More about $\overline{\mathbf{R}}$, see bibliography; also § 5.6 and Appendix IV.

Problem 3.3
From the Table 3.2 which gives the monthly global radiation at horizontal in Patra estimate the Daily global solar irradiation (kWh/m^2) on a plane at inclination of 45^0 to horizontal. Calculate the PSH per month for a PV-panel at 45^0 to horizontal.

Solution:

The procedure to convert monthly solar global irradiation values from column 3 of Table 3.2 to daily irradiation on a plane at 45^0, expressed in kWh/m^2, are self explanatory and are shown in the Table below.

The effort is to:

a. determine the conversion factor, $\overline{\mathbf{R}}$, using the proper formulae for $\overline{\mathbf{R}}$, as in § 5.6, equation (5.12). $\overline{\mathbf{R}}$ values are given in column (1). This task is left to the reader.

b. calculate the mean daily irradiance from the monthly one, by dividing the monthly value over the number of days of the month column (2).

c. multiply the above value by the convertion coefficient $\overline{\mathbf{R}}$ and divide by 3600 to convert the value to kWh/m^2.

Table 3.2: *Mean monthly and mean Daily global solar irradiation (kWh/m^2) at horizontal and on a plane at 45^0 in Patra, Greece.*

Month	$\overline{R}$ Convertion coefficient from horizontal to 45^0 (1) *see next chapter	Number of days per month (2)	Monthly global irradiation (MJ/m^2) (3)	Daily irradiation at 45^0, in kWh/m^2, $\frac{(1)\times(3)\times 10^3}{(2)\times 3600}$ (4)	PSH (h) (5)
J	1.655	31	220	3.28	3.28
F	1.380	28	259	3.55	3.55
M	1.160	31	400	4.16	4.16
A	0.965	30	493	4.40	4.40
M	0.845	31	684	5.18	5.18
J	0.790	30	745	5.45	5.45
J	0.810	31	781	5.67	5.67
A	0.920	31	713	5.88	5.88
S	1.105	30	526	5.38	5.38
O	1.355	31	367	4.46	4.46
N	1.610	30	241	3.58	3.58
D	1.700	31	187	2.85	2.85
Average value				$4.49\left(\frac{kWh}{m^2}\right)$	4.49h

Notice: *The numbers in columns (4) and (5) are the same, as explained above, but of course have a different meaning, as they represent completely different quantities.*

Remark:

The Question & Answer under the Table 3.1, is associated to PSH for the summer for Crete, for the inclination $\beta=30^0$. This PSH is a bit higher than 6 hrs for Crete. So, multiplying P_m=6.4kW with the PSH for Crete, 6h, one get a value close to 40.3 kWh which is the load to be met. This procedure outlines a simple solution to the sizing of PV- sizing systems.

Problem 3.4

Let us study a PV-system in Patra, Greece, which must provide to the load $\mathbf{R_L}$, a mean current, i_L=1.5A during all year long.

Estimate the number N of PV-panels and the configuration of the circuitry.

Solution

Let the system be inclined at $\beta=45^0$. This is a value quite effective for having a high annual average. In such cases holds: $\beta \cong \varphi$ **(latitude).**

Let these PV-panels be connected as fig. 3.7 shows.

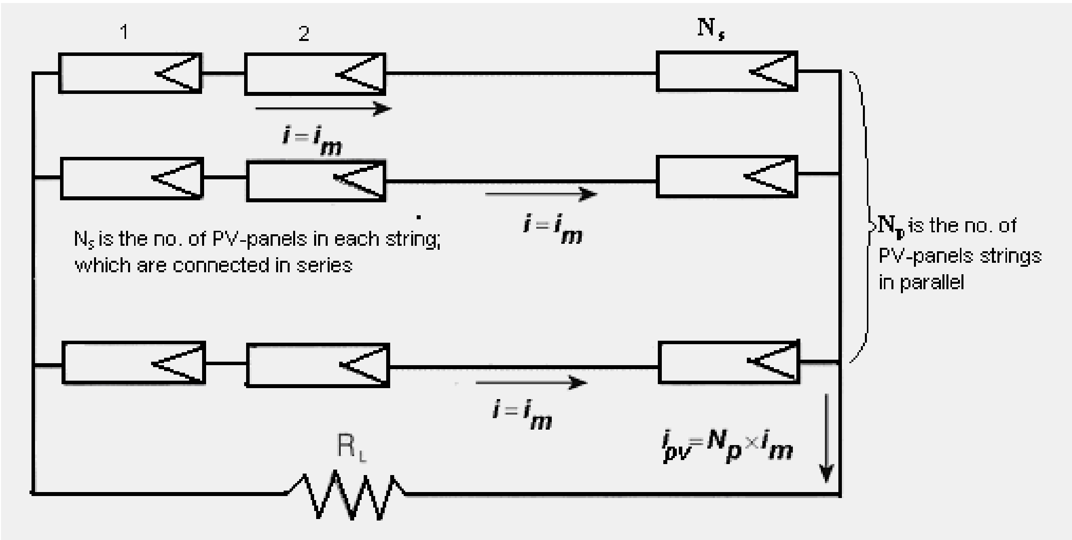


Figure 3.7: *A schematic circuitry of PV-panels, which form the PV-generator studied.*

Let $\mathbf{N_s}$ be the PV-panels in series and $\mathbf{N_p}$ is parallel.

Then, $\mathbf{N=N_s \times N_p}$

Let the solar irradiation be as Table 3.2 provides.

The energy, $\mathbf{E_L}$, for the load per day can be given by:

$$\mathbf{E_L}\left(\frac{\mathbf{Wh}}{\mathbf{day}}\right) = \mathbf{PSH} \times \mathbf{V_{DC}} \times \mathbf{i_{pv}}, \tag{3.1}$$

where, $\mathbf{i_{pv}}$ is the current the PV-generator provides under the condition which holds for the period PSH.

Similarly, one may write for $\mathbf{E_L}$ the following expression:

$$\mathbf{E_L}\left(\frac{\mathbf{Wh}}{\mathbf{day}}\right) = \mathbf{V_{DC}} \times \mathbf{i_L} \times \mathbf{24\,h/day}, \tag{3.2}$$

Hence, from the above equations, one obtains:

$$\mathbf{i}_{pv} = \frac{\mathbf{24\,h/day \times i_L}}{\mathbf{PSH}}, \qquad (3.3)$$

Substituting, $\mathbf{i_L}$ and **PSH** to eq.(3.3) with the value of $\mathbf{i_L}$ given above and the **PSH** as calculated before, we get:

$$\boldsymbol{i_{pv}} = \frac{24\,h/day \times 1.5A}{4.49\,h/day\,(seeTable3.2)} = \boldsymbol{8.02A}$$

Let, now 2.1A be the $\mathbf{i_m}$ current that the PV-panels generate at MPP, at S.T.C..
Then, the number of the parallel strings of PV-panels, according to the 1st Ohm's law is :

$$\boldsymbol{N_p} = \frac{\boldsymbol{i_{pv}}}{\boldsymbol{i_m}} = \frac{8.02A}{2.1A} = 3.81 \qquad (3.4)$$

The integer number closest to 3.81 is $[N_p]$=4.
So, we set N_p=4, that is 4 parallel strings of PV-panels. However, we have not determined $\mathbf{N_s}$ i.e. the number of PV-panels in each string.
Having chosen this larger integer value for $\mathbf{N_p}$, one has to define a sizing factor, (**SF**), which equals to:

$$\boldsymbol{(SF)} = \boldsymbol{[N_p]} \cdot \frac{\boldsymbol{i_m}}{\boldsymbol{i_{pv}}} = \frac{4 \times 2.1A}{8.02A} = 1.047 \qquad (3.5)$$

That is, we have oversized the system by 4.7%.

- The number of $\mathbf{N_s}$ is obtained from the Voltage required, **V**, over the $\mathbf{V_m}$ value of the PV-panel. i.e. :

$$\mathbf{N_s} = \frac{\mathbf{V}}{\mathbf{V_m}} \qquad (3.6)$$

- However, as the problem does not specify what Voltage is required to be fed to the load we cannot determine $\mathbf{N_s}$.

Notice: *once again, that the design chooses as* $\boldsymbol{N_s}$ *the closest integer* $\boldsymbol{[N_s]}$ *higher to* $\boldsymbol{N_s}$*.*

- The values of Table 3.2, either the mean daily irradiation in kWh/m^2 per month or the PSH values per month, can be used to make the histogram, which is shown in fig3.8.

Verification:

We construct the Table 3.3 below with the $\mathbf{i_m}$ values of the PV-panels assumed at S.T.C. equal to i_m=2.1 A. As $\mathbf{N_p}$ was determined equal to 4 and PSH was estimated in Table 3.2, one can easily estimate $\mathbf{i_L}$ from eq.(3.3). The annual mean value of $\mathbf{i_L}$ should be equal to 1.5 A, as set by this exercise at the very beginning.

Table 3.3: *Monthly i_L values*

Month	$\mathbf{i_m}$ (1)	$\mathbf{N_p}$ (2)	**PSH** (3)	$\bar{\mathbf{i}}_{\mathbf{L}}$ (1)×(2) ×(3)/24
January	2.1	4	3.26	1.14
February	2.1	4	3.55	1.24
March	2.1	4	4.16	1.46
April	2.1	4	4.41	1.54
May	2.1	4	5.18	1.81
June	2.1	4	5.45	1.91
July	2.1	4	5.67	1.98
August	2.1	4	5.88	2.06
September	2.1	4	5.38	1.88
October	2.1	4	4.46	1.56
November	2.1	4	3.58	1.25
December	2.1	4	2.85	1.00
Average value			4.49h	$\bar{\mathbf{i}}_{\mathbf{L}}$ =1.57 A

Remarks:

1. The calculation, really, provides for i_L=1.57A.

This value 1.57 is by 4.7% higher than 1.5 A : $\left(\frac{1.57-1.5}{1.5}=0.047\right)$, which is the effect of the oversizing.

2. For more accurate calculations one should take into account the change of i_m during the year.

Figure 3.8 below provides the monthly solar irradiation in Patra and simultaneously the monthly PSH values.

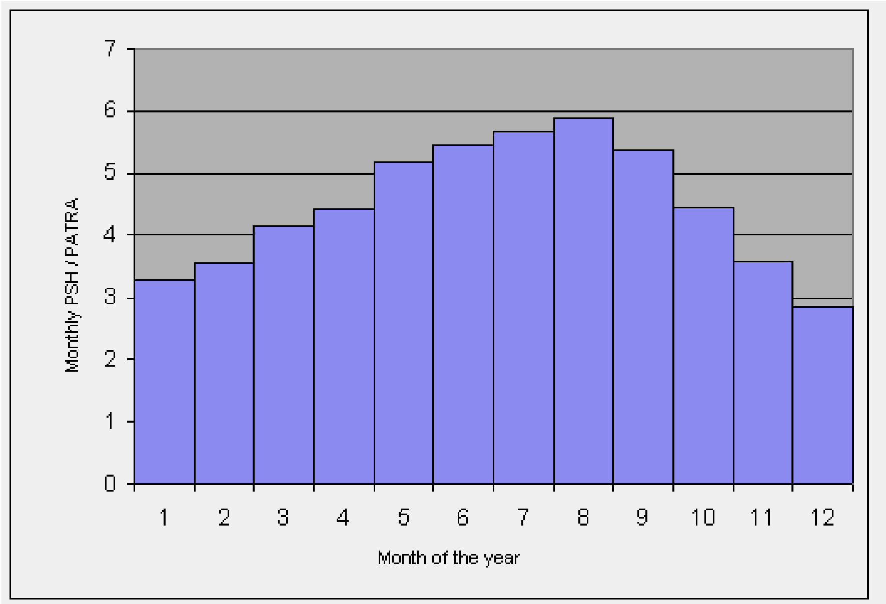


Figure 3.8: *The figure provides in this histogram the mean monthly energy (in kWh/m^2) and the P.S.H. for Patra city in Greece.*

- The $\mathbf{i_L}$ values for each month, as calculated above and given in Table 3.3, are shown by the following histogram.

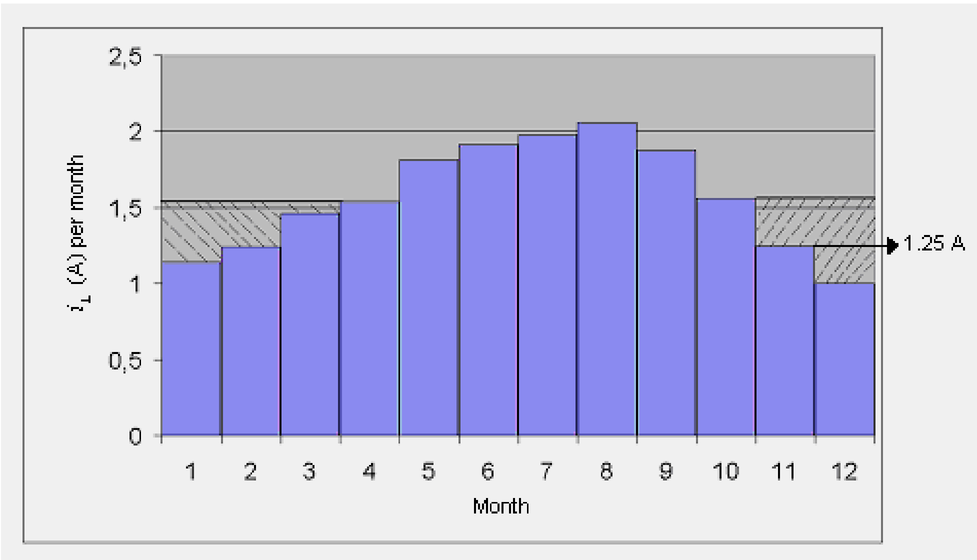


Figure 3.9: *This histogram gives the $\mathbf{i_L}$ values per month. From these $\mathbf{i_L}$ values, $\mathbf{i_{pv}}$ may be obtained, using Table 3.3 and eq. (3.3).*

- **Analysis**

From the histogram above:

1. One may distinguish the months that supplementary electric energy is required.
2. Also, if one assumes that for three days, d=3, there might be no sunshine, then the PV-system should be equipped with a conventional back-up or additional

PV-panels should be assumed in the sizing to provide more energy. This energy should be stored in batteries and be used during the period of no or inadequate sunshine.
The charge required for these **d** days is:

$\mathbf{Q_L = d \times i_L \times 24\ h/day}$	(3.7)

For example, for November the deficit is equal to:
(1.25-1.5)×24 h/day ×30 day = -180Ah (see fig 3.9) or 180 Ah are required.
The total additional charge required is the one estimated by the shadowed parts of the histogram, due to insufficient sizing.
One, then, has to add the charge required for the energy independence policy of the PV-system for **d**=3 days, that is:
$\mathbf{Q_L = d \times i_L \times 24\ h/day = 3 \times 1.57\ A \times 24\ h = 113\ Ah}$
Hence, the total additional charge required for November is equal to:
(180+113) Ah=293Ah.

Problem 3.5
Estimate the number of PV – panels, you may choose, and the configuration to make an array in Bucharest region to meet a load of 1.5 MWh per annum.

1. **Let's choose PV-panels with P_m = 45W at i_m=2.6A.**
2. **Estimate (P. S. H.)**

The annual mean **PSH** value for Bucuresti is given in the relevant Table in Appendix IV. We determine **PSH**=3.63 h.
Remember that these 45W per PV – panel are delivered at MPP when $I=10^3$ W/m^2.
For a more detailed estimation, one should use each month's PSH value.
⇒So, each PV-panel produces:

$$\mathbf{45W \times 365Wdays \times 3.63h/day = 59.6kWh/PV - panel}$$

Then, $N_{PV} = \frac{1500kWh/annum}{59.6kWh/annum} = 25.2PV - panels\,of \quad 45W \cong 26$ PV-panels.

3. **Estimate N_P and N_S.**

Let, the voltage at $\mathbf{R_L}$ should be 50Volts : $V_{R_L} = 50Volts$, while.

$$E_L(kWh/day) = \frac{1500kWh/annum}{365days/annum} = 4.11kWh/day$$

We alredy know that :

$\boldsymbol{E_L = i_L \times V_{DC} \times 24h/day}$, that is: $4110\frac{Wh}{day} = \boldsymbol{i_L}(A) \times 50V \times 24\frac{h}{day}$

$\Rightarrow \boldsymbol{i_L} = 3.425A$

Also,

$$\boldsymbol{E_L} = \boldsymbol{i_{pv}} \times \boldsymbol{V} \times \boldsymbol{PSH} \Rightarrow 4110\frac{Wh}{day} = i_{pv}(A) \times 50V \times 3.63\frac{h}{day} \Rightarrow i_{pv} = 22.6A$$

From the above we get :

$$\mathbf{i_{pv}} = \mathbf{24h} \times \mathbf{i_L}/\mathbf{PSH} = \frac{24 \times 3.425}{3.63} = 22.6\,.$$

Hence, $\boldsymbol{N_P} = \frac{\boldsymbol{i_{pv}}}{\boldsymbol{i_m}} \cdot \boldsymbol{(SF)} = \frac{22.6}{2.6} \cdot (SF) = 8.69 \cdot (SF) \cong 9$

$\boldsymbol{N_S} = \frac{\boldsymbol{V}}{\boldsymbol{V_m}} = \frac{\boldsymbol{50}}{\boldsymbol{V_m}}$. We determine $\mathbf{V_m}$ from: $\mathbf{P_m} = \mathbf{i_m} \times \mathbf{V_m} \Rightarrow \mathbf{V_m} = 17.3Volts$

$\Rightarrow$ Hence, $\boldsymbol{N_s} = \frac{50}{17.3} = 2.89 \rightarrow [N_s] = 3$

- **How to determine N_P, in general.**

$\rightarrow$ Let $\mathbf{i_{pv}}$ is the current delivered by the PV – generator to meet the load. This will be for the case of $I=10^3 W/m^2$ and for the operation at MPP.

$\rightarrow$ Let i_m the current at MPP by PV – panel used.

$$\Rightarrow \boldsymbol{N_P} = \frac{\boldsymbol{i_{pv}}}{\boldsymbol{i_m}}\,.$$

- **Analysis**

Let, Load, $\mathbf{R_L}$, requires $\mathbf{E_L}$(Wh / day), under $\mathbf{V_{DC}}$.

Let the PV – system operates all the 24 hrs of a day.

$\Rightarrow$ we define an average current $\mathbf{i_L}$ for $\mathbf{R_L}$; while the PV – generator under I_T will provide the system, as we said, with $\mathbf{i_{pv}}$ under $\mathbf{V_{DC}}$ Volts.

$$\Rightarrow \boldsymbol{i_L} = \frac{\boldsymbol{E_L(Wh/day)}}{\boldsymbol{V_{DC}} \times \boldsymbol{24(h/day)}}\,.$$

3.3 Batteries

In PV-systems, either autonomous or hybrids, it is necessary to include in the design, a power storage system i.e. battery banks.
This stored power is to be used when the PV-generator does not operate or does not produce adequate power to meet the loads, as analyzed in the previous sub-chapter.
The most commonly used batteries in PV-systems are the ones of Pb-acid.

3.3.1 Battery characteristics:

1. **Capacity: C (Ah):** $\mathbf{C(Ah)=i_{disc}(A)\times t(h)}$ (3.8.a)
where $\mathbf{i_{disc}}$ is the current which provides a battery when discharges.
2. **Electric Energy (E.E.):** **EE** (Wh)=**V** (Volts)×**C** (Ah)=**V**×**C**.(Wh) (3.8.b)
Let **C=200 Ah**.
This implies that the battery provides:

100A	in	t=2 h, or
50 A	in	t=4 h, represented by C/4
25 A	in	t=8 h, represented by C/8
20 A	in	t=10 h, represented by C/10
10 A	in	t=20 h, represented by C/20

In general, the smaller the discharge, rate, the higher the available capacity is, see fig. 3.10.

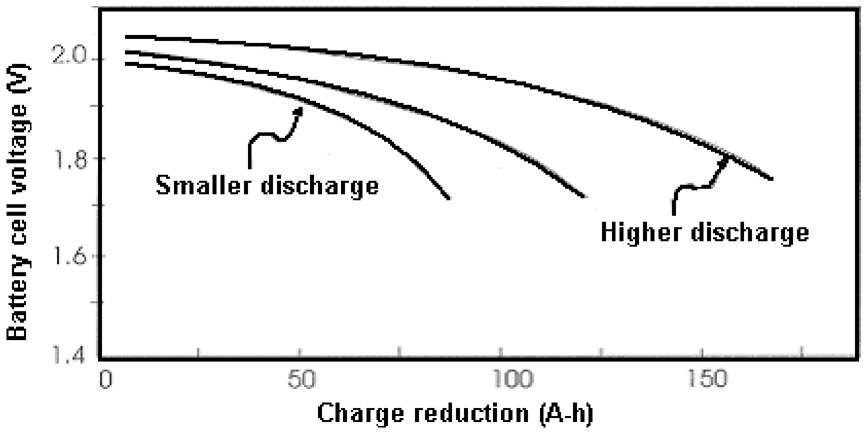


Figure 3.10: *The effect of discharge rate to the available energy or equivalently the available capacity in **Ah** for a Pb- acid battery.*

3. The capacity, **C**, depends on the temperature, **T**, too:

$$\frac{C}{C_0} = 0.00575 \times T + 0.54 \text{ [T in } {}^0\text{F] ,} \qquad (3.9)$$

To convert **T** from **^{0}F** to **^{0}C** use the expression:

$$\frac{100 - {}^0 C}{212 - {}^0 F} = \frac{5}{9} \qquad (3.9a)$$

4. **DOD: D**epth **o**f **D**ischarge

DOD is the % of the nominal capacity of the battery that is available for use. The value is given by the manufacturer.

- For shallow Batteries: **DOD 10%-25%**
- For Deep Discharge Batteries: **DOD 80%.**

This implies, for C=200Ah, that the battery may provide during a low discharge rate: $0.8 \times 200Ah = 160Ah$, provided that: Temperature is 27 ^{0}C, and

$i_{disch} \leq C/20$ i.e. for C=200 Ah, the discharge current showld be: (3.10)

$i_{disch.} \leq 200/20 \leq 10A$.

5. **Self-Discharge:** Batteries undergo self-discharge. Typical rates are:

at	T=5^{0}C	2%	per month	self-discharge
at	T=15^{0}C	4%	per month	self-discharge
at	T=25^{0}C	10%	per month	self-discharge
at	T=40^{0}C	25%	per month	self-discharge

6. **Efficiency of battery:** It may be defined in two ways:

a. by the **Ah stored** or

b. by the **Wh stored**

$$\eta_B(Ah) = \frac{(Ah)_{disch}}{(Ah)_{ch}} \text{ ; typical values } \quad \eta(Ah) = 0.9 \rightarrow 1. \qquad (3.11)$$

$$\eta_B(Wh) = \frac{(Wh)_{disch}}{(Wh)_{ch}} \text{ ; typical values } \quad \eta(Wh) = 0.8 \qquad (3.12)$$

7. **SOC** (**S**TATE **O**F **C**HARGE)

SOC or **SOC(t)** provides the **Ah** stored available by the battery at time t.

Sometimes, we use **SOC** to give the **percentage of C** of a battery that is available at a given time.

The quantities: **i, V, SOC**, are inter-related.

From the above analysis, one gets:

SOC = Q(t)/C_b = Charge (Coulomb) of battery at t/nominal capacity (3.13)

Also, it can easily be proven that:
DOD = 1-SOC (3.14)

Notice: *Effective recharging takes place when **SOC**<0.7 and the Voltage of the battery cell is < 2.3Volts.*
*The efficiency, η for **(re)charging** reaches zero (0) as **SOC** $\rightarrow$ Q_b, where Q_b is the maximum charge that the battery can hold.*

- For Pb batteries with high **DOD**, holds:

Cycles × DOD ≈ 1200 , (3.15)

where : **Cycle = Charge – Discharge cycle operation.**

Problem 3.6

Let an energy scenario to meet the load demand of 83 Ah/day. Let us choose batteries of 300Ah with DOD=80%=0.8.
Try to investigate on the decision for the battery choice.

Solution

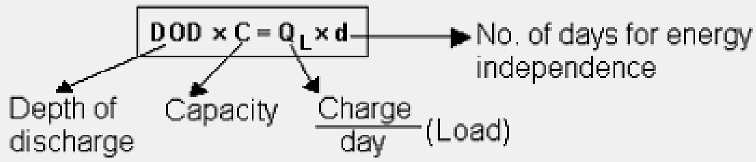
From the above, data in a day the (**DOD**) Depth Of Discharge $= \frac{83Ah}{300Ah} = 0.28$

This implies that if the load draws energy from the battery for 3 days, i.e.(d=3 days). Then, the final depth of discharge will be: $0.28 \times 3 = 0.84$ or 84%, which is very close to DOD=0.80.

Conclusion: Such a battery may surely stand an autonomy for d=3 days according to the energy scenario of 83 Ah/day, as set above.
Of course, the economic analysis based on prices and cycles to sustain will give the optimum choice.

This issue is delt in § 3.3.3 later on.

3.3.2 Generally, the following relationship holds



(3.16)

- The battery capacity, $\mathbf{C_N}$, to meet load $\mathbf{Q_L}$ with energy independence of **d** days is estimated by:

$$\mathbf{C_N = \frac{C_L}{1 - t_b \times (C_c + C_a)}} \qquad \text{, where} \tag{3.17}$$

$$\mathbf{C_L = \frac{Q_L \times d \times f_c}{V \times DOD}} \tag{3.18}$$

which is a more general expression of eq. (3.16).

$\mathbf{t_b}$**:** no. of years that the battery will run effectively (according to specifications)
$\mathbf{Q_L}$**:** daily load (Wh/day). It depends on the external consumers or loads
$\mathbf{C_c}\approx 0.007\text{-}0.01$. it is a correction factor due to cycles / recycling
$\mathbf{C_a}$: correction due to the ageing of the battery. i.e. charging-discharging.
More specifically:
$\mathbf{C_a}\approx 0.015$ (for a battery with flow of electrolyte) and 0.020 (for conventional electrolyte)
f_c: correction due to Joule effect in battery
V: voltage across battery.

Problem 3.7
Let a stand alone PV-generator, designed to meet the load for a building in Bucharest. Let the Load be 100Ah/day. The voltage to be established due to DC/AC load requirements is V = 48Volts. The energy autonomy is assumed to be d = 3days. Determine the details of the battery bank and the type of the batteries to be used.

- **Step 1:**

Let's choose: Exide Tubular Modular of 192 Ah, see Table 3.4 below.

Table 3.4a: *Battery detailed information*

Manufacturer and Model	Model Number	Shallow / Deep Cycle (S / D)	Nominal Capacity (Ah)	Nominal Voltage (V)	Daily Depth of Discharge (%)	Life (Cycles)	Number of sets over 20-Year PV Lifetime	Total Power delivered (kWh)
Exide Tubular Modular	6E95-5	S	192	12	15 20	4100 3900	2 2	1417 1797
	6E120-9	S	538	12	15 20	4100 3900	2 2	3970 5036
	3E120-21	S	1346	6	15 20	4100 3900	2 2	4967 6299

Table 3.4b: Other types of batteries according to manufacturers.

Manufacturer and Type	Model	Nominal Capacity (Ah)	Nominal Voltage (V)	DOD (%)	Life Cycles	Total to be delivered Energy (kWh)
GNB Absolyte	638	42	6	50	1000	126
	1260	59	12	50	1000	359
	6 – 35A09	202	12	50	3000	3636
	3 – 75A25	1300	6	50	3000	1700
Exide Tubular Modular	6E120 – 5	192	12	15 20	4100 3900	1417 1797
	6E120 – 9	538	12	15 20	4100 3900	3970 5036
	3E120 – 21	1346	6	15 20	4100 3900	4967 6299
Delco – Remy Photovoltaic	2000	105	12	10 15 20	1800 1250 850	227 236 214
Global Solar Reserve gel Cell	3SSSSRC – 125G	125	6	10	2000	150
	SRC – 250C	250	2	10	2000	100
	SRC – 375G	375	2	10	2000	150
Globe	GC12 – 800-38	80 80	12 12	20 80	1500 250	288 240
GNB Absolyte	638	40	6	80	500	96
	1260	56	12	80	500	269
	6 – 35A09	185	12	80	1500	2664
	3 – 75A25	1190	6	80	1500	8568

Let the Table's specifications for this battery type be:
DOD=0.20, C=192 Ah, V=12 Volts, Life Cycles (L.C.)=3900, 4.9 years

- Is it a successful choice? To answer we follow the analysis below:

a. Let the 100 Ah be required in 8 hours. (Assumption of the load scenario)

$\Rightarrow \quad \boldsymbol{i}_{disch.} = \frac{100Ah}{8h} \approx 12.5A$. This is a high discharge rate > $C/20 = \frac{100Ah}{20h} = 5A$.

So, it has a negative effect to the available capacity. Later on in "Case Studies" (Chapter V), we will estimate the correction to the capacity due to high discharge rate.

b. $\boldsymbol{DOD}_{day} = \frac{100Ah}{192Ah} = 52.08\%$, which is bigger than 20% according to the specification for DOD of this battery type.

This is , also, a big disadvantage for the case when only one battery might be used. One should look for the case in detail as more batteries would rather be connected in parallel. A detailed investigation is required. This is to be analyzed below.
The battery's circuitry depends also on the voltage to be developed across the battery bank, also effects. This is governed by the voltage input to the DC/AC inverter or to the loads, which depends on the PV-system configuration.

c. As discharge rate is somehow high, the available capacity will be less than 192 Ah. A proper diagram is required, as the one of fig.3.11, which holds for Delco 2000 type of battery.
Let this corrected capacity be 170-180 Ah instead of 192 Ah.

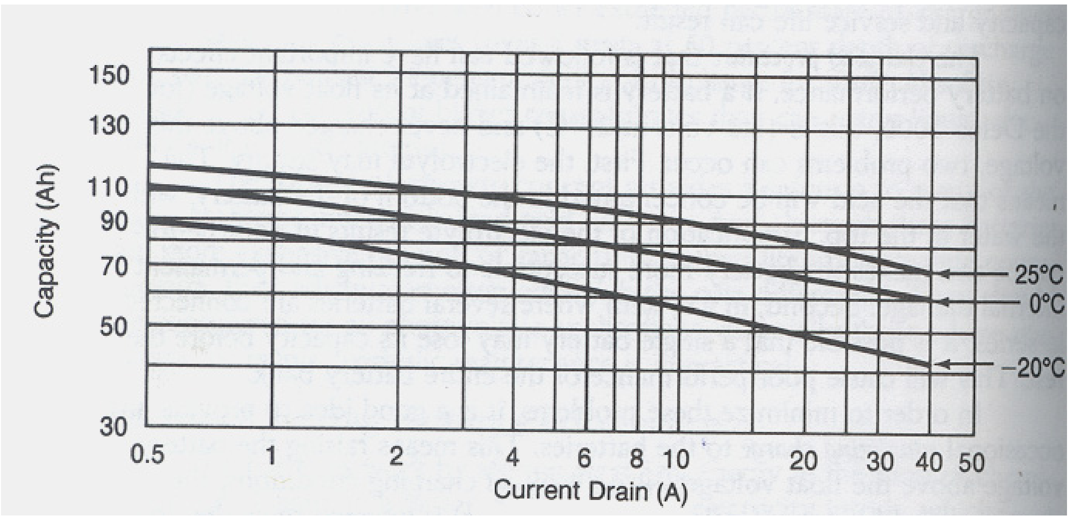


Figure 3.11: *A graph showing amp-hour capacity as a function of temperature and discharge rate for the Delco 2000 battery.*

Hence, the available capacity is

$\boldsymbol{DOD \times 180Ah = 0.20 \times 180Ah = 36Ah \ll 100Ah}$

Perhaps, bad choice, but one can never decide in such an early stage.

The answer has to be given upon the final configuration of the battery bank: i.e. how many batteries will be in series and how many in parallel; see next step.

- **Step 2:**

Let us choose **GNB Absolyte** with characteristics: **56 Ah, V=12 V, DOD=0.8**

Let's us accept that for same discharge rate the following values hold:

$i_{disch.}$=12.5 A $\Rightarrow$ C=50 Ah (T=25 ^{0}C)

Then, the:

Total Usable (or Available) Capacity =T.U.C.=$C_{i=12.5\,A}$×DOD	(3.19)

=50 Ah×0.8=40 Ah

- **Step 3:**

The number of battery series in parallel, $\mathbf{N_{b,p}}$ is given by:

$$\mathbf{N_{b,p} = \frac{Q_L \times d}{DOD \times C} = \frac{100\frac{Ah}{day} \times 3days}{0.8 \times 50Ah} = \frac{300}{40} = 7.5} \qquad (3.20)$$

$\Rightarrow$ Hence, the design of the batteries bank requires 8 series of batteries in parallel.

- **Step 4:**

Check if $\mathbf{DOD_{per\ day}}$ is less than $\mathbf{DOD_{specs}}$.

As 8 series of batteries will be in parallel, then the nominal charge will be $8 \times 50Ah = 400Ah$

Hence, $\frac{100Ah(Load / day)}{400Ah(available)} = 0.25$ which is **<<0.80** so, the Life Cycles will be close to the specifications, see Table 3.4b.

- **Step 5:**

The number of batteries in series is given by:

$$\mathbf{N_{b,s}} = \frac{\mathbf{V}}{\mathbf{V_b}} = \frac{48Volts}{12Volts} = 4$$

V is the Voltage required to be developed as input to the DC/DC or DC/AC or any DC Load. This V=48 Volts were given by this exercise in the data requirements of the PV-generator.
Hence the total No. of batteries **N**:

$\mathbf{N} = \mathbf{N_{b,p}} \times \mathbf{N_{b,s}} = 8 \times 4 = 32$ batteries.

Remark: A more detailed analysis will be given in a next version of this book.

3.3.3 Economics of the batteries and PV-generators, in general

It is essential to examine the possible solutions for those PV & battery systems as far as it concerns the economics. The **Present Worth (P.W.)** of a system is an important factor to build this economic analysis. This notion will be explained below.
The economics of the batteries is a serious issue as these elements is the weak point of the PV-system.
Hence, the **life cycle** and the number of **charge-discharge cycles** have to be considered along with DOD and the price of the battery unit, too.

1. Let the inflation be π**%** and that
2. An asset $\mathbf{A_0}$ is required for the purchase of the battery. This asset might be deposited with an interest of ε**%.**
3. Let this unit (eg. battery) costs **No** €uros at the time of the installation.

It is evident that $\mathbf{A_0 = No}$. (3.21)
However, if the asset $\mathbf{A_0}$ is deposited, then after ***n*** **years** it becomes:

$$\boldsymbol{A(n) = A_0(1+\varepsilon)^n} \quad , \tag{3.22}$$

On the other hand, the cost of the (this) unit if to be purchased after ***n*** **years**, (if this good still exists & if inflation it is the same) is given by:

$$\boldsymbol{N(n) = No(1+\pi)^n} \tag{3.23}$$

That is, if someone could purchase a good, at a time, with $\mathbf{A_0}$ €uros, of **No** value, then this will not hold after ***n*** years.
Therefore:

1. One defines the **present value coefficient**, **CV** as:

$$\boldsymbol{CV = \frac{A(n)}{N(n)} = \left(\frac{1+\pi}{1+\varepsilon}\right)^n} \tag{3.24}$$

This helps to determine the value of the good **in present price** in case it is to be purchased at a period of ***n*** years later. (*n* = 2,3,…..)

2. The value of the unit / good in present prices is :

$$\boldsymbol{P.W. = CV \cdot No} \qquad (3.25)$$

Problem 3.8

Let us consider the two possible solutions for the battery banks as analyzed in the previous problem.

1st solution :	4 batteries	50 Ah each	Life: 2.7 years
2nd solution :	1 battery	200 Ah	Life : 8 years

The Question rises:
Which is the most cost effective scenario to be adopted?
As a PV-system will live for 15-20 years let's consider a life span of 16 years.
During this period, the batteries from the 1st model will be replaced 5 times, while the battery from the 2nd model only once.

	50 Ah	200Ah
Initial purchase	*150€ × 4 = 600€*	*1× 850€ = 850€*
2.7years(1st replacement)	*600€ × CV^n = 456€*	
5.4years (2nd replacement)	*600€ × CV^n = 399€*	
8.1years (3rd replacement)	*600€ × CV^n = 325€*	*465€* (replacement at 8 years)
10.8years (4th replacement)	*600€ × CV^n = 265€*	
13.5years (5th replacement)	*600€ × CV^n = 216€*	
TOTAL	*2294€*	*1315€*

Notice: ***n*** *takes the values of: 2.7, 5.4, 8.1, 10.8, 13.5 years to estimate costs using (3.23) and (3.24).*

Remark: the following data were considered for this case

- Let π%=2% and ε%=10%

Then, $CV = \dfrac{(1+0.02)}{(1+0.1)} = 0.92727$

- Also n(=year of battery replacement) takes values:

n = 2.7	5.4	8.1	10.8	13.5	1st scenario
n		8			2nd scenario

Conclusions:

1. It is obvious that the purchase of one battery big capacity provided it meets the technical characteristics of a PV-generator seems to be more economically. It is also more economic from the case of four batteries and also more economic because four batteries need longer wirings.

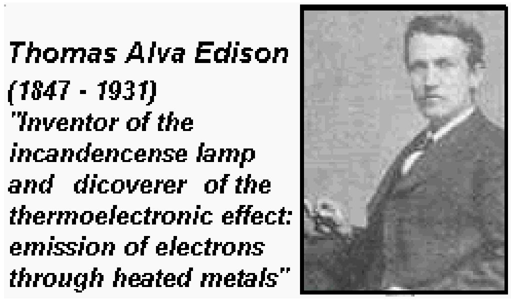
   However, the solution with one battery takes the risk that the effect of small operational problems in one battery affects dramatically the PV insolation.
2. The above analysis is based on the assumption that the 2^{nd} solution with one battery is feasible.

   However, even if the battery capacity meets the requirement of the storage systems for example the capacity of the battery is 200Ah, while the capacity required is 192Ah, we have to check if the other requirement with the battery capacity 192Ah.

   For example: the voltage across the battery storage needs to be 48V that is for the battery for GNB Absolyte we need four such units and not only one.

So in the analysis above has to be corrected so that four battery to be considered and not only one.

The exercise is left to the reader.



CHAPTER IV

PV-SYSTEMS ENGINEERING. THE SIZING ISSUE.

4.1 Sizing a PV system

4.1.1 Introduction

Sizing a photovoltaic system is an important task in the system's design. In the sizing process one has to consider three basic factors:

a. the solar insolation of the site
b. the daily power consumption (Wh) or the electric loads, and
c. the storage system to contribute to system's energy independence for a time period.

If the system is oversized it will have a big impact in the final cost and the price of the power produced.
If on the other hand, the system is undersized, problems might occur in meeting the power demand at any time.
The sizing should be carefully planned in order to get a cost effective system.
Three sizing case studies will be discussed in this chapter.

4.1.2 Solar radiation data

The amount of sunshine available at a given location is called "**solar resource**" or **solar insolation**.
The amount of electrical energy produced by a PV-array depends primarily on the insolation at a given location and time. Data are usually given in the form of global radiation over a horizontal surface. The procedure of solar radiation calculation on a sloped surface, is given as a case study in § 5.6.

4.1.3 Load Data

As it concerns the loads, one may get the proper information on data according to the appliances to be powered by the system.

These appliances could be domestic appliances like: TV sets, lights, refrigerator, kitchen, vacuum cleaner, washing machine, coffee machine etc.

The determination of the total daily energy consumption requires the following steps:

a. identification of all the electrical devices that will be powered by the PV-generator,

b. determination of each device's power usage (in Watts),

c. estimation of the average daily operation of each device in hours per day,

d. multiplication of **b** and **c** provides **d**: i.e. **b** (Watts)×**c** (h/day)=**d** (Wh/day)

So, one gets as result the load in Wh/day

e. summation of the watts-hours for all the devices in order to get the total daily energy requirement.

An example of such a load profile is shown below.

Table 4.1: *An example of a simplified energy profile for a household is shown in the table below.*

Type of Appliance	*No.*	*Rated Power (Watts)*	*Daily usage (hrs/day)*	*Daily Load (Wh/day)*
Cooker	1	3000	1	3000
Clothes dryer	1	2000	0.25	500
Lights	5	80	6	2400
TV	1	100	4	400
Total				6300

Note: *More detailed data about domestic loads are provided in § 5.9.*

The daily energy requirement would equal the sum of the calculated values in kWh per day. If the energy requirement varies from season to season, it must be calculated for each season or each month, provided that better accuracy on the load requirements are sought. For even more effective load management, the daily profile of each load must be studied, see fig. 4.1.

Residences tend to use more energy in winter when the days are shorter, since lights and other appliances as televisions are longer.

Of course, if air-conditioning is included, then the summertime loads are also considerable.

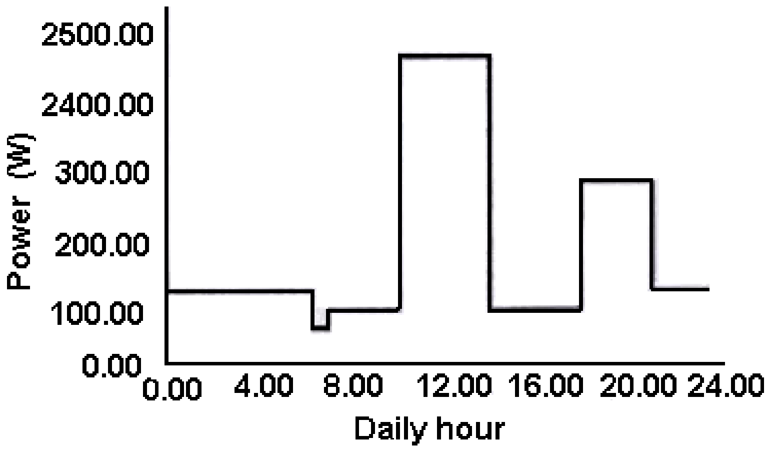


Figure 4.1: *The figure shows the daily load*

4.1.4 Sizing Procedure

The system design will be based on the yearly energy balance between the solar radiation and the load. A block diagram of the sizing procedure is shown in fig. 4.2.

- **Input data for the sizing procedure**

The available solar energy on the PV-panels for a typical day of each month and different panel inclinations can be determined from blocks 1-3, see fig. 4.2.
The load specifications are used in order to calculate the average daily load power demand for a typical day in each season (blocks 4-5).

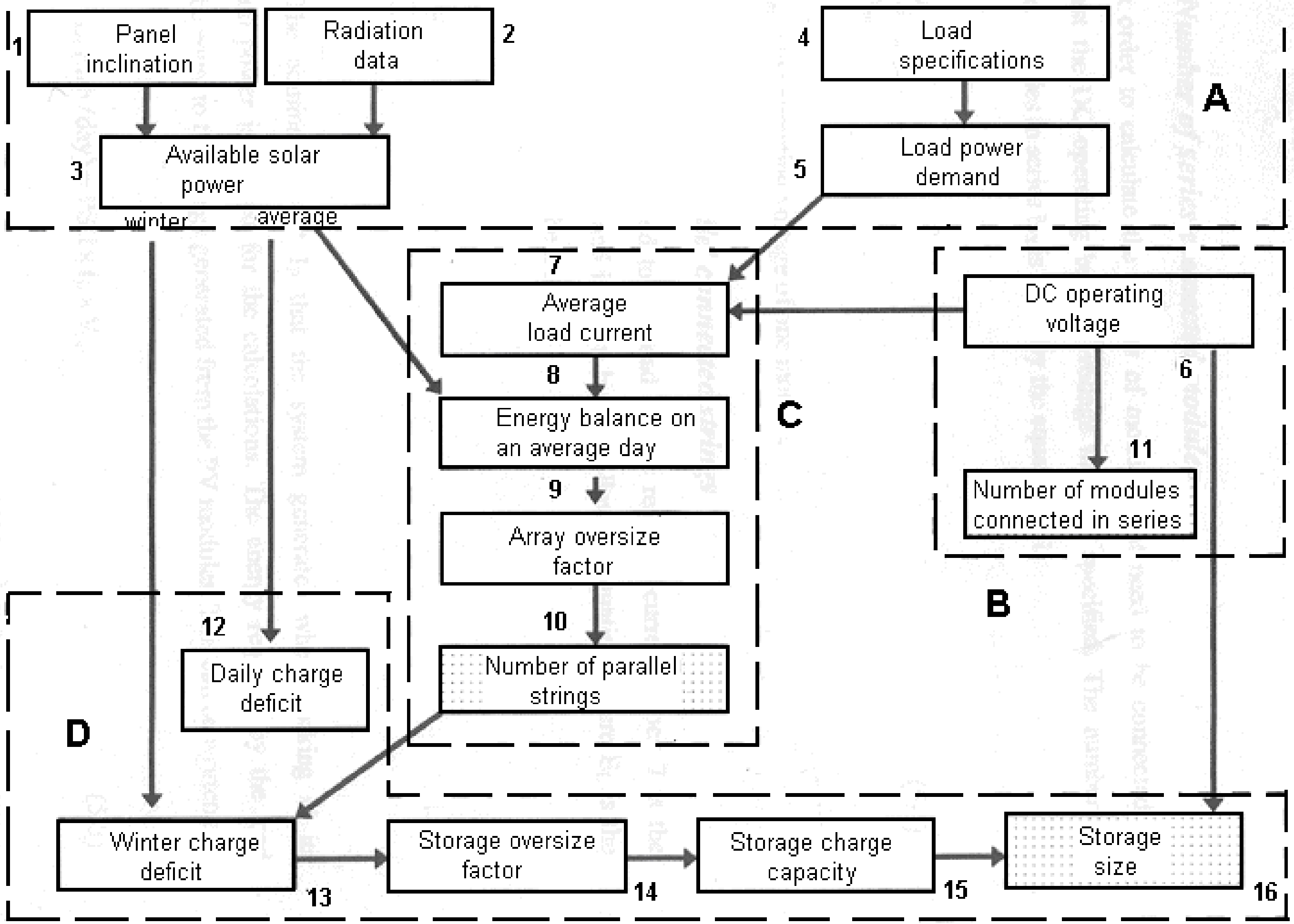


Figure 4.2: *Sizing procedure based on energy balance (from Tomas Markvart)*

- **Number of series connected modules, N_s**

In order to calculate the number of PV-modules that need to be connected in series, first the **DC** operating bus bar voltage must be specified. The number of connected modules in series, N_s, is given by the equation (4.1).

$$N_s = \frac{V_{DC}}{V_m} \qquad (4.1)$$

where V_m is the operating voltage on the PV-modules.
The effort of the design itself and the electronic components, mainly the **MPPT**, is to set the operation voltage at V_{MPP}.
V_{DC} attracts the designer's attention due to the electric losses (**Joule effect**). When V_{DC} is small, then **i** takes high values, so the Joule effect ($i^2 \times R_L$) causes more electric energy to be converted (wasted) into heat.
V_{DC} should take values like 48 or 120 Volts and not 24 Volts in order to reduce current and consequently electric energy losses.

- **Number of parallel connected strings, N_p**

This number, N_p, is related to the **energy load** and its **required current**.
In block 7, it is estimated the average current, i_L, needed by the load and it is given by the following equation, where E_L is the average power required by the load.

$$i_L = \frac{E_L(Wh/day)}{24h/day \times V_{DC}(Volts)} \text{ (A)} \qquad (4.2)$$

The nominal current i_{pv} that the PV-system generates when working at its maximum power (MPP) is needed for the calculations.
All those above issues were analyzed in § 3.2 with the problem 3.3-3.6.

Energy Balance principle:

The energy required by the load should be equal to the energy generated from the PV-modules.

This principle takes the form:

$$E_L(Wh/day) = PSH \times V_{DC} \times i_{pv} \qquad (4.3)$$

where, **PSH** is numerically equal to the irradiation on the PV-generator in kWh/m^2.
Substituting equation (4.2) to (4.3) and solving for i_{pv}, yields:

$$i_{pv} = \frac{24(h/day) \times i_L(A)}{PSH(h/day)}(A) \qquad (4.4)$$

Equation (4.4) displays that the average daily load current $\mathbf{i_L}$ multiplied by the number of hours, 24 h, should be numerically equal to the charge produced during a day which is equal to the current in **A**mps that the system produces multiplied by the number of **P**eak **S**olar **H**ours (**PSH**).
The number of modules connected in parallel, $\mathbf{N_p}$, see (blocks 9-10) is given by the following equation, where **SF** is the safety factor, or **S**izing **F**actor, introduced to oversize the current produced from the array in order to cover any loads;
$\mathbf{i_m}$ is the current generated from one PV-module.

$$\mathbf{N_p} = (\mathbf{SF})\frac{\mathbf{i_{pv}}}{\mathbf{i_m}} \tag{4.5}$$

The total number of modules needed to set up the PV-generator is:

$$\mathbf{N} = \mathbf{N_p} \times \mathbf{N_s} \tag{4.6}$$

Remark:
Corrections to $\mathbf{i_m}$, $\mathbf{V_m}$, or $\mathbf{P_m}$ due to higher temperatures than the **S.T.C.** determines have to be introduced, see § 1.2.7.

4.1.5 Sizing of the storage subsystem

An analysis of the sizing of storage systems was presented in the case of Problem 3.4.
Here, we may summarize:
1. The daily and seasonal energy deficit is calculated in the block 12. The loads during the nights and periods with very little sunshine must be net satisfactory.
2. Also, excess (unused) energy must be stored in order to be used later. Such a case was approached with Problem 3.6 followed by the economical issues of the batteries in § 3.3.3.
This sizing analysis determines the daily charge/discharge of the battery which should not exceed a certain value, as we saw in § 3.3.2.
3. The charge deficit (block 13) is a value, usually given in **Ah**, that is related to the energy balance of the year, see § 3.2. Excess energy during the summer periods has to be stored in order to cover the energy deficit during the winter.
• The charge deficit is given by the following equation, where $\mathbf{\Delta E_w}$ is the winter energy deficit.

$$\mathbf{Q_{Yd}} = \frac{\mathbf{\Delta E_w}}{\mathbf{V_{DC}}} \tag{4.7}$$

If during summer there is an excess energy $\mathbf{\Delta E_s}$ stored, the annual charge deficit is:

$$\mathbf{Q_{Yd}} = \frac{-\mathbf{\Delta E_w} + \mathbf{\Delta E_s}}{\mathbf{V_{DC}}} \tag{4.7'}$$

4. A second approach for the charge deficit was fully presented in Problem 3.4.
5. Another charge deficit (block 14) is used to allow for a certain number of days, **d**, of operation with no energy input (no sunshine, system is maintenance period etc.). This number is determined from experience and depends on the PV-system's management.
However, for more reliable data the following relationships are used to determine **d**, for the **critical** and **non-critical loads** respectively:

$$d_{cr} = -1.9 \times (PSH)_{min} + 18.3 (days) \quad (4.8a)$$

$$d_{n\text{-}cr} = -0.48 \times (PSH)_{min} + 4.58 (days) \quad (4.8b)$$

A system is considered as **critical** when for only 88 h in a year the system is allowed of no operation.
For the less **critical loads**, the relationship to be used is equation (4.8b).
The charge deficit due to this policy is given by the equation (4.8c).

$$Q_d = i_L \times 24 \times d \,(Ah) \quad (4.8c)$$

6. The nominal capacity of the battery bank Q_b in (Ah) will be given by equation 4.9 (block 15) where **(DOD)** is the battery's maximum discharge depth (**DOD**: **D**epth **o**f **D**ischarge).

$$Q_b = (Q_{Yd} + Q_d) \cdot (1/DOD) \quad (4.9)$$

7. From the operating voltage and capacity of one battery, the total number of batteries can be calculated (block 16). The same methodology was followed to determine the number of PV-panels.
8. The number of batteries in series, $N_{b,s}$, is given by equation (4.10) below, where V_B is the nominal voltage of the battery.

$$N_{b,s} = \frac{V_{DC}}{V_B} \quad (4.10)$$

9. The number of batteries in parallel, $N_{b,p}$, is given by equation (4.11) where Q_C is the nominal capacity of a single battery.

$$N_{b,p} = \frac{Q_b}{Q_C} \quad (4.11)$$

10. The total number of batteries is then calculated by:

$$N_b = N_{b,p} \times N_{b,s} \quad (4.12)$$

Table 4.2: *Notation and units of quantities in PV-sizing problems*

Symbol		**SI** ***unit***
E_L	Daily load energy requirement	Wh
i_L	Average load current	A
i_m	Module current at maximum power point	A
i_{pv}	Current generated from PV at maximum power point under standard conditions	A
N_s	Number of series connected modules	
N_p	Number of parallel strings	
$N_{b,s}$	Number of batteries connected in series	
$N_{b,p}$	Number of batteries connected in parallel	
PSH	Peak solar hours	H
Q_d	Charge deficit to compensate for loss of sunshine in a period of d days	C (Ah)
Q_{Yd}	Yearly charge deficit	C (Ah)
Q_b	Nominal battery capacity	C (Ah)
Q_c	Single battery capacity	C (Ah)
SF	Array oversize factor, **S**izing **F**actor	
V_{DC}	DC bus bar voltage	V
ΔE	Yearly energy deficit	Wh
ΔE_w	Winter (energy) deficit	Wh
ΔE_s	Summer excess energy stored	Wh
DOD	Lowest permitted state of charge	%

Wolfgang Pauli
(1900 - 1958)
Nobel Laureate in Physics in 1945 - "The principle of exclusion"

Chapter V: CASE STUDIES ON PV-SYSTEMS

CASE STUDY 1: Feasibility study for a PV-system for Sifnos Island (Greece) and Glasgow (UK)

5.1 Introduction

In this chapter, an application of the previous sizing methodology will be used in order to size a PV-generator.
This methodology will be used for two different locations one in Greece and one in Scotland.
The first step will be to determine the available average daily insolation for each site.
Then, the average power consumption and finally the size the PV-system which is just adequate to cover the desired load will be estimated.
Solar insolation data can be downloaded from the METEONORM data bank for many cites of any country; see references.

5.2 Average daily solar radiation

- **Sifnos-Greece**

The available solar energy impinging on the PV-panels will be computed according to the procedure to be described in §5.6. Some of the parameters that are needed are the site's latitude and the clearness index $\mathbf{K_t}$. These parameters are shown in § 5.6 along with the complete set of solar insolation calculations for the Sifnos Island-Greece.
Finally, the results of the average daily radiation in Wh/m^2 on an inclined surface are shown in Table 5.1, and in fig. 5.1, below.

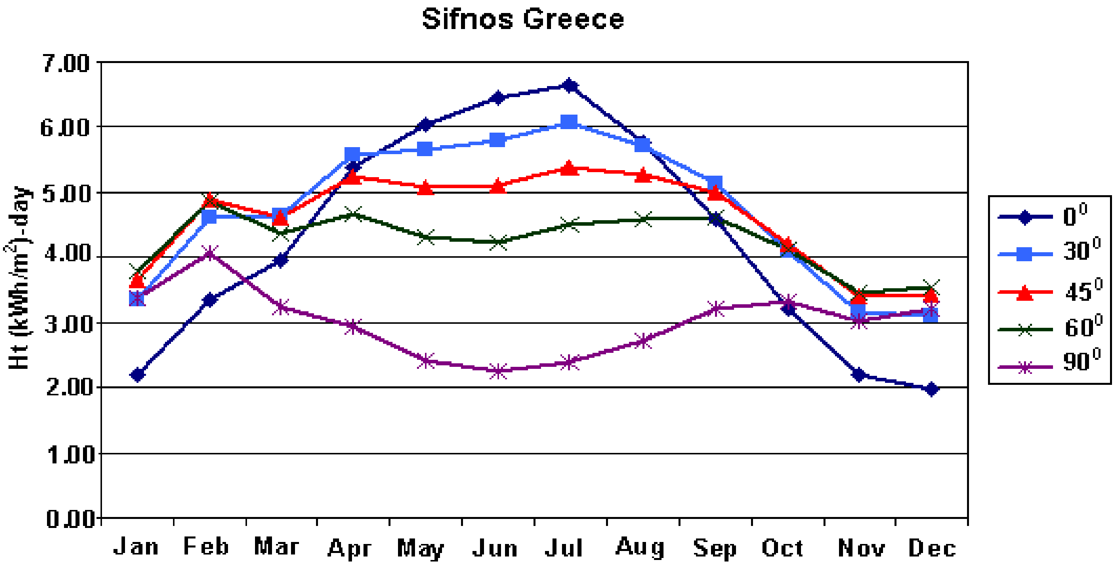


Figure 5.1: *Shows the average daily radiation for different inclination of PV-panels , in Sifnos island.*

Table 5.1: *Daily irradiation in Sifnos (in kWh/m² per day) for a typical day every month as a function of the panel inclination in degrees.*

Panel Tilt, Degrees	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	Annual KWh/m²
0	2.20	3.36	3.96	5.39	6.03	6.46	6.63	5.77	4.58	3.20	2.20	1.98	**4.31**
5	2.43	3.63	4.13	5.50	6.04	6.42	6.61	5.84	4.74	3.40	2.40	2.21	**4.44**
10	2.64	3.87	4.28	5.57	6.02	6.36	6.56	5.88	4.87	3.58	2.58	2.42	**4.55**
15	2.85	4.10	4.41	5.62	5.97	6.26	6.48	5.88	4.98	3.73	2.75	2.61	**4.64**
20	3.03	4.30	4.51	5.63	5.89	6.14	6.37	5.86	5.05	3.87	2.90	2.79	**4.70**
25	3.20	4.47	4.59	5.61	5.79	5.98	6.23	5.80	5.10	3.99	3.04	2.96	**4.73**
30	3.35	4.61	4.64	5.57	5.65	5.80	6.06	5.71	5.12	4.08	3.16	3.10	**4.74**
35	3.47	4.73	4.66	5.49	5.49	5.60	5.86	5.60	5.11	4.15	3.26	3.23	**4.72**
40	3.58	4.82	4.65	5.38	5.30	5.37	5.63	5.45	5.06	4.19	3.34	3.34	**4.68**
45	3.66	4.88	4.62	5.24	5.09	5.11	5.38	5.27	4.99	4.21	3.40	3.43	**4.61**
50	3.72	4.90	4.57	5.07	4.85	4.84	5.10	5.07	4.89	4.21	3.44	3.49	**4.51**
55	3.76	4.90	4.48	4.88	4.59	4.54	4.80	4.84	4.77	4.18	3.46	3.53	**4.39**
60	3.78	4.87	4.37	4.66	4.31	4.23	4.49	4.59	4.61	4.12	3.45	3.55	**4.25**
65	3.77	4.80	4.24	4.42	4.02	3.91	4.15	4.32	4.44	4.04	3.43	3.55	**4.09**
70	3.73	4.71	4.08	4.16	3.71	3.58	3.81	4.03	4.23	3.94	3.39	3.53	**3.91**
75	3.68	4.59	3.90	3.87	3.39	3.24	3.45	3.72	4.01	3.81	3.32	3.48	**3.71**
80	3.60	4.44	3.70	3.57	3.06	2.90	3.09	3.40	3.76	3.66	3.24	3.41	**3.49**
85	3.49	4.26	3.48	3.26	2.74	2.56	2.74	3.07	3.49	3.50	3.13	3.32	**3.25**
90	3.37	4.06	3.24	2.93	2.41	2.24	2.39	2.73	3.21	3.31	3.01	3.21	**3.01**

***Notice**: the numbers above provide the PSH values, too.*

- **Glasgow-Scotland**

Using the same procedure, one obtain the data for Glasgow, as presented in the appropriate Table 5.26 in § 5.6.

These data on the average daily solar radiation falling on an inclined surface in Glasgow are given by Table 5.2, and fig 5.2, below.

Table 5.2: *Daily irradiation in Glasgow (in kWh/m^2 per day) for a typical day every month as a function of the panel inclination in degrees.*

Panel Tilt	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	Annual KWh/m^2
0	0.65	0.93	1.91	3.33	4.48	4.22	4.12	3.30	2.45	1.33	0.55	0.34	**2.30**
5	0.82	1.03	2.04	3.44	4.54	4.23	4.14	3.38	2.58	1.47	0.63	0.41	**2.39**
10	0.98	1.12	2.16	3.54	4.58	4.23	4.16	3.44	2.71	1.60	0.70	0.47	**2.48**
15	1.14	1.21	2.27	3.63	4.61	4.22	4.16	3.48	2.81	1.72	0.78	0.54	**2.55**
20	1.29	1.29	2.36	3.69	4.61	4.20	4.15	3.51	2.90	1.83	0.84	0.60	**2.61**
25	1.44	1.37	2.45	3.74	4.60	4.15	4.12	3.53	2.98	1.93	0.91	0.65	**2.66**
30	1.57	1.43	2.52	3.77	4.56	4.10	4.07	3.52	3.04	2.02	0.97	0.71	**2.69**
35	1.70	1.49	2.57	3.77	4.51	4.02	4.00	3.50	3.08	2.10	1.02	0.75	**2.71**
40	1.81	1.54	2.61	3.76	4.43	3.93	3.92	3.47	3.11	2.17	1.07	0.80	**2.72**
45	1.91	1.58	2.64	3.73	4.33	3.82	3.82	3.41	3.12	2.22	1.11	0.84	**2.71**
50	2.00	1.62	2.65	3.68	4.22	3.70	3.71	3.34	3.11	2.26	1.14	0.87	**2.69**
55	2.07	1.64	2.65	3.61	4.08	3.56	3.58	3.25	3.08	2.29	1.17	0.90	**2.66**
60	2.13	1.65	2.63	3.52	3.92	3.41	3.43	3.15	3.04	2.30	1.19	0.92	**2.61**
65	2.18	1.65	2.60	3.41	3.75	3.24	3.27	3.04	2.98	2.30	1.20	0.94	**2.55**
70	2.21	1.65	2.55	3.28	3.56	3.07	3.10	2.91	2.91	2.28	1.21	0.95	**2.47**
75	2.23	1.63	2.49	3.14	3.36	2.89	2.92	2.77	2.81	2.25	1.21	0.95	**2.39**
80	2.23	1.61	2.41	2.98	3.15	2.69	2.73	2.61	2.71	2.21	1.20	0.95	**2.29**
85	2.21	1.57	2.32	2.81	2.92	2.49	2.54	2.45	2.59	2.16	1.18	0.94	**2.18**
90	2.18	1.53	2.22	2.62	2.69	2.29	2.33	2.28	2.45	2.09	1.15	0.93	**2.06**

Note: *Comparing data in Tables 5.1 and 5.2 one understands that as PSH values for Glasgow are quite shorter than the corresponding ones for Sifnos island, energy delivered by the PV-generator is much bigger for Sifnos.*

In addition to that loads differ as natural lighting is richer for Sifnos.

If air-conditioning is to be taken into account, Sifnos has some disadvantage due to higher ambient temperature compared to Glasgow.

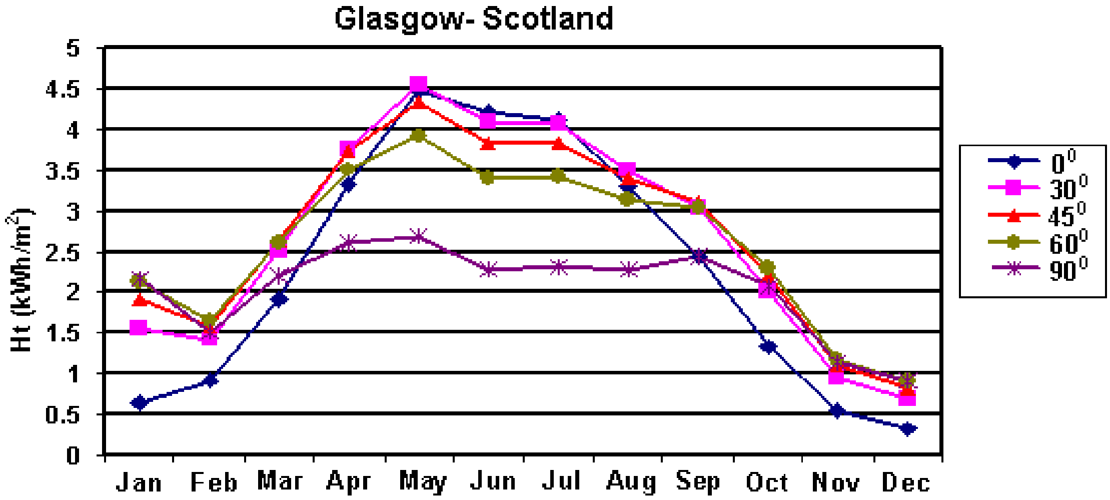


Figure 5.2: *Average daily radiation for different inclination angles in Glasgow*

5.3 Load demand

A table showing the most common appliances used in a household is given in the next page. They are described by their nominal power and the time they are used during the day.

These two numbers have to be multiplied in order to find the total energy; in Wh, consumed during a typical day, see also § 4.1.3 .

Four seasons are included in the load profile study, with different utilization times for the appliances. These values, as estimated for each season, are used to determine the average daily annual consumption on a seasonal basis. These are just estimates, and they can vary according to the place, time of season or residential customs.

The percentage of the average daily electric load for winter is shown in fig. 5.3.

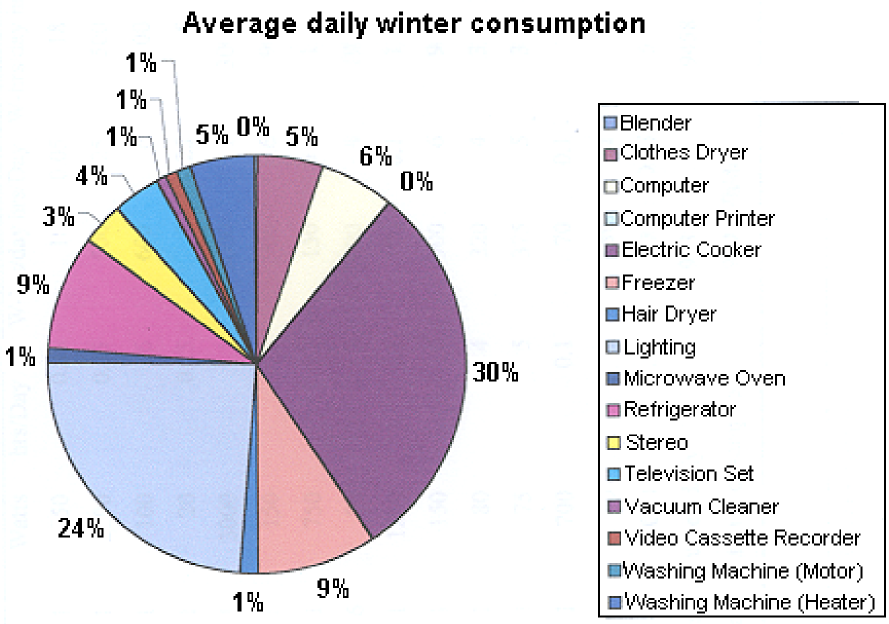


Figure 5.3: *Percentage of average daily electric load in winter time*

5.4 Sizing of the PV-system; determination of important settings.

a. The optimum tilt angle (**β**) for both PV-systems in the two locations must be determined.
b. The operating voltage of the PV-system is set equal to 12 V. The voltage of the PV-system should be equal to the storage subsystem: battery bank usually 12 V or if in series 24 V-48 V etc., see § 2.2. However, these are low $\mathbf{V_{DC}}$ values which imply high losses due to Joule effect, see § 4.1.4.
c. The PV-panels chosen for the sizing procedure is KC120, which has a relative high conversion efficiency (13%).

Note: *This choice to keep operating voltage low, 12 or 24 Volts, is not the best one. In Case study 2 we will analyze two scenario for 24 and 48 Volts operating voltage. The higher the voltage, the lower the Joule effect (*$\boldsymbol{i^2R}$*) is, and hence losses are kept low.*

Some available PV-panel types, which can be used in the PV systems are shown in Table 5.3 and in Appendix III.
A different choice of PV-panels may affect the number of PV-modules required, according to their efficiency, power and electrical characteristics.

Table 5.3: *Various PV- panel types with their electrical characteristics*

Module Name	Peak Power (W_p)	Voltage (V)	Current (i)	Length (m)	Width (m)	Total Area (m^2)	Efficiency %	Price €
MSX120	120	17.7	7	1.12	0.99	1.11	0.12	560
MSX83	83	17.1	4.85	1.12	0.66	0.74	0.11	419
MSX77	77	16.9	4.56	1.12	0.66	0.74	0.10	389
VLX80	80	17.1	4.71	1.12	0.66	0.74	0.11	420
KC120	120	16.9	7.1	1.43	0.65	0.93	0.13	573
KC80	80	16.9	4.73	0.98	0.65	0.64	0.13	382
SR100	100	17	6	1.5	0.6	0.90	0.11	505
SR90	90	17	5.4	1.5	0.6	0.90	0.10	460
SP75	75	17	4.4	1.2	0.53	0.64	0.12	405

The complete calculations for sizing of the PV-system for this case study are presented in detail in § 5.7.

As we will see in § 5.4.2. The optimum tilt angle, at which the system covers the energy needs with the minimum costs, is not the same for both sites. Table 5.5 gives the total number of PV-panels and batteries for different tilt angles in the two sites: Sifnos and Glasgow .

Calculations are made using the same type of PV-panels and the same load requirements for comparison.

5.4.1Storage subsystem

The energy balance of the system and the energy independence period, **d** days, play an important role upon the size of the storage subsystem, since the two charge deficits $\mathbf{Q_{Yd}}$ and $\mathbf{Q_d}$ depend upon these factors.

The monthly energy balance of the system will be equal to the energy input from the PV-generator, $\mathbf{E_{PV}}$, minus the energy needed by the load $\mathbf{E_L}$**;** $\mathbf{(E_{PV} - E_L)}$ for every month.

The complete sizing procedure for the storage subsystem is presented in § 5.7.

The same type of batteries is chosen for both site calculations (Sifnos and Glasgow) and the same number **d** days for energy independence. Let, **d**=5.

Attention:

However, this is not right, as for Sifnos, **d** might be (according to 4.8a and 4.8b) equal to d=3 days or even 2 days, which reduces the final cost of the PV-system considerably.

Other available battery types for sizing of the storage subsystem are given in Table 5.4.
As mentioned earlier, the number of batteries required to meet the energy scenario, as set above for different tilt angles is shown in Table 5.5.

Table 5.4: *Various types of batteries to be used in PV power storage systems.*

Battery Name	***Voltage (V)***	***Capacity (Ah)***	***Price-€ ****
6-50A-07	12	180	212
6-50A-09	12	210	251
6-50A-11	12	265	285
6-50A-13	12	320	320
6-50A-15	12	370	354
6-90A-07	12	265	266
6-90A-09	12	350	311
6-90A-11	12	440	366
6-90A-13	12	530	428
3-90A-17	6	700	557
3-90A-19	6	790	603

***** Prices for year 2001-2002.

5.4.2 Optimum tilt angle

Table 5.5 shows the required number of PV-panels and batteries for various tilt angles, if we follow the sizing steps already studied in Chapter IV, to be concretized for this case in § 5.7. The results are also plotted in two different graphs for Sifnos and Glasgow in figures 5.4 and 5.5.
From these Tables and figures, it is shown that the best tilt angle for Sifnos is between 40^o and 55^o, since there is a balance between the number of PV-panels and batteries.
This issue can, also, be clarified from the **total capital cost** of the system, plotted in figure 5.6.

The fact that a system has low capital cost does not mean that its total lifetime cost will be low, too. Maintenance and replacement costs might increase the overall system cost over the time, as the analysis in § 5.5.4 proves. For a tilt 15^0 to 45^o the required number of PV-panels and batteries remains the same as shown in fig. 5.4. For Sifnos the tilt angle is chosen to be 55^o, **as for this angle optimum values of PV-panels and batteries occur;** see Table 5.5.

Examining the results obtained for Glasgow, it is shown that the optimum tilt angle for the system is 75 to 85^o, where the number of the batteries and panels is balanced, see fig. 5.5. For lower values of tilt angles the number of panels is decreasing, but the number of batteries is substantially high. This could result to very high maintenance and replacement costs (for the batteries). The tilt is chosen to be 80^o for Glasgow.

Table 5.5: *Number of PV-panels and batteries and capital costs for different tilt angles*

Sfinos				*Glasgow*			
Tilt	*Panels*	*Batteries*	*Cost-€*	*Tilt*	*Panels*	*Batteries*	*Cost-€*
0	27	10	19738	0	51	51	51056
5	26	11	19594	5	49	55	51626
10	26	11	19594	10	47	60	52625
15	25	14	20308	15	46	63	53338
20	25	14	20308	20	45	66	54052
25	25	14	20308	25	44	68	54337
30	25	14	20308	30	43	71	55050
35	25	14	20308	35	43	71	55050
40	25	14	20308	40	43	71	55050
45	26	11	19594	45	43	71	55050
50	26	11	19594	50	43	71	55050
55	27	10	19738	55	44	68	54337
60	28	10	20309	60	45	66	54052
65	29	10	20882	65	46	63	53338
70	31	10	22027	70	47	60	52625
75	32	10	22599	75	49	55	51626
80	34	10	23744	80	51	51	51056
85	37	10	25460	85	53	48	50916
90	40	10	27185	90	56	44	50917

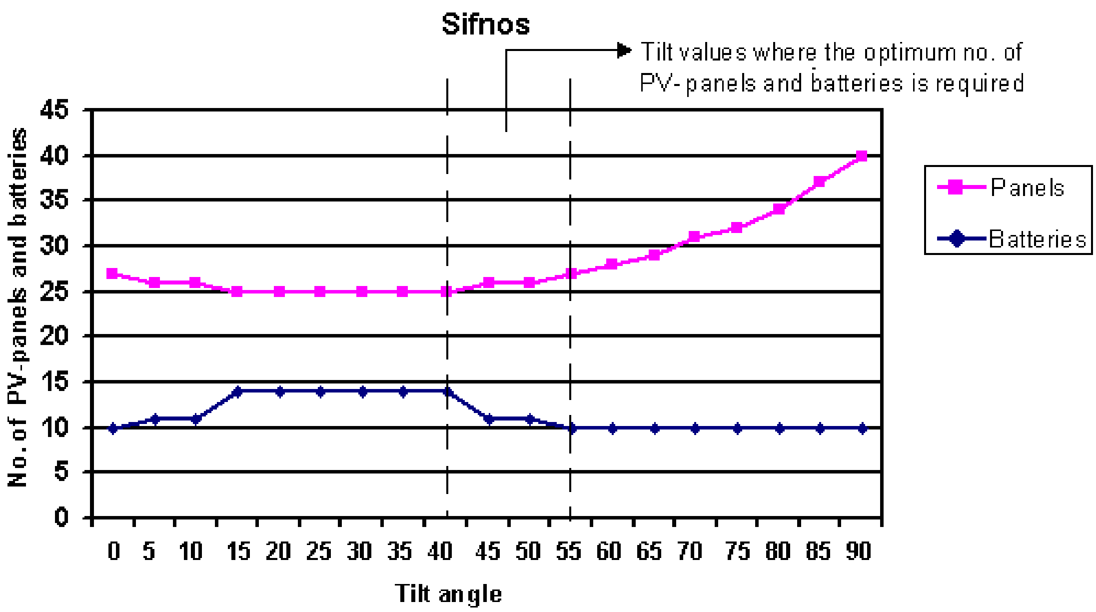


Figure 5.4: *Number of panels and batteries for different tilt angles in Sifnos island.*

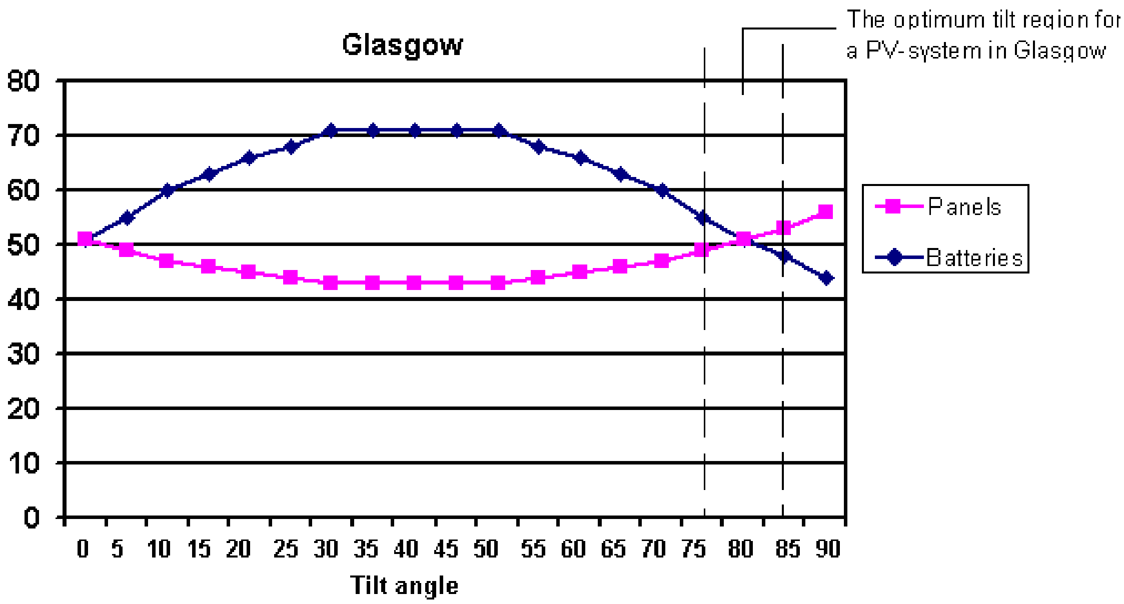


Figure 5.5: *Number of panels and batteries for different tilt angles in Glasgow.*

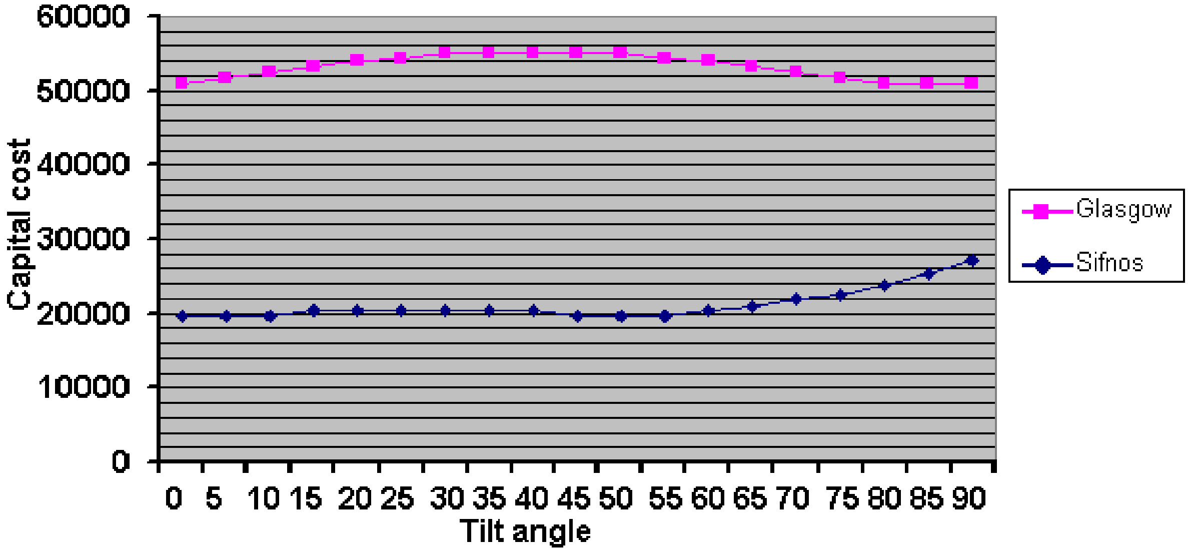


Figure 5.6: *Capital cost as a function of tilt angle*

Finally, the chosen angle, along with the number of panels and batteries is presented in Table 5.6.

Table 5.6: *Final values for Sifnos and Glasgow*

	Tilt	PV-panels	Batteries
Sfinos	55^0	27	10
Glasgow	80^0	51	51

One may realize the big difference or the advantage of Sifnos (South) against Glasgow (North) for the PV-system.

Conclusion:

The technical part of the sizing procedure included: the PV-generator (panels) and the batteries. So, it integrated both methodological approaches as developed in Chapter III for the PV-generator and for the storage system. The optimum of the solution was determined from the combination of the number of PV-panels and batteries, too. So, that cost on a **life cycle basis** is kept at minimum.

5.5 Economic considerations

5.5.1 Economic issues for PV energy systems

The price of power generated from PV-systems, depends upon two factors:
a. the system's capital cost and
b. the running cost.
Capital cost is considered to be:
a. the cost of PV-panels,
b. the **b**alance **o**f **s**ystem cost (**BOS**) –which includes the power conditioning, the wirings, support structures etc – and finally
c. the cost of the storage subsystem.
In this Chapter, the economic data for the PV-systems in both sites will be calculated, so that it can be compared with other alternative methods of power generation (grid connection, Diesel etc).
Even though the capital cost for a PV-system is substantially high, the running costs are low compared with other renewable or non-renewable systems, since it consumes no fuel nor has any moving parts (except if a tracking system is included). Maintenance of the system becomes more demanding if battery storage is included. In this case, special attention is required for the proper maintenance of batteries. Also, the batteries need to be replaced in regular periods of time, as the analysis in § 5.9.4 and in § 3.3.3 makes it clear.

5.5.2 Life **C**ycle **C**osting (**LCC**)

The two PV-systems described in § 5.4, will be evaluated using a **L**ife **C**ycle **C**ost **A**nalysis. Doing a life cycle analysis (**LCC**), the total cost of the PV-system including all expenses incurred over the life of the system is estimated.
There are two reasons to do a **LCC** analysis:

1. to compare different power options, and
2. to determine the most cost-effective system design.

If PV power is the only option, **L**ife-**C**ycle **C**ost (**LCC**) analysis can be helpful for comparing costs of different designs and/or determining **whether a hybrid system would be a cost-effective option.**

An **LCC** analysis allows the designer to study the effect of using different components with different reliabilities and lifetimes. Some might want to compare the cost of power supply options such as photovoltaic, fuelled generators, or extending utility power lines. The initial costs of these options will be different, as will the costs of the operations, maintenance, and repair or replacements be.
An **LCC** analysis can help compare the power supply options.
The **LCC** analysis consists of the estimation of the **Present Worth** (**PW**) of any expenses expected to occur over the reasonable life of the system. The **PW** methodology is briefed in § 5.5.3, below, while it was more extended in § 3.3.3 .

- In order to make a valid comparison, all future costs have to be discounted to equivalent present values. This is called "**Present Worth**" **value** or **PW**. To find the **PW** of a future cost, this must be **multiplied by an estimated discount factor**.

The parameters that need to be established for the calculations of the **LCC** are the following:

1. **Period of analysis**. It is **based on the lifetime** of the longest lived system under comparison.
2. **Excess inflation**. The **rate of price increase** of a component **above (or below) inflation** (usually assumed **to be zero**).
3. **Discount rate** (**d**). The rate (relative to general inflation) at which money will increase in value, if invested.
4. **Capital cost**. It includes the initial capital expense for equipment, the system design, engineering and installation. This cost is always considered as a single payment occurring in the initial year of the project.
5. **Operation and maintenance**. The amount spent each year in keeping the system operational.
6. **Replacement costs**. The costs of replacing each component at the end of its lifetime, as presented in § 5.4.

5.5.3 Calculations of Present Worth, PW, or Present Value.

The **PW** of a system will be calculated by considering all the expenses (running costs, replacements etc) made in one year of operation as a single payment.
The sum of discounted values (present worth) over the lifetime of the system is the life cost cycle of the system.
The **PW** of a single payment is given by equation (5.1).

$$\mathbf{PW = CV \times No} \quad (5.1)$$

where **No** is the cost of each unit of the PV-system in the time of the installation.
CV is the **present worth coefficient**, and it is given by the equation (5.2), where **i** is the excess inflation, **d** the discount rate and the number of years (life time) or the period of each replacement, see Problem 3.8 in § 3.3.3. Finally, **CV** is calculated by:

$$CV = \left(\frac{1+i}{1+d} \right)^{n} \quad (5.2)$$

5.5.4 Case study for the economic analysis issues of the PV-systems in Sifnos Island and Glasgow.

5.5.4a PV systems

The life cycle cost of both PV-systems in Sifnos (Greece) and Glasgow (Scotland) will be calculated over a lifetime period of 20 years. The system will be compared with a Diesel engine system and finally, with the utility grid.
The excess inflation is set equal to zero.
Table 5.7 gives the total required number of PV-panels and batteries. The results are obtained analytically in § 5.7. The prices are found in Tables 5.3 and 5.4, too.

Tabel 5.7

	Panels	*Price (€)*	*Batteries*	*Price (€)*
Sifnos	27	572	10	428
Glasgow	51	572	51	428

The **total capital** cost for the system will **include also the BOS costs**, which includes power conditioning, installation, wirings etc.
These costs even though represent a considerable part of the total cost, will be neglected for convenience.

The running costs are set to be equal to 31 € per year, and replacement time for the batteries is set to 7 years, assuming proper maintenance.

The complete procedure for the Life Cycle Costing is found in § 3.3.3. The results are shown in the next Table 5.8. A detailed analysis is provided in § 5.8, in Table 5.28.

Tabel 5.8: *Life cycle costs for PV-system in Sifnos and Glasgow.*

Location	***Life Cycle Cost (€)***
Sifnos	27917
Glasgow	80591

The final cost for the system in Glasgow, seems very high.

A way to reducing this cost is by increasing the **safety factor** (**SF**) of the equation (4.5). The result is that more PV-panels would be needed as this factor is increased, but at the same time less batteries would be required, and hence the replacement costs are less.

Remember: battery costs have a considerable effect to the high costs of a PV-system.

The next Table 5.9 shows the number of PV-panels and batteries required for different values of safety factors,(**S.F.**) along of the **LCC**.

Tabel 5.9: *LCC for different values of the Safety Factor (S.F.); the case of the PV-system in Glasgow.*

Safety factor	***PV-panels***	***Batteries***	***LCC (€)***
1.0	51	51	80592
1.1	56	44	76807
1.2	61	36	72070
1.3	66	29	68285
1.4	71	23	65448
1.5	76	19	64512
1.6	81	16	64524
1.7	86	13	64536

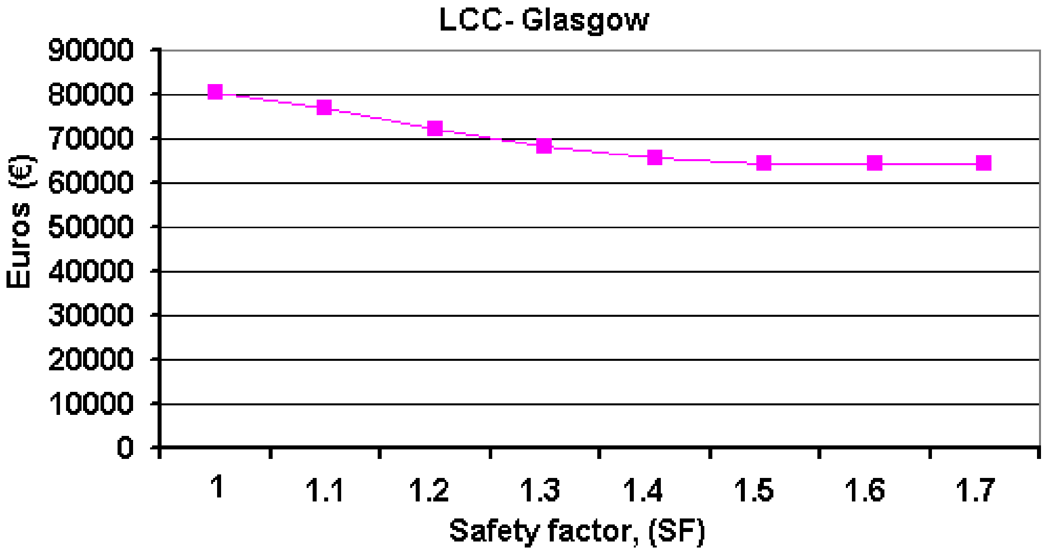


Figure 5.7: ***LCC*** *as a function of the Safety Factor (**S.F.**) for Glasgow.*

Remark:
A changing of the safety factor (**S.F.**) in Sifnos increases eventually the final **LCC**, since the number of the batteries required as determined from the analysis above is very small, indeed.
An increase in **S.F.** increases the total number of PV-panels and hence the final system cost.

5.5.4b Diesel Generator

The Diesel generator chosen for the comparison is a 12 kW generator. The specifications and data needed for the calculation of the **LCC** of the engine are shown below, in Table 5.10.

Table 5.10

Model	HD-295-12kW
Power	12kW
Fuel consumption	0.3 lt. per kW per hour
Price	4426 €

The average load that the engine needs to cover is nearly 10 kWh per day.

The fuel consumption each day will be: $\mathbf{10\frac{kWh}{day}\times 0.3\frac{l}{kWh} = 3\frac{l}{day}}$.

The total fuel consumption for the whole year will be: $\mathbf{365day \times 3 \frac{l}{day} = 1090liters}$.

The price for heating diesel in Greece is roughly; 0.70 € per liter, while in UK is 0.60 € per liter. Operation and maintenance costs are set equal to 385 € per year. The above are shown in Table 5.11.

Table 5.11

Location	**Load**	**Yearly fuel Consumption**	**Price per liter**	**Total fuel cost**	**Op. & Maint. €**
Sifnos	10kW	1095lt	0.60 €	654€	385
Glasgow	10kW	1095lt	0.70 €	763 €	385

Doing an **LCC** analysis for both systems –as described in § 5.5 – yields the following results.

Table 5.12: *Life cycle cost for diesel generator*

Location	**Life cycle cost (€)**
Sifnos	12019
Glasgow	12173

5.5.4c Utility grid

An **LCC** analysis will be done also for the utility grid , in order to be compared with a PV-system. The capital costs to the grid connection vary according to the distance from the nearest power substation.

It is assumed for this analysis, that there are no significant costs occurring when connecting to the grid. The energy prices for UK and Greece are 0.14 € and 0.12 € per kWh respectively. Repeating the analysis described in § 5.5 for a 20-year period, the **LCC** for utility generated electricity is shown below.

Table 5.13: *LCC for utility generated electricity*

Location	**LCC**
Sifnos	5393 €
Glasgow	6355 €

- **Comparison of the Results**

The results obtained from the previous analysis, are shown in figures 5.8 and 5.9.

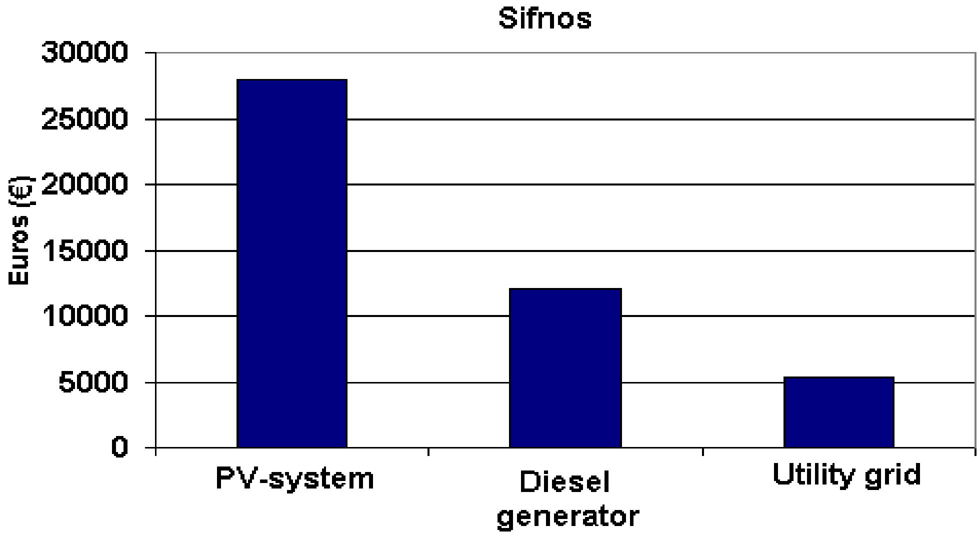


Figure 5.8: *Sifnos LCC comparison for different ways of providing electricity*

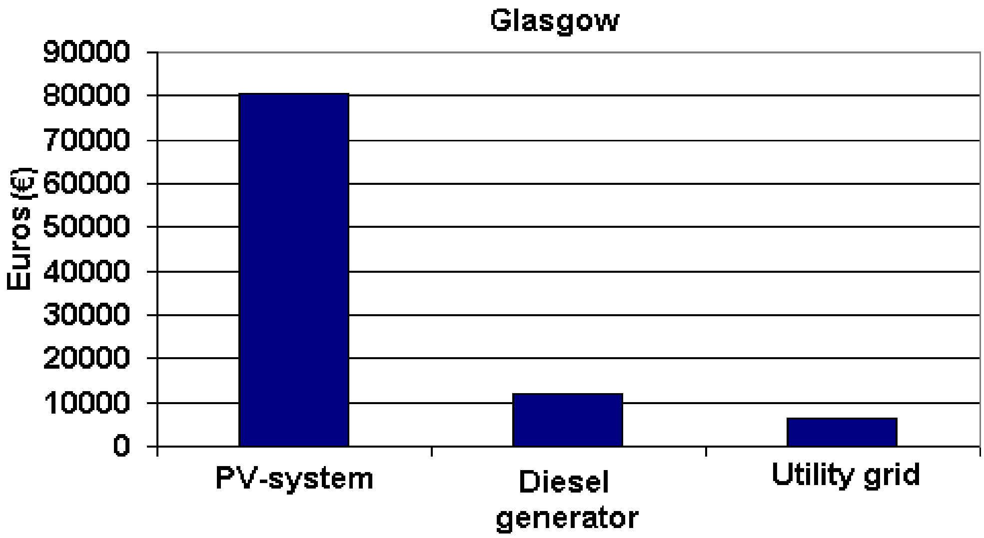


Figure 5.9: *Glasgow LCC comparison for different ways of providing electricity.*

It can be seen from both figures above, that the **LCC** is substantially higher than the other available options. Comparing the two PV-systems, Glasgow has much higher **LCC** cost than the PV-system located in Sifnos, and both systems don't seem to have an obvious advantage.
Doing various analyses with different kinds of PV-panels and batteries in order to find the most economical solution, one may optimize both systems further.

This however, will only improve the system, but not to an extent that PV-system **LCC** becomes of equal size with the other options (for the present status).
The disadvantage shown in the above figures will not be changed unless technological or other improvements are made.

5.6 Basic Formulae and Methodology to calculate Solar Radiation on inclined planes.

A. Same basic angles and basic quantities or parameters have to be studied before one proceeds to the solar radiation calculations for inclined planes. Details for these basic calculations are given in Appendix I .

B. Available solar radiation. One should study the above paragraph and especially Appendix I in order to proceed to the appropriate calculations in this paragraph.

Case 1: Sifnos-Greece: Latitude 36.6^{o}
Let us determine the Clearness Index , $\mathbf{K_t}$, for Sifnos

Definition:
Clearness Index $\mathbf{K_t}$; has to be determined for every month.
$\mathbf{K_t}$ is the ratio of the monthly solar energy at horizontal, $\overline{\mathbf{H}}$, in a site, over the solar energy at extra-terrestrial $\mathbf{H_{ext}}$ for the latitude of the site:

$$K_t = \overline{H}/H_{ext} \tag{5.3}$$

Extra-terrestrial Radiation is given in Table 5.19 and in the relevant table in Appendix IV .
The $\overline{\mathbf{H}}$ values for Sifnos are given by the data in Table 5.20, also in the relevant Table in Appendix IV .
Table 5.15 gives the $\mathbf{K_t}$ values for Sifnos, as calculated by dividing the corresponding values of Table 5.20 and Table 5.19.

Tabel 5.15: *Values for K_t in Sifnos*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
K_t	0.466	0.543	0.496	0.551	0.548	0.563	0.591	0.564	0.532	0.477	0.432	0.453

The reflectivity, **r**, of the area of Sifnos is 0.2, while for sites with more green and snow takes up higher values:
r : 0.2 - 0.7

• The sun's declination angle, δ, is given by the equation:

$$\boldsymbol{\delta} = \mathbf{23.45sin}\left(\mathbf{360}\,\frac{\mathbf{284+n}}{\mathbf{365}}\right) \tag{5.4}$$

where **n** is the number of the day, of the year. Starting date is the point 1st January: **n=1**.

δ values are given in Table 5.16. These values are the same for both, Sifnos and Glasgow or any other place. δ values depend only on the typical (mean) day of the each month; usually taken as the 16th –17th day of the month. For February we take the 14th

Tabel 5.16: *Solar declination (It does not depend on the site; it is dependent only in the day of the year).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n	15	47	75	105	135	162	198	228	258	288	318	344
δ	-21.3	-13.0	-2.4	9.4	18.8	23.1	21.2	13.5	2.2	-9.6	-18.9	-23.0

Note: *The figure 75 for March is obtained by: 31(January)+28(February)+16(March)=75.*

• The sunset hour angle, $\boldsymbol{\omega_s}$, on a horizontal surface for a typical day of each month is given by the equation:

$\boldsymbol{\omega_s = \cos^{-1}(-\tan\varphi\tan\delta)}$, where $\boldsymbol{\varphi}$ is the site's latitude 36.6^0, for Sifnos.

• $\boldsymbol{\omega_s}$ values for Sifnos are calculated and given in Table 5.17.

Tabel 5.17: *Sun's hour angle for Sifnos.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n	15	47	75	105	135	162	198	228	258	288	318	344
ω_s	73.2	80.2	88.2	97.1	104.6	108.4	106.7	100.2	91.6	82.8	75.3	71.6

• The ratio $\frac{\overline{\mathbf{H}}_\mathbf{d}}{\overline{\mathbf{H}}}$ i.e. the diffuse solar radiation over the total (global) one is given by (5.5). It is related with the clearness index $\mathbf{K_t}$, according to the equation:

$$\frac{\overline{\mathbf{H}}_d}{\overline{\mathbf{H}}} = \mathbf{1.39 - 4.03K_t + 5.53K^2{}_t - 3.11K^3{}_t} \tag{5.5}$$

$\frac{\overline{\mathbf{H}}_d}{\overline{\mathbf{H}}}$: mean monthly diffuse solar radiation on horizontal global.

Tabel 5.18: *Ratio $\overline{H}_d / \overline{H}$ as calculated by (5.5) using data from Table 5.15*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\frac{\overline{H}_d}{\overline{H}}$	0.40	0.33	0.37	0.33	0.33	0.32	0.30	0.32	0.34	0.39	0.43	0.41

- In order to estimate the monthly average daily total radiation on a horizontal surface **H**, the extraterrestrial insolation **(H_{ext})** on a horizontal surface must be calculated first.

H_{ext}, is the integral (global) **daily extraterrestrial radiation** on horizontal surface, determined as follows:

$$H_{ext} = \frac{24 \times 3600 \times I_{sc}}{\pi}\left(1 + 0.033\cos\left(\frac{n}{365} \times 360\right)\right) \times (\cos\varphi\cos\delta\cos\omega_s + \frac{\pi \times \omega_s}{180}\sin\varphi\sin\delta)$$

where I_{sc} is the solar insolation constant , I_{sc} = 1353 (W/m^2)

Table 5.19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H_{ext} (kWh/m^2) per day	4.71	6.19	7.98	9.78	11.00	11.48	11.22	10.23	8.62	6.71	5.10	4.38

- The values of **H** on horizontal can be calculated using the formula:

$$\overline{H} = \overline{K}_t \times \overline{H}_{ext} \qquad (5.7)$$

where **K_t** is usually tabulated. If not it has to be calculated as shown above.

Table 5.20: *Average total (global) radiation per month on horizontal surface for Sifnos.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H (kW/m^2)day	2.20	3.36	3.39	5.39	6.03	6.46	6.63	5.77	4.58	3.20	2.20	1.98

- The next step is to calculate **R_b** i.e. the conversion coefficient of the beam solar insolation from the horizontal to the inclined panel.

$$R_b = \frac{I_{b,n}}{I_{b,h}} = \frac{\text{solar beam (direct) on a tilted plane}}{\text{solar beam (direct) on horizontal}} \qquad (5.8)$$

$\Rightarrow$ **$I_{b,n} = R_b \times I_{b,h}$** , while (5.9)

$\overline{R}_b$ is the mean monthly value of $\mathbf{R_b}$, as the simulation in our case is on monthly basis.

$\overline{R}_b$ is function of the site's latitude, **φ**, the panel's slope, β, and the sunset hour angle, ω'_s, on a tilted surface, according to:

$$\overline{R}_b = \frac{\cos(\varphi-\beta)\cos(\delta)\sin(\omega'_s)+\left(\pi/180\right)\omega'_s\sin(\varphi-\beta)\sin(\delta)}{\cos(\varphi)\cos(\delta)\sin(\omega_s)+\left(\pi/180\right)\sin(\varphi)\sin(\delta)} \quad (5.10)$$

The sunset hour angle ω'_s to the inclined plane is given by the equation:

$$\omega'_s = \min\left[\cos^{-1}(-\tan\varphi\tan\delta), \cos^{-1}(-\tan(\varphi-\beta)\tan\delta)\right] \quad (5.11)$$

That is: ω'_s is the lower value of the above two angles :

ω_s and $\cos^{-1}(-\tan(\phi-\beta)\tan\delta)$.

ω'_s values for any surface tilted with angle β in Sifnos are given in Table 5.21.

Tabel 5.21: *Sunset hour angle on a tilted surface*

Panel Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	73.2	80.2	88.2	97.1	104.6	108.4	106.7	100.2	91.6	82.8	75.3	71.6
5	73.2	80.2	88.2	95.9	102.1	105.2	103.8	98.5	91.4	82.8	75.3	71.6
10	73.2	80.2	88.2	94.8	99.8	102.3	101.2	96.9	91.1	82.8	75.3	71.6
15	73.2	80.2	88.2	93.8	97.7	99.7	98.8	95.4	90.9	82.8	75.3	71.6
20	73.2	80.2	88.2	92.8	95.8	97.3	96.6	94.1	90.7	82.8	75.3	71.6
25	73.2	80.2	88.2	91.9	94.0	95.0	94.6	92.8	90.5	82.8	75.3	71.6
30	73.2	80.2	88.2	91.1	62.3	92.8	92.6	91.6	90.3	82.8	75.3	71.6
35	73.2	80.2	88.2	90.3	90.5	90.7	90.6	90.4	90.1	82.8	75.3	71.6
40	73.2	80.2	88.2	89.4	88.8	88.5	88.7	89.2	89.9	82.8	75.3	71.6
45	73.2	80.2	88.2	88.6	87.1	86.4	86.7	88.0	89.7	82.8	75.3	71.6
50	73.2	80.2	88.2	87.7	85.3	84.2	84.7	86.7	89.5	82.8	75.3	71.6
55	73.2	80.2	88.2	86.8	83.5	81.8	82.6	85.4	89.3	82.8	75.3	71.6
60	73.2	80.2	88.2	85.9	81.5	79.4	80.3	84.1	89.0	82.8	75.3	71.6
65	73.2	80.2	88.2	84.9	79.4	76.7	77.9	82.6	88.8	82.8	75.3	71.6
70	73.2	80.2	88.2	83.7	77.0	73.7	75.2	80.9	88.5	82.8	75.3	71.6
75	73.2	80.2	88.2	82.4	74.3	70.2	72.1	79.1	88.2	82.8	75.3	71.6
80	73.2	80.2	88.2	81.0	71.2	66.2	68.5	76.9	87.9	82.8	75.3	71.6
85	73.2	80.2	88.2	79.2	67.5	61.3	64.1	74.4	87.5	82.8	75.3	71.6
90	73.2	80.2	88.2	77.1	62.7	55.0	58.5	71.2	87.0	82.8	75.3	71.6

So, $\mathbf{R_b}$, values for Sifnos are given in Table 5.22, below, as calculated from (5.8).

Tabel 5.22: *Ratio R_b, for Sifnos during the year for various slopes*

Panel Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.18	1.12	1.07	1.03	1.00	0.99	1.00	1.02	1.05	1.10	1.16	1.19
10	1.34	1.23	1.13	1.05	1.00	0.98	0.99	1.03	1.10	1.19	1.31	1.37
15	1.50	1.33	1.19	1.07	0.99	0.96	0.97	1.03	1.13	1.28	1.44	1.54
20	1.64	1.42	1.23	1.07	0.97	0.93	0.95	1.03	1.16	1.35	1.57	1.70
25	1.77	1.50	1.26	1.07	0.95	0.90	0.92	1.02	1.18	1.42	1.69	1.85
30	1.89	1.57	1.29	1.06	0.92	0.86	0.89	1.00	1.19	1.47	1.79	1.98
35	2.00	1.63	1.31	1.04	0.88	0.82	0.85	0.97	1.19	1.51	1.88	2.10
40	2.09	1.67	1.31	1.02	0.84	0.77	0.80	0.94	1.18	1.54	1.95	2.20
45	2.16	1.71	1.31	0.99	0.80	0.72	0.75	0.90	1.17	1.56	2.01	2.28
50	2.22	1.72	1.29	0.95	0.74	0.66	0.70	0.85	1.14	1.57	2.06	2.35
55	2.26	1.73	1.27	0.90	0.69	0.60	0.64	0.80	1.11	1.56	2.09	2.40
60	2.28	1.72	1.23	0.85	0.62	0.54	0.57	0.74	1.06	1.55	2.10	2.43
65	2.28	1.70	1.19	0.79	0.56	0.47	0.51	0.68	1.01	1.52	2.09	2.44
70	2.27	1.67	1.14	0.72	0.49	0.40	0.44	0.61	0.95	1.48	2.08	2.44
75	2.24	1.62	1.08	0.65	0.42	0.33	0.37	0.54	0.89	1.43	2.04	2.41
80	2.20	1.56	1.01	0.58	0.35	0.26	0.30	0.47	0.82	1.37	1.99	2.37
85	2.13	1.49	0.93	0.50	0.27	0.19	0.23	0.39	0.74	1.29	1.93	2.31
90	2.05	1.41	0.85	0.42	0.20	0.13	0.16	0.31	0.65	1.21	1.85	2.23

The ratio, $\overline{\mathbf{R}}$ of the monthly average daily total radiation on a tilted surface, β, over that on a horizontal surface is determined by equation:

$$\overline{\mathbf{R}} = \frac{\overline{\mathbf{H}}_T}{\mathbf{H}} = \left(\mathbf{1} - \frac{\overline{\mathbf{H}}_d}{\mathbf{H}}\right)\overline{\mathbf{R}}_\mathbf{b} + \frac{\overline{\mathbf{H}}_\mathbf{d}}{\mathbf{H}}\left(\frac{\mathbf{1}+\cos\boldsymbol{\beta}}{\mathbf{2}}\right) + \mathbf{r}\left(\frac{\mathbf{1}-\cos\boldsymbol{\beta}}{\mathbf{2}}\right) \qquad (5.12)$$

Tabel 5.23: *Ratio* $\overline{\mathbf{R}}$*. Conversion coefficient. (mean monthly value) to convert global solar irradiation from the horizontal to a tilted surface. These values hold for Sifnos.*

Panel Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.11	1.08	1.04	1.02	1.00	0.99	1.00	1.01	1.03	1.06	1.09	1.11
10	1.20	1.15	1.08	1.03	1.00	0.98	0.99	1.02	1.06	1.12	1.17	1.22
15	1.30	1.22	1.11	1.04	0.99	0.97	0.98	1.02	1.09	1.17	1.25	1.32
20	1.38	1.28	1.14	1.04	0.98	0.95	0.96	1.02.	1.10	1.21	1.32	1.41
25	1.46	1.33	1.16	1.04	0.96	0.93	0.94	1.01	1.11	1.25	1.38	1.49
30	1.52	1.37	1.17	1.03	0.94	0.90	0.91	0.99	1.12	1.28	1.43	1.56
35	1.58	1.41	1.18	1.02	0.91	0.87	0.88	0.97	1.11	1.30	1.48	1.63
40	1.63	1.43	1.18	1.00	0.88	0.83	0.85	0.94	1.10	1.31	1.52	1.68
45	1.67	1.45	1.17	0.97	0.84	0.79	0.81	0.91	1.09	1.32	1.54	1.73
50	1.70	1.46	1.15	0.94	0.80	0.75	0.77	0.88	1.07	1.31	1.56	1.76
55	1.71	1.46	1.13	0.91	0.76	0.70	0.72	0.84	1.04	1.31	1.57	1.78
60	1.72	1.45	1.10	0.87	0.72	0.65	0.68	0.80	1.01	1.29	1.57	1.79
65	1.72	1.43	1.07	0.82	0.67	0.60	0.63	0.75	0.97	1.26	1.56	1.79
70	1.70	1.40	1.03	0.77	0.62	0.55	0.57	0.70	0.92	1.23	1.54	1.78
75	1.67	1.36	0.99	0.72	0.56	0.50	0.52	0.64	0.87	1.19	1.51	1.76
80	1.64	1.32	0.93	0.66	0.51	0.45	0.47	0.59	0.82	1.15	1.47	1.72
85	1.59	1.27	0.88	0.60	0.45	0.40	0.41	0.53	0.76	1.09	1.42	1.68
90	1.54	1.21	0.82	0.54	0.40	0.35	0.36	0.47	0.70	1.03	1.37	1.62

Finally, the average daily total radiation on a sloped surface, is equal to:

$$\overline{\mathbf{H}}_{\mathbf{T}} = \overline{\mathbf{H}} \times \overline{\mathbf{R}} \qquad (5.13)$$

Table 5.24: *Daily **irradiation** in Sifnos (in **kWh/m^2 per day**) for a typical day in every month as a function of the panel inclination in degrees*

Panel Tilt	Jan *	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual kWh/m^2 per day **
0	2.20	3.36	3.39	5.39	6.03	6.46	6.63	5.77	4.58	3.20	2.20	1.98	4.31
5	2.43	3.63	4.13	5.50	6.04	6.42	6.61	5.84	4.74	3.40	2.40	2.21	4.44
10	2.64	3.87	4.28	5.57	6.02	6.36	6.56	5.88	4.87	3.58	2.58	2.42	4.55
15	2.85	4.10	4.41	5.62	5.97	6.26	6.48	5.88	4.98	3.73	2.75	2.61	4.64
20	3.03	4.30	4.51	5.63	5.89	6.14	6.37	5.86	5.05	3.87	2.90	2.79	4.70
25	3.20	4.47	4.59	5.61	5.79	5.98	6.23	5.80	5.10	3.99	3.04	2.96	4.73
30	3.35	4.61	4.64	5.57	5.65	5.80	6.06	5.71	5.12	4.08	3.16	3.10	4.74
35	3.47	4.73	4.66	5.49	5.49	5.60	5.86	5.60	5.11	4.15	3.26	3.23	4.72
40	3.58	4.82	4.65	5.38	5.30	5.37	5.63	5.45	5.06	4.19	3.34	3.34	4.68
45	3.66	4.88	4.62	5.24	5.09	5.11	5.38	5.27	4.99	4.21	3.40	3.43	4.61
50	3.72	4.90	4.57	5.07	4.85	4.84	5.10	5.07	4.89	4.21	3.44	3.49	4.51
55	3.76	4.90	4.48	4.88	4.59	4.54	4.80	4.84	4.77	4.18	3.46	3.53	4.39
60	3.78	4.87	4.37	4.66	4.31	4.23	4.49	4.59	4.61	4.12	3.45	3.55	4.25
65	3.77	4.80	4.24	4.42	4.02	3.91	4.15	4.32	4.44	4.04	3.43	3.55	4.09
70	3.73	4.71	4.08	4.16	3.71	3.58	3.81	4.03	4.23	3.94	3.39	3.53	3.91
75	3.68	4.59	3.90	3.87	3.39	3.24	3.45	3.72	4.01	3.81	3.32	3.48	3.71
80	3.60	4.44	3.70	3.57	3.06	2.90	3.09	3.40	3.76	3.66	3.24	3.41	3.49
85	3.49	4.26	3.48	3.26	2.74	2.56	2.74	3.07	3.49	3.50	3.13	3.32	3.25
90	3.37	4.06	3.24	2.93	2.41	2.24	2.39	2.73	3.21	3.31	3.01	3.21	3.01

Remark:

* The values in the column provide the **PSH** values for each month for any inclination of the PV-panel.

** These values also represent **PSH** values on a mean annual basis.

Case 2:Glasgow- Scotland

- Latitude 55.3^0. The Clearness Index, $\mathbf{K_t}$ for Glasgow. Here, the same method as for Sifnos is followed in order to calculate $\mathbf{K_t}$.

$\mathbf{K_t}$ values for Glasgow are given below:

Table 5.25

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\mathbf{K_t}$	0.406	0.297	0.355	0.410	0.433	0.371	0.379	0.368	0.385	0.352	0.275	0.264

Using the same approach described in the previous section, the monthly average daily radiation on a slope surface is found to be:

Table 5.26: *Daily irradiation in Glasgow (in kWh/m^2 per day) for a typical day in every month as a function of the panel inclination in degrees*

Panel Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	0.65	0.93	1.91	3.33	4.48	4.22	4.12	3.30	2.45	1.33	0.55	0.34	2.30
5	0.82	1.03	2.04	3.44	4.54	4.23	4.14	3.38	2.58	1.47	0.63	0.41	2.39
10	0.98	1.12	2.16	3.54	4.58	4.23	4.16	3.44	2.71	1.60	0.70	0.47	2.48
15	1.14	1.21	2.27	3.63	4.61	4.22	4.16	3.48	2.81	1.72	0.78	0.54	2.55
20	1.29	1.29	2.36	3.69	4.61	4.20	4.15	3.51	2.90	1.83	0.84	0.60	2.61
25	1.44	1.37	2.45	3.74	4.60	4.15	4.12	3.53	2.98	1.93	0.91	0.65	2.66
30	1.57	1.43	2.52	3.77	4.56	4.10	4.07	3.52	3.04	2.02	0.97	0.71	2.69
35	1.70	1.49	2.57	3.77	4.51	4.02	4.00	3.50	3.08	2.10	1.02	0.75	2.71
40	1.81	1.54	2.61	3.76	4.43	3.93	3.92	3.47	3.11	2.17	1.07	0.80	2.72
45	1.91	1.58	2.64	3.73	4.33	3.82	3.82	3.41	3.12	2.22	1.11	0.84	2.71
50	2.00	1.62	2.65	3.68	4.22	3.70	3.71	3.34	3.11	2.26	1.14	0.87	2.69
55	2.07	1.64	2.65	3.61	4.08	3.56	3.58	3.25	3.08	2.29	1.17	0.90	2.66
60	2.13	1.65	2.63	3.52	3.92	3.41	3.43	3.15	3.04	2.30	1.19	0.92	2.61
65	2.18	1.65	2.60	3.41	3.75	3.24	3.27	3.04	2.98	2.30	1.20	0.94	2.55
70	2.21	1.65	2.55	3.28	3.56	3.07	3.10	2.91	2.91	2.28	1.21	0.95	2.47
75	2.23	1.63	2.49	3.14	3.36	2.89	2.92	2.77	2.81	2.25	1.21	0.95	2.39
80	2.23	1.61	2.41	2.98	3.15	2.69	2.73	2.61	2.71	2.21	1.20	0.95	2.29
85	2.21	1.57	2.32	2.81	2.92	2.49	2.54	2.45	2.59	2.16	1.18	0.94	2.18
90	2.18	1.53	2.22	2.63	2.69	2.29	2.33	2.28	2.45	2.09	1.15	0.93	2.06

5.7 PV-System sizing.

Case: Sifnos Greece

a. Number of series connected modules

From Table 5.3, the PV-panel type KC 120 is chosen. The number of PV-modules connected in series will be:

$$\mathbf{N_s} = \frac{\mathbf{V_{DC}}}{\mathbf{V_m}} = \frac{12}{17.7} = 0.7 \quad (5.12)$$

The final number of modules is the nearest number above 0.7 which is 1.
Therefore N_S= 1.

Remark: As said before V_{DC}=12 Volts is not a proper value for a PV-generator. To lower losses $\mathbf{V_{DC}}$ has to be at 48 Volts.

b. Number of parallel connected modules

Equation (4.2) for the equivalent load current, $\mathbf{i_L}$, gives:

$$\mathbf{i_L} = \frac{\mathbf{E_L}}{\mathbf{24V_{DC}}} = \frac{9823Wh}{24h/day \times 12V} = 34.1A \quad (5.13)$$

where $\mathbf{E_L}$ is the average power required by the load.

Notice: *9823 Wh is the energy per day required (Load) for a household; see Table 5.27.*

The nominal current from the PV-system, from equation (4.4), will be equal to

$$\mathbf{i_{pv}} = \frac{\mathbf{24} \times \mathbf{i_L}}{\mathbf{PSH}} = \frac{24 \times 34.1}{4.25} = 192.6A, \quad (5.14)$$

where **PSH** is numerically equal to the calculated irradiation, in kWh/m^2 day, see Table 5.24, for a panel tilt angle of 60 degrees, in Sifnos.
The number of parallel-connected modules is given by equation (5.5).

$$\mathbf{N_p} = \frac{\mathbf{i_{pv}}}{\mathbf{i_m}} = \frac{192.6}{7.1} = 27.1 \quad (5.15)$$

So, the final number it will be N_P=27 modules. The total number of modules will be:

$$\mathbf{N} = \mathbf{N_S} \times \mathbf{N_P} = 1 \times 27 = 27 \quad (5.16)$$

The same procedure is repeated for Glasgow and the results are shown in Table 5.6.

c. Storage subsystem

The energy required by the load per month is 9823 Wh per day.

The energy produced by the system on a typical day is

$$\mathbf{E_{pv}} = \mathbf{Insolation} \times \mathbf{A_{pv}} \times \boldsymbol{\eta}_\mathbf{f} = \mathbf{P_m} \times \mathbf{PSH\,(month)}$$

where η_f is the efficiency of the modules and A_{pv} is the total area of the array. We construct the Table below to obtain the monthly energy balance.

Tabel 5.27: *Monthly energy balance*

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
E_{pv} (kWh/day)	11.72	12.10	13.44	13.26	14.78	15.02	15.95	17.23	17.10	15.06	12.64	10.37
E_L (kWh/day)	9.82	9.82	9.82	9.82	9.82	9.82	9.82	9.82	9.82	9.82	9.82	9.82
E_n balance	1.90	2.28	3.61	3.44	4.96	5.20	6.12	7.41	7.28	5.23	2.82	0.55
Deficit (kWh/day)	0	0	0	0	0	0	0	0	0	0	0	0
Monthly balance	0	0	0	0	0	0	0	0	0	0	0	0

From the above table it is shown that the energy deficit ΔE during the year is zero, so the charge deficit Q_{Yd} will be equal to zero since $Q_{Yd} = \frac{\Delta E}{V_{DC}} = \frac{0}{12} = 0$.

Another charge deficit has to be considered (4.8c) , $Q_d = i_L \times 24 \times d$). (5.17)

The chosen number of days with no energy input is chosen to be 5.
So, the value of Q_d is:

$$Q_d = i_L \times 24 \times 5 = 34.1 \times 24 \times 5 = 4092Ah \quad (5.18)$$

The total battery capacity required is equal to:

$$Q_B = \frac{Q_{Yd} + Q_d}{DOD} = \frac{0 + 4092}{0.8} = 5115Ah \quad (5.19)$$

where **DOD** is the battery max. discharge level.
The total number of battery string required is derived from:

$$N_{B,P} = \frac{Q_B}{\text{Capacity of one battery}} = \frac{5115}{440} = 11.625 \approx 12 \quad (5.20)$$

The number of the batteries in series will be equal to

$$N_{BS} = \frac{V_{DC}}{V_B} = \frac{12}{12} = 1 \quad (5.21)$$

The total number of batteries will be:

$$N_B = N_{BP} \times N_{BS} = 12 \times 1 = 12 \quad (5.22)$$

5.8 LCC analysis for a PV-generator.

The capital cost for Sifnos is found from Table 5.7. Total cost is given by equation (5.23). Running cost for every year is 32 € and battery replacement as mentioned in § 5.5 is done every seven (7) years. Discount rate is set equal to 0.05 for the calculation of the factor **CV**, equation (5.2).

Cost = 27 panels×573 €+10 batteries×366 €=19131 € (5.23)

A complete analysis for twenty years is shown in Table 5.28. The **PW** for costs in the 7th year of operation is calculated by adding all payments made that year. The discount factor for the 7th year will be equal to:

$$CV_7 = \left(\frac{1+0}{1+0.05}\right)^7 = 0.71$$

The final discounted value will be equal to total cost for the year, multiplied by **CV**.

Table 5.28: *Yearly cost analysis for Sifnos*

Year	Capital	Replacement	O&M	Total	Discounted
1	22582		28	22611	22610
2			28	28	25
3			28	28	25
4			28	28	23
5			28	28	22
6			28	28	20
7		4329	28	4357	3097
8			28	28	19
9			28	28	19
10			28	28	17
11			28	28	17
12			28	28	16
13			28	28	16
14		4329	28	4357	2200
15			28	28	14
16			28	28	12
17			28	28	12
18			28	28	11
19			28	28	11
20			28	28	11
				Total Discounted	**28195**

The life cycle cost for a PV-system in Sifnos will be 28195 €. The same calculations have to be made for Glasgow. The results were shown previously in Table 5.8.

CASE STUDY 2

5.9 Design and Integration of PV-configurations for a Household in Germany

This design methodology introduced the daily load profile and the load seasonal dependence . Also, load corrections due to losses and $\mathbf{P_m}$ corrections as field conditions differ from the **S.T.C.** have to be included in PV-sizing or PV feasibility study. It fallow a more complete technical approach is followed here.

5.9.1 General and Preparatory tasks

Target: Design and Integrate, possible PV-configurations for a household and determine the most cost-effective solution including all PV-elements.

Consider a case of a house in Germany. Assume or estimate the loads for that house. For this, use the values from Table 5.29 or use any data available from a proper reference material. Solar radiation data to be retrieved by a meteorological database or METEONORM.
Similarly, assume the power of each load, its demand factor and the time period the loads require energy, that is, the daily profile of the loads.
To meet the loads a PV-generator is proposed. The analysis to be outlined hereafter has to answer the following:

1. Describe the possible PV-configuration(s) which might be established and determine the most cost-effective proposed solution.
   For all the PV-elements in the configuration(s) one has to examine the costs of these. PV-elements. Also, to give details (performance, construction etc) of the PV-configurations. For the costs one may visit the web, too, to determine competitive prices.
2. Outline and estimate the size of the PV-generator to meet the load. That is:

a. To choose the PV-modules: type, characteristics etc.
b. To determine the number of PV-modules, electric connections etc.

Remark:
One may consider any possible scenario to cover, thoroughly or partially (hybrid system) the load.

3. Size a battery bank:
   For this sizing problem, we will follow both approaches: **Ah** and **Wh method,** to determine the battery bank capacity.
   Choose the type, and determine the number of batteries: **Ah**, **DOD**, no. connected in series and parallel, energy autonomy in days etc.
   Comparison of the various battery types, which meet the requirements of the problem in order to reach to the most cost-effective solution.

4. Decide on the size of any supplementary source when the proposed PV-system is hybrid

To make a proper analysis the following issues have to be covered.

1. Site conditions:

a. House orientation

b. Area: dimensions

c. Roof area

d. *Height from the ground level*

2. Load profile

a. Data sheets

3. Choosing Modules: type, number, configuration.

4. Choosing Batteries: type, number, configuration.

5. Choosing a Power Inverter

6. Conclusions and recommendations.

- To have a detailed view of the task, the following are the titles of the subtasks:

1) Description of all the required elements for the household.
2) Outline and estimation of the size of the PV-generator.
3) Sizing of the Battery bank.
4) Determination of the supplementary source if, the PV-system is a Hybrid one.

The preliminary requirements to carry out this study are:

a) House; the house is chosen in Krauthasen (Jüelich), Germany. Details are given in fig 5.11.

b) Solar irradiation data, obtained from the METEONORM package, for this site. The details of the site location are determined, too.

c) The descriptions of the respective modules, batteries, inverter, charge regulator etc, may be obtained from Internet, from various companies for better evaluation of the results.

- **Description of all the required elements for the House to be Solar House.**

Describe all possible elements of the PV-configuration for the Solar House

1) PV-Generator
2) Charger
3) Power inverter
4) Batteries
5) Diesel Generator
6) Meters, cabling, indicators etc.; see also fig. 5.10

The house structural details are:

a. House direction : N-W

b. Area : ground lot on which house is built: = 152.37m^2
total surface = 857m^2
useful roof surface = 83m^2.

c. Height from the ground level = 18.25m.

The view of the house is given in fig. 5.11.

Load Profile:

The total load for one day is considered, and the load profile is studied in detail giving some important information regarding the PV-modules selection.

The load study conclusions:

The load was divided into two segments, **winter** and **summer load**, as the difference in both will clearly provide us with valuable information on the PV-configuration to be chosen.

The details given by Table 5.29, are summarized as such:

- ✓ Winter load : 72,534Wh/day
- ✓ Summer load : 27,994Wh/day
- ✓ Common load : 29,334Wh/day: study Table 5.29 to find out the common load for the two seasons

A pre-analysis of the loads provides the following:

- An overload time lies between 12.00 -16.00 p.m., as seen in figs 5.12 & 5.13.
- A constant load of 3kW for 24h in winter, (to meet the winter load), is planned.
- The load for a winter day is split as follows:
  - during the day : 38.340Wh i.e., 53% of the total load requirement
  - during the night : 34.194Wh i.e., 47% of the total load requirement.

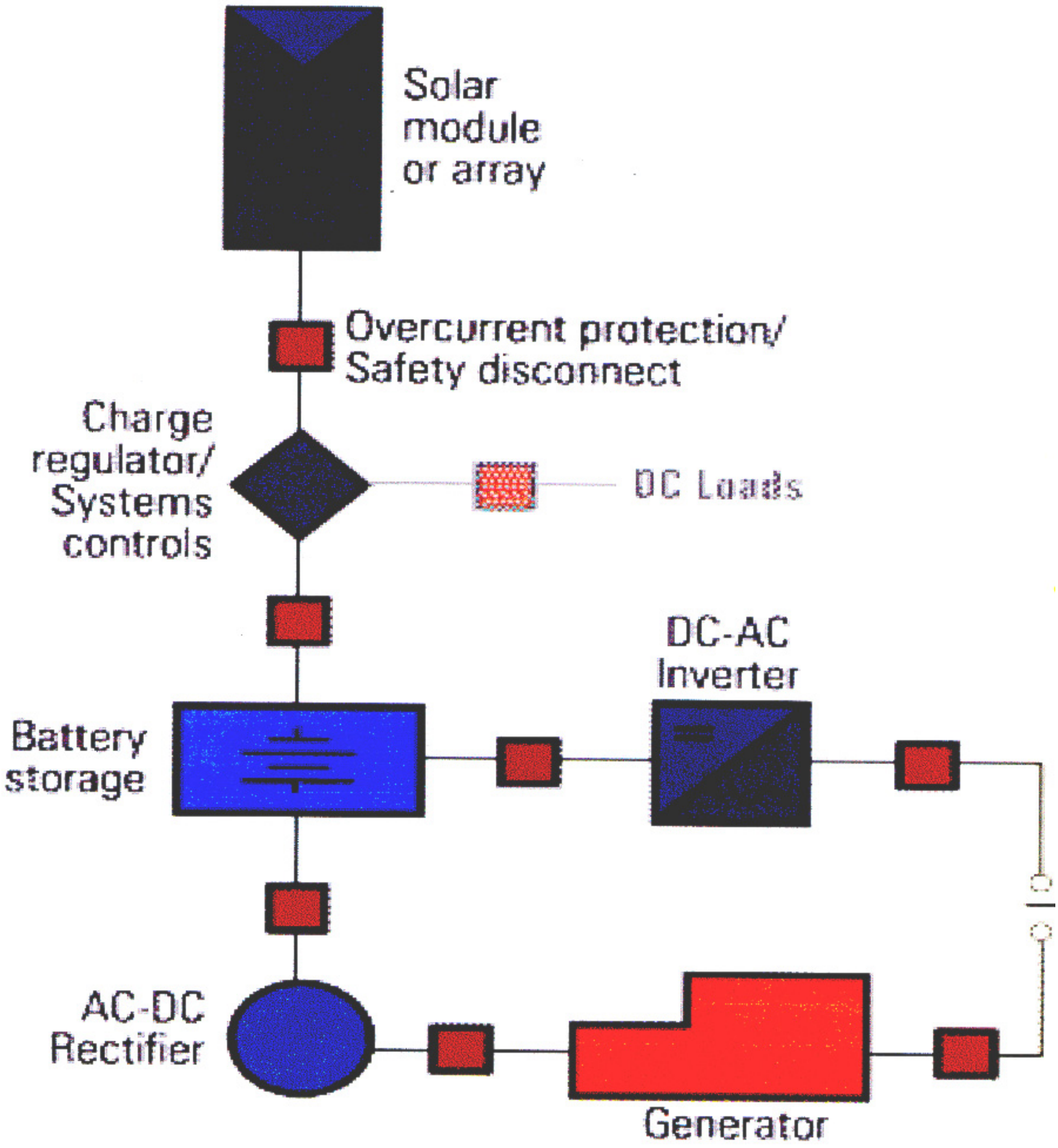


Figure 5.10: *A general lay out of PV-generator backed up by a storage system (battery bank) and a Diesel generator.*

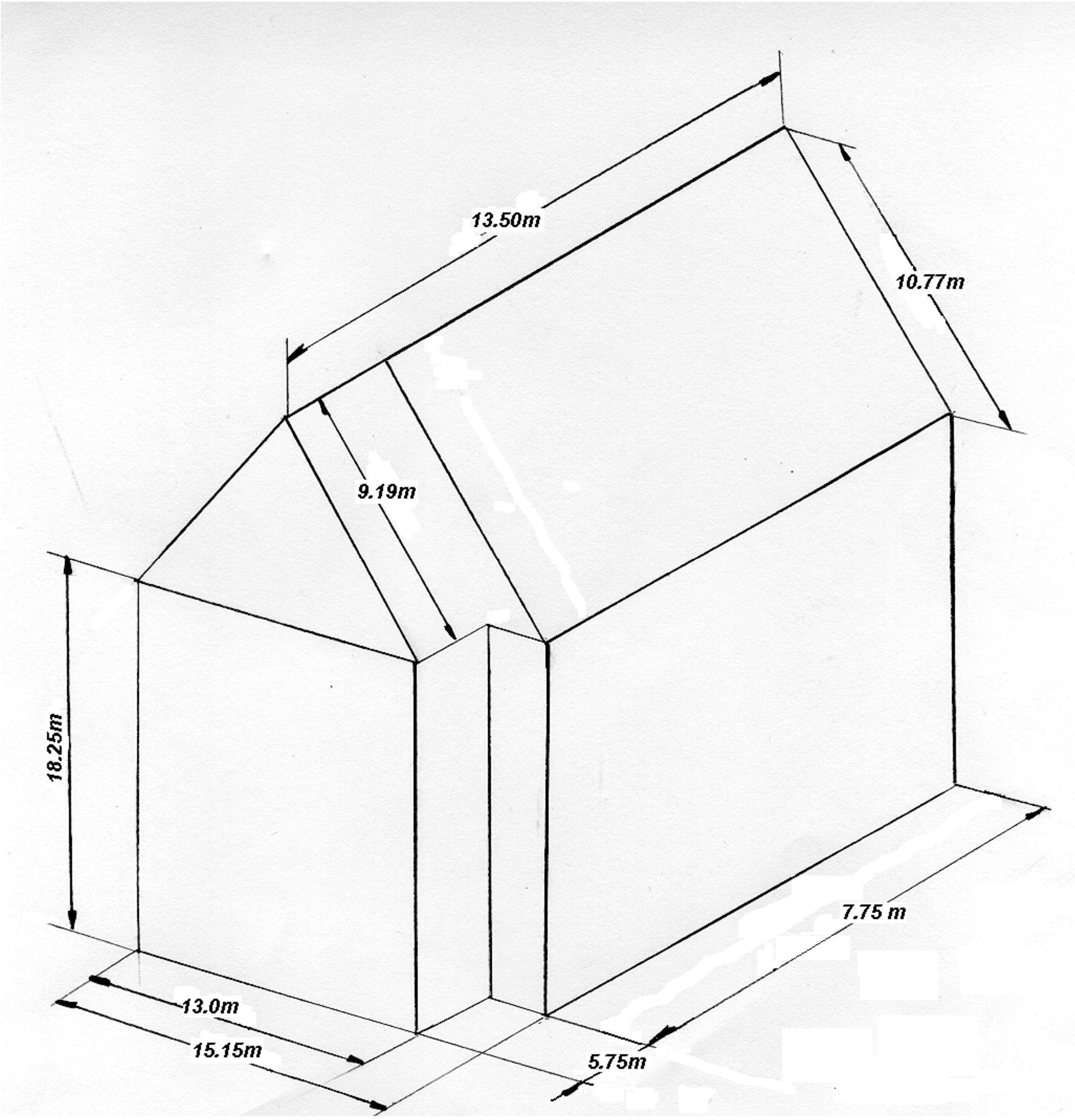


Figure 5.11: *The view of the house with dimensions and overall architecture. This is the house to be designed as a Solar House.*

Table 5.29: *Typical Loads for a household*

Load Type	Demand factor	Time (h)		Total load (Wh)	
		Winter	Summer	Winter	Summer
Lamps 2×10W	0.4	17-23	21-23	48	16
32×20W	0.4	17-23	20-24	1536	768
6×25W	0.5	18-20	21-23	150	150
2×50W	0.6	22-23	22-23	60	60
1×80W	0.6	20-21	22-23	48	48
1×300W	0.6	17-23	20-23	1080	540
Personal computer 3×180W	0.6	20-23	20-23	972	972
T.V. 2×100W	0.4	17-23	17-23	480	480
Refrigerator 2×150W	0.6	0-24	0-24	4320	4320
Wash machine with dryer 1×3600W	0.6	12-16	12-16	8640	8640
Electric oven 1×3000W	0.6	11-13 19-21	11-13 19-21	7200	7200
Dish wash machine 1×3600W	0.6	14-16	14-16	4320	4320
Heater 1×3000W	0.6	0-24	-----	43200	-----
Water heating 1×200W	0.6	19-23	19-23	480	480
Total load: 15730				**72534**	**27994**

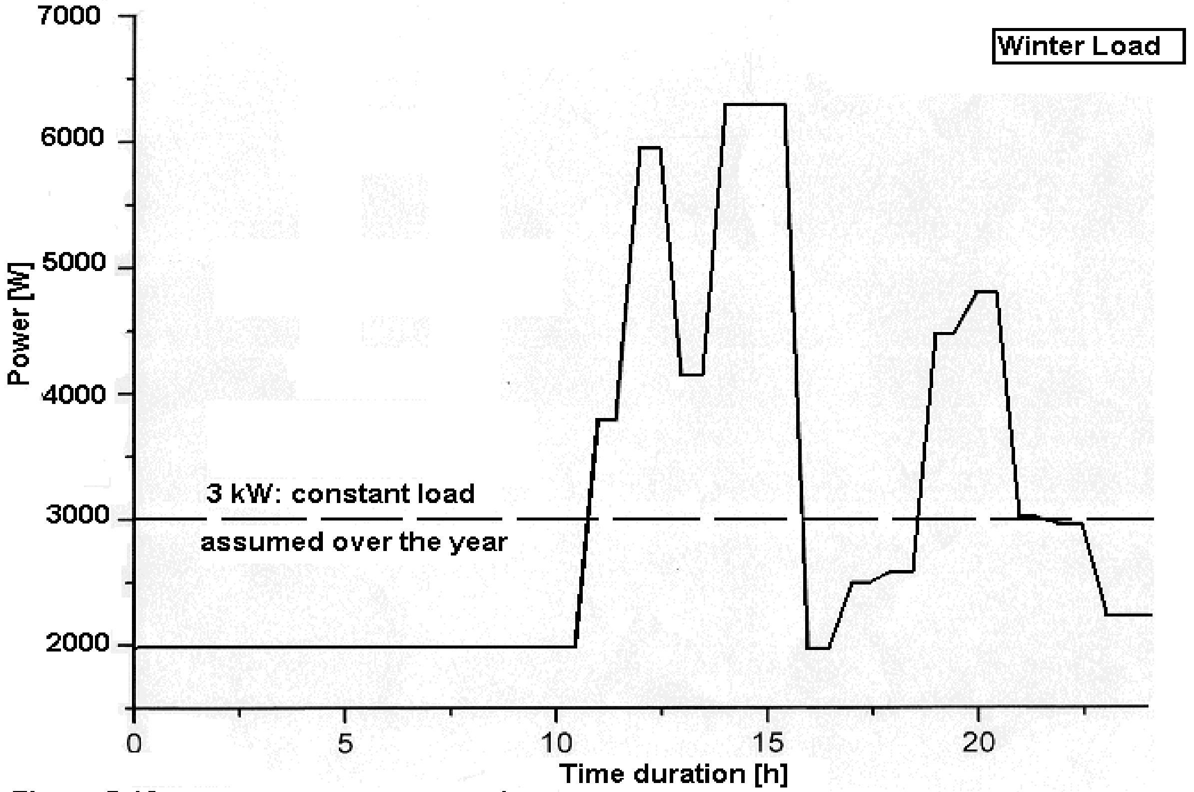


Figure 5.12: *Daily load profile according to the demand factor.*

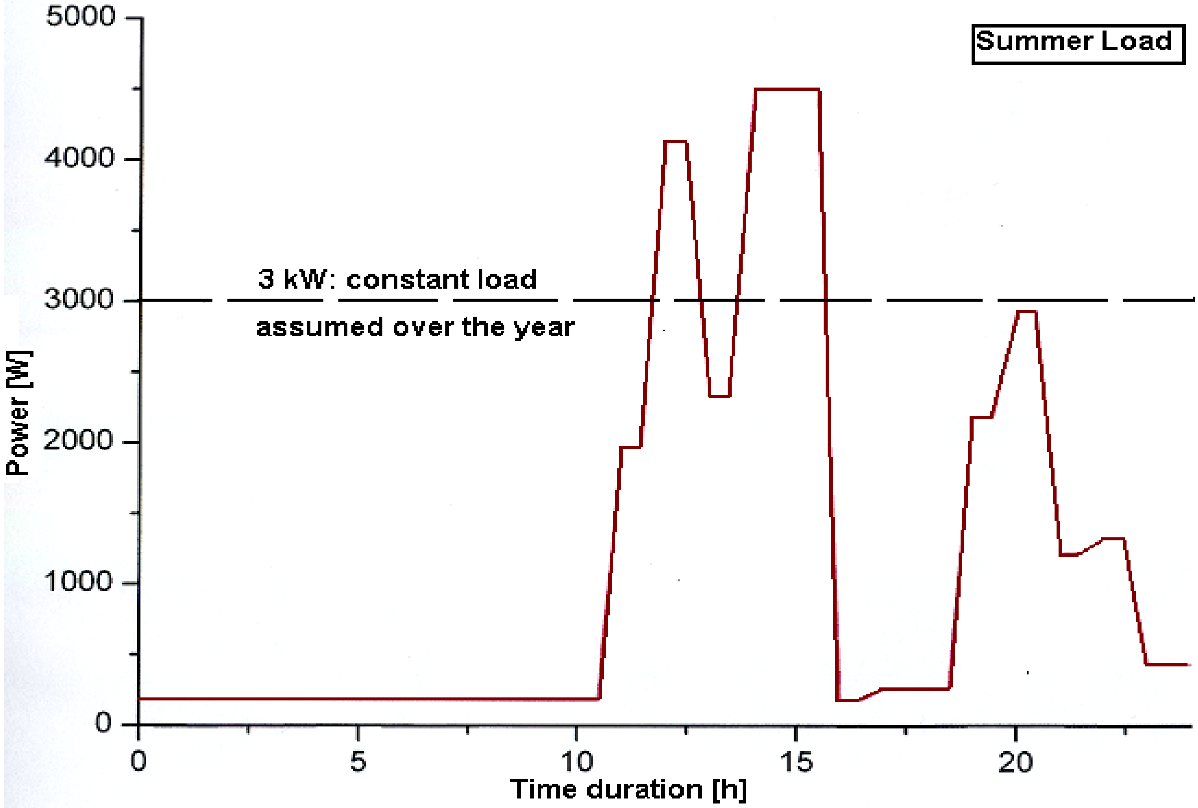


Figure 5.13: *Daily load profile according to the demand factor*

5.9.2 Outline and estimate the size of the PV-generator

This task includes: the choice of the PV-modules, the number of PV-modules required and the circuitry.
This will be answered using both methodologies:

1) **Wh approach**
2) **Ah approach.**

A detailed analysis of the whole load situation was carried out taking into consideration different PV-modules. This helped to decide which module is better or optimum for the given task.
The load is divided into three parts to make the PV-sizing analysis more effective:

a. taking the winter load
b. taking the summer load
c. a constant load of 3kW for the whole day all over the year was assumed. The assumption was based on the winter load profile, which is much higher than the summer one: see figs 5.12 & 5.13.

The PV-modules chosen for the study, keeping in mind the load requirements, are:

1. Solarex MSX - 120,

rated peak power P_{max} =120W
i_{sc} =7.6A, V_{oc} =21.3V, i_m =7.0A, V_m =17.1V.

2. Siemens SP 150,

rated peak power P_{max} =150W
i_{sc} =4.8A, V_{oc} =43.4V, i_m =4.4A, V_m =34.0V.

3. A.S.E. ASE-300-DGF/50,

rated peak power P_{max} = 300W
i_{sc} =6.5A, V_{oc} =60.0V, i_m =5.9A, V_m =50.0V.

4. Entech Inc. concentrating module EN-430

rated peak power P_{max} =430W
i_{sc} =22.9A, V_{oc} =24.5V, i_m =21.3A, V_m =20.2V.

5.9.3 Corrections in the Load due to Losses

Table 5.30	Wh method	Ah method
Cable losses & Charger losses	5%	5%
Battery efficiency losses (including cabling)	20%	0% in Ah method battery charging losses are assumed zero, see § 3.3.1
DC/AC invertor (including cabling)	15%	15%

Therefore, the corrected Load due to losses is:

- for Wh method: 1.4 × 72534Wh for winter = 101547.6Wh/day
  1.4 × 27994Wh for summer = 39191.6Wh/day
  1.4 × 29334 Wh for common = 41067.6Wh/day
- for Ah method: 1.2 × 72534Wh for winter = 87040.8Wh/day
  1.2 × 27994Wh for summer = 33592.8Wh/day
  1.2 × 29334Wh for common = 35200.8Wh/day

• **Corrections to: P_{max}, V_m, i_m for field conditions**

NOCT: Normal Operating Cell Temperature, the temperature a PV-module reaches operating under SOC.

SOC: Standard Operating Conditions, defined as :

- I_T= 800 W/m^2, T_a = 20 ^{0}C, V_m = 1 m/s.
- $\omega = 0^0$
- measured at V_{oc} conditions.

$T_c = T_a + h_w \times I_T$ where: h_w = 0.03 m$^{2\ 0}$K/W. (obtained from research)

T_a = 10 ^{0}C for Jüelich, as taken from METEONORM data. Hence, from the above relationship:

T_c = 34 ^{0}C

NOCT is given equal to: 39.2 ^{0}C

I_{sc} varies very slightly with temperature. So, we consider it be independent of temperature. This does not hold for V_{oc}, see § 2.2, equation (2.8). Hence, for V_{oc} holds:

dV_{oc}/dT = -0.0023V/^{0}C per PV-cell. Therefore, for n_s PV-cell in series in a panel the corrected V'_{oc} value is estimated by:

$$V'_{oc} = V_{oc} - 0.0023 \times n_s \times (34\text{-}10)^0C$$

✓ For Solarex PV-module:

V'_{oc} = 21.3 – 0.0023 × 36 ×24^{0}C
= 19.31 V
FF = 120/7.6 × 21.3 =0.741
P'_{max} = i_{sc} × V'_{oc} × FF = 109 W.
V'_m =P'_{max} /i_m = 109/7.0=15.57 V.

✓ For A.S.E. PV-module:

V'_{oc} = 60.0 – 0.0023 × 100 ×24^{0}C
= 54.48 V
FF = 300/6.5 × 60.0 =0.769
P'_{max} = i_{sc} × V'_{oc} × FF = 272.4 W.
V'_m =P'_{max} /i_m = 272.4/5.9= 46.16 V.

✓ For Siemens PV-module:

V'_{oc} = 43.4 – 0.0023 × 72 ×24^{0}C
= 39.42 V
FF = 150./4.8 × 43.4 =0.720
P'_{max} = i_{sc} × V'_{oc} × FF = 136.2 W.
V'_m =P'_{max} /i_m = 136.2/4.4=30.95 V.

✓ For Entech. Inc. PV-module:

V'_{oc} = 24.5 – 0.0023 × 40 ×24^{0}C
= 22.29 V
FF = 430/22.9 × 24.5 =0.766
P'_{max} = i_{sc} × V'_{oc} × FF = 390.9 W.
V'_m =P'_{max} /i_m = 390.9/21.3= 18.35 V.

- The annual of Peak Solar Hour (**PSH**) in Jüelich from the Meteonorm Database is equal to: PSH = 2.92 h. Detailed **PSH** monthly values are given in fig 5.14.

The voltage, **V** that power is transferred from the PV-array to the batteries, that is, the PV-system's voltage is taken to be: V_s = 48 V.

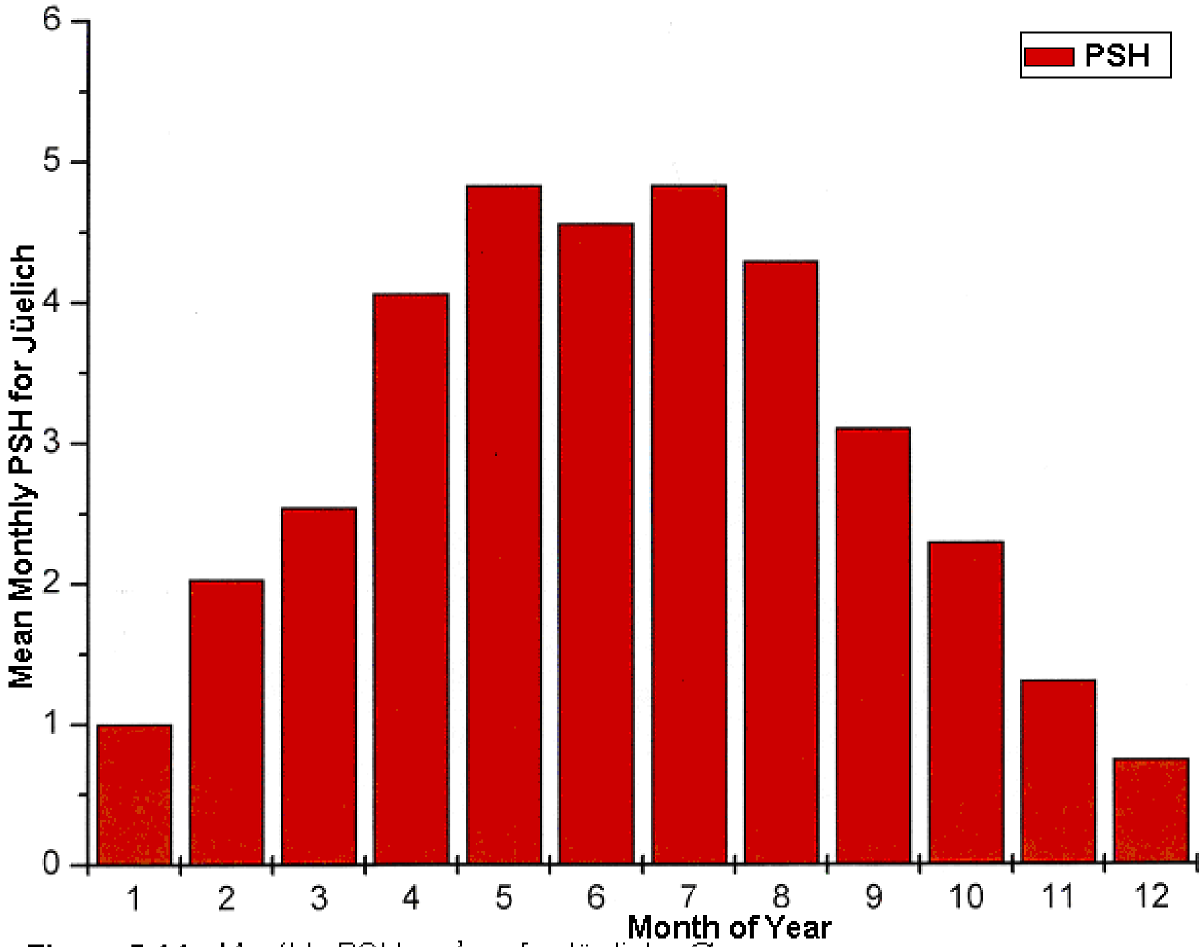


Figure 5.14: *Monthly PSH values for Jüelich, Germany*

Solutions: Scenario no. I

Taking the **winter load** into consideration and using both **Wh** and **Ah** methods, we finally get:

Wh method

1. Rough P_w determination: E_L/PSH

   = 101547.6 [Wh/day] / 2.92 [h/day]

   = 34776.5 W

2. Number of PV- Panels required are:

   for choice 1. (SOLAREX) → 34776.5/109 = 319

   for choice 2. (SIEMENS) → 34776.5/136.2 = 255

   for choice 3. (A.S.E.) → 34776.5/272.5 = 127

   for choice 4. (Entech.Inc.) → 34776.5/390.9 = 89

3. Number of PV- Panels in series,

   $N_{p,s} = V_s / V'_m$ are:

   for choice 1. → 48/17.1 =2.8 ≈ 3

   for choice 2. → 48/34.0 = 1.4 ≈ 2

   for choice 3. → 48/51.0 = 0.9 ≈ 1

   for choice 4. → 48/20.2 = 2.3 ≈ 3

4. Number of strings in parallel, $N_{p,p}$ are:

   for choice 1. → 319/3 = 106.3 ≈ 107

   for choice 2. → 255/2 = 127.5 ≈ 128

   for choice 3. → 127/1 = 127

   for choice 4. → 89/3 = 29.6 ≈ 30

Ah method

1. Determination of the charge delivered daily by the PV- Generator

   = 87040.8 Wh/48 V = 1813.35 Ah

2. Determination of the mean daily current from the PV-Generator

   i_L = 1813.35 [Ah] / 2.92 [h] = 621 A

3. Number of strings in parallel,

   $N_{p,p} = i_L/i_m$ are:

   for choice 1. → 621/7.0 = 88.7 ≈ 89

   for choice 2. → 621/4.4 = 141.1 ≈ 142

   for choice 3. → 621/5.9 = 105.2 ≈ 105

   for choice 4. → 621/21.3 = 29.1 ≈ 29

4. Number of PV- Panels in series,

   $N_{p,s} = V_s / V'_m$ are:

   for choice 1. → 48/15.57 = 3.09 ≈ 3

   for choice 2. → 48/30.95 = 1.55 ≈ 2

   for choice 3. → 48/46.16 = 1.03 ≈ 1

   for choice 4. → 48/18.35 = 2.61 ≈ 3

Remark:

According to these methods one may calculate the number of strings required in parallel. These parallel strings contain the PV-panels in series. One should observe, in detail, the differences between both methods in order to avoid the oversizing of the PV-System.

Solutions: Scenario no. II

Taking the **summer load** into consideration the two approaches give the following results:

Wh method

1. Rough P_w determination:
   = 39191.6 [Wh/day] / 2.92 [h/day]
   = 13421.7 W
2. Number of PV- Panels required are:
   for choice 1. → 13421.7/109 = 123
   for choice 2. → 13421.7/136.2 = 99
   for choice 3. → 13421.7/272.5 = 50
   for choice 4. → 13421.7/390.9 = 35
3. Number of PV- Panels in series,
   $N_{p,s} = V_s / V'_m$ are:
   for choice 1. → 48/17.1 =2.8 ≈ 3
   for choice 2. → 48/34.0 = 1.4 ≈ 2
   for choice 3. → 48/51.0 = 0.9 ≈ 1
   for choice 4. → 48/20.2 = 2.3 ≈ 3
4. Number of strings in parallel, $N_{p,p}$ are:
   for choice 1. → 123/3 = 41
   for choice 2. → 99/2 = 44.5 ≈ 45
   for choice 3. → 50/1 = 50
   for choice 4. → 35/3 = 11.6 ≈ 12

Ah method

1. Determination of the charge delivered daily by the PV- Generator
   = 33592.8 Wh/48 V = 700 Ah
2. Determination of the mean daily current from the PV-Generator
   i_L = 700 [Ah] / 2.92 [h] = 239.72≈ 240 A
3. Number of strings in parallel,
   $N_{p,p} = i_L/i_m$ are:
   for choice 1. → 240/7.0 = 34.2 ≈ 35
   for choice 2. → 240/4.4 = 54.5 ≈ 55
   for choice 3. → 240/5.9 = 40.6 ≈ 41
   for choice 4. → 240/21.3 = 11.26 ≈ 12
4. Number of PV- Panels in series,
   $N_{p,s} = V_s / V'_m$ are:
   for choice 1. → 48/15.57 = 3.09 ≈ 3
   for choice 2. → 48/30.95 = 1.55 ≈ 2
   for choice 3. → 48/46.16 = 1.03 ≈ 1
   for choice 4. → 48/18.35 = 2.61 ≈ 3

Solutions: Scenario no. III

Taking the **common load** into consideration the two approaches give the following results:

Wh method

1. Rough P_w determination:
   = 41067.6 [Wh/day] / 2.92 [h/day]
   = 14064.24 W
2. Number of PV- Panels required are:
   for choice 1. → 14064.24/109 = 129
   for choice 2. → 14064.24/136.2 = 103
   for choice 3. → 14064.24/272.5 = 52
   for choice 4. → 14064.24/390.9 = 36
3. Number of PV- Panels in series,
   $N_{p,s} = V_s / V'_m$ are:
   for choice 1. → 48/17.1 =2.8 ≈ 3
   for choice 2. → 48/34.0 = 1.4 ≈ 2
   for choice 3. → 48/51.0 = 0.9 ≈ 1
   for choice 4. → 48/20.2 = 2.3 ≈ 3
4. Number of strings in parallel, $N_{p,p}$ are:
   for choice 1. → 129/3 = 43
   for choice 2. → 103/2 = 51.5 ≈ 52
   for choice 3. → 52/1 = 52
   for choice 4. → 36/3 = 11.6 ≈ 12

Ah method

1. Determination of the charge delivered daily by the PV- Generator
   = 32500.8 Wh/48 V = 733.35Ah
2. Determination of the mean daily current from the PV-Generator
   i_L = 733.35 [Ah] / 2.92 [h] = 251.1≈ 251A
3. Number of strings in parallel,
   $N_{p,p} = i_L/i_m$ are:
   for choice 1. → 251/7.0 = 34.2 ≈ 35
   for choice 2. → 251/4.4 = 57.04 ≈ 57
   for choice 3. → 251/5.9 = 42.5 ≈ 43
   for choice 4. → 251/21.3 = 11.7 ≈ 12
4. Number of PV- Panels in series,
   $N_{p,s} = V_s / V'_m$ are:
   for choice 1. → 48/15.57 = 3.09 ≈ 3
   for choice 2. → 48/30.95 = 1.55 ≈ 2
   for choice 3. → 48/46.16 = 1.03 ≈ 1
   for choice 4. → 48/18.35 = 2.61 ≈ 3

Remark:

According to these methods the number of strings required in parallel, containing the panels in series, is calculated. If we observe in detail the difference between both methods it will help to avoid oversizing the PV-generator.

5.9.4 Sizing the Batteries bank for storage and energy independence.

1. Determination of number of days of autonomy **d**, given by the formula (4.8b). Let us assume that the load is not a critical one. Hence:

$d = 0.48 \times PSH + 4.58$ [days]

$= 0.48 \times 2.92 + 4.58$

$= 6$ days

Here, again, we will examine all the three possible scenarios for the load. i.e., we will examine different load situations in order to estimate the necessary batteries required. As estimated before:

Winter Load	: 72534 Wh/day
Summer Load	: 27994 Wh/day
Common Load	: 29334 Wh/day

2. Let's consider Winter Load: 72534 Wh/day

2.1 Determination of the load storage for d days autonomy, i.e.:

Q = 72534 Wh/day × 6 days / 48 V = 9066.7≈ 9067 Ah (Wh method),

or equivalently

Q = 1511.12 Ah/day × 6 days = 9066.7 ≈ 9067 Ah (Ah method)

2.2 Correction due to temperature, see (5.25)

$f_{b,T} = 0.01035 \times 10\ {}^{0}C + 0.724 = 0.8275$

($10^{0}C$ is the mean ambient temperature of the site)

Remark: $f_{b,T}$ is 1 (one) for mild climates where $T=25\text{-}27\ {}^{0}C$

2.3 Correction due to Charge Discharge Efficiency:

Let us take $f_{b,cd}$, defind in the next Case Study in Part C, as equal to:

$f_{b,cd} = 0.85$.

This is because we estimate that battery demand for power discharge is to be faster than the recommended rate, see equation (5.26).

2.4 Depth of Discharge:

$DOD_{max} = d / (d+1)$

$= 6 / 7 = 0.85$

2.5 The corrected battery bank capacity C_{cor} is estimated as in equation (5.28), later in the next Case Study.

$C_{cor} = Q / f_{b,T} \times f_{b,cd} \times DOD_{max}$

$= 15174.2$Ah

2.6 Determination of the Type of Batteries:

Total capacity C_{cor} = 15174.2 Ah

2.7 Voltage across the bank = 48 V, while
DOD =0.85 as estimated before.

2.8 Let's choose three different battery types, from GNB IIP Absolyte, with different Ah and Voltages

1) GNB – 6-90A15 12V and 615Ah.
2) GNB – 3-100A33 6V and 1600Ah.
3) GNB – 1-100A99 2V and 4800Ah.

2.9 Batteries required in series: $N_{b,s}$=V/V_b

1) 4 in series 48V:12V= 4
2) 8 in series 48V: 6V= 8
3) 24 in series 48V: 2V=24

2.10 Batteries required in Parallel connection (strings):

$$\text{strings} = \frac{\text{total (corrected) battery capacity}}{\text{battery capacity (nominal)}}, \quad \mathbf{N_{b,p} = Q / C = Q_{cor}/C}$$

1) 15174.2 / 615 = 24.6 ≈ 25
2) 15174.2 / 1600 = 9.4 ≈ 10
3) 15174.2 / 4800 = 3.1 ≈ 3

2.11 Confirmation that during the Charge Discharge Process, DOD< $DOD_{spec.}$
Daily Total Discharge is equal to 1511.1 Ah ≈ 1512 Ah.

Total Capacity is $N_{b,p} \times$ C:

1) 25 × 615 = 15375 Ah
2) 10 × 1600 = 16000 Ah
3) 3 × 4800 = 14400 Ah.

Notice: *this value is smaller that the daily discharge, as we considered that the battery bank has 3 battery strings in parallel, while the calculated figure was 3.1.*
If we took 4 as the number of battery strings that would be a good overestimation which would lead to high costs (batteries is a costly element due also to their short life cycle).

Daily Discharge is:

1) 1512 / 15375 = 0.098 or 9.8% per day
2) 1512 / 16000 = 0.0945 or 9.4% per day
3) 1512 / 14400 = 0.105 or 10.5% per day

Total Available Capacity is:

1) 15375 × 0.80 = 12300Ah
2) 16000 × 0.80 = 12800Ah

3) 14400 × 0.80 = 11520Ah

2.12 The required amount is 1512 Ah/day × 6day = 9072Ah.
Therefore the Available Capacity is much higher than the required amount.
If the Batteries operate continuously for 6 days:
1) 9072 Ah / 15375 Ah = 0.59<0.80
2) 9072 Ah / 16000 Ah = 0.56<0.80
3) 9072 Ah / 14400 Ah = 0.63<0.80
Hence, the batteries chosen in this analysis are appropriate, but the actual selection depends on the prices, which will be discussed later on.

3. Lets consider Summer Load

Summer Load: 27994 Wh/day
We proceed similarly as in the section for the Winter Load.

3.1 Determination of the load storage for d days autonomy, i.e.:
Q = 27994 Wh/day × 6 days / 48V = 3499.25 ≈ 3500Ah (Wh method),
or equivalently
Q = 583.0 Ah/day × 6 days = 3499.25 ≈ 3500 Ah (Ah method)

3.2 Correction due to temperature:
$f_{b,T}$ = 0.01035 × 10 ^{0}C + 0.724 = 0.8275
(10^{0}C is the mean ambient temperature of the site)

3.3 **Correction due to Charge Discharge Efficiency**:
$f_{b,cd}$ = 0.85.

3.4 Depth of Discharge:
DOD_{max} = d / (d+1)
= 6 / 7= 0.85

3.5 $C_{cor} = Q / f_{b,T} \times f_{b,cd} \times DOD_{max}$
= 5773.98 ≈ 5774 Ah

3.6 Determination of Type of Batteries:
Total capacity C_{cor} = 5774 Ah

3.7 Voltage across the bank = 48 V, while DOD =0.85 as obtained above.
3.8 Lets choose three different battery types, from GNB IIP Absolyte with different Ah and Voltages
1) GNB – 6-90A15 12V and 615Ah.
2) GNB – 3-100A33 6V and 1600Ah.
3) GNB – 1-100A99 2V and 4800Ah.

3.9 Batteries needed in series:

1) 4 in series
2) 8 in series
3) 24 in series.

3.10 Batteries needed in Parallel, $N_{b,p} = Q_{cor} / C$

1) 5774 / 615 = 9.3 ≈ 10
2) 5774 / 1600 = 3.6 ≈ 4
3) 5774 / 4800 = 1.2 ≈ 2

3.11 Confirmation during the Charge Discharge Process, DOD < $DOD_{spec.}$

Daily Total Discharge is equal to 583.2 ≈ 584 Ah.

Total Capacity is $N_{b,p} \times C$:

1) 10 × 615 = 6150 Ah
2) 4 × 1600 = 6400 Ah
3) 2 × 4800 = 9600 Ah.

Daily Discharge is:

1) 584 / 6150 = 0.094 or 9.4% per day
2) 584 / 6400 = 0.0912 or 9.1% per day
3) 584 / 9600 = 0.060 or 6.05% per day

Total Available Capacity is:

1) 6150 × 0.80 = 4920Ah
2) 6400 × 0.80 = 5120Ah
3) 9600 × 0.80 =7680

3.12 The required amount is 584 × 6 = 3504Ah.

Therefore, the Available Capacity is much higher than the required amount.
If the Batteries operated continuously for 6 days; then the discharge level would be:

1) 3504 Ah / 6150 Ah = 0.569<0.80
2) 3504 Ah / 6400 Ah = 0.547<0.80
3) 3504 Ah / 9600 Ah = 0.359<0.80

Hence, the batteries chosen for the study are appropriate, but the actual selection depends on the prices, which will be discussed later, in this case study.

4. Let's consider the Common Load

The **Common Load** was estimated to be**: 29334 Wh/day**

4.1 Determination of the load storage for d days autonomy, i.e.:

Q = 29334 Wh/day × 6 days / 48 V = 3666.7 ≈ 3667 Ah (Wh method), or equivalently
Q = 611.12 Ah/day × 6 days = 3666.7 ≈ 3667 Ah (Ah method)

4.2 Correction due to temperature:

$f_{b,T}$ = 0.01035 × 10 ^{0}C + 0.724 = 0.8275

(10^{0}C is the mean ambient temperature of the site)

4.3 Correction due to Charge Discharge Efficiency:

$f_{b,cd}$ = 0.85.

4.4 Depth of Discharge:

DOD_{max} = d / (d+1)

= 6 / 7= 0.85

4.5 C_{cor} = Q / $f_{b,T}$ × $f_{b,cd}$ × DOD_{max}

= 6137.16 ≈ 6137 Ah

4.6 Determination of Type of Batteries:

Total capacity **Q_{cor}** = 6137 Ah

4.7 Voltage across the bank = 48 V, DOD =0.85

4.8 Lets choose three different battery types, from GNB IIP Absolyte with different Ah and Voltages

1) GNB – 6-90A15 12V and 615Ah.
2) GNB – 3-100A33 6V and 1600Ah.
3) GNB – 1-100A99 2V and 4800Ah.

4.9 Batteries needed in series:

1) 4 in series
2) 8 in series
3) 24 in series.

4.10 Batteries needed in Parallel, $N_{b,p}$ = Q_{cor} / C

1) 6137 / 615 = 9.9 ≈ 10
2) 6137 / 1600 = 3.8 ≈ 4
3) 6137 / 4800 = 1.2 ≈ 2

4.11 Confirmation that during the Charge Discharge Process, DOD < $DOD_{spec.}$

Daily Total Discharge is equal to 611.12 ≈ 611 Ah.

Total Capacity is $N_{b,p}$ × C:

1) 10 × 615 = 6150 Ah
2) 4 × 1600 = 6400 Ah
3) 2 × 4800 = 9600 Ah.

Daily Discharge is:

1) 611 / 6150 = 0.098 or 9.8% per day
2) 611 / 6400 = 0.095 or 9.5% per day

3) 611 / 9600 = 0.063 or 6.3% per day

Total Available Capacity is:

1) 6150 × 0.80 = 4920Ah
2) 6400 × 0.80 = 5120Ah
3) 9600 × 0.80 =7680

4.12 The required amount is 611 × 6 = 3666Ah.

Therefore the Available Capacity is much higher than the required amount.

If the Batteries operate continuously for 6 days:

1) 3666 Ah / 6150 Ah = 0.59<0.80
2) 3666 Ah / 6400 Ah = 0.57<0.80
3) 3666 Ah / 9600 Ah = 0.38<0.80

Hence, the batteries chosen for this study are appropriate, but the actual selection depends on the prices, which will be discussed below.

5.9.5 Selection of the Appropriate Choice

After the full analysis of the load situations presented and the required PV-modules and battery banks details for the given household, we may choose Solution III, where the common load is taken into account on a whole year basis. The additional amount of energy required may be supplied by a supplementary source like:

a. Diesel Engine
b. Wind Generator , etc.

PV-Modules chosen for this case are the A.S.E. – 300-DGF/50 300 W_p, keeping in mind that the useable area of the roof and the high value of W_p keep the price, paid per Ampere produced low.

Batteries are chosen according to the cost-effective study, which follows:

Power Inverter is from TRACE; type DR3624, 3.6 KVA, 24V DC input, 120V AC output, 60 Hz, with a built in Charger 70 amps, and additional 30 amps, transfer relay. Number of units required: 2.

5.10 Financial Issues,

An attempt is made in order to make clear what it means economics in the battery branch of a PV-generator.

Let's start with batteries details from the above analysis:

a. The price of a 48 V battery bank giving an output of 1600 Ah(see step 4.8 in §5.9.4) is ≈11496.00 € (prices of 2002)
b. The price of a 48 V battery bank giving a output of 615 Ah is ≈7000.00 €

According to Scenario III, for a common load, the total capacity required is 6137 Ah, see step 4.5 in §5.9.4.
The number of batteries required in series, because the bank provides a voltage of 48 V, and V_s=48 is 1, i.e. only one string is required.

Batteries required in parallel:

a. $\mathbf{N_{b,p}}$ = 6137 / 1600 = 3.8 ≈ 4
while for the other type of battery:
b. $\mathbf{N_{b,p}}$ = 6137 / 615 = 9.9 ≈ 10
Let: Inflation rate = 2% (Inf.)
Interest rate = 4% (Int.)

- Let the initial amount to purchase the battery bank be $\mathbf{N_0}$

a.11496€ × 4 = 45984 €

b.7000€ × 10 = 70000 €

- This amount after **n** years, if deposited will increase, but also inflation pushes the other direction .

An estimate for **n**, is done by assuming 1 cycle per day and that the life of the batteries is around 6 years.
Present value co-efficient (**CV**):

CV = (1+Infl.) / (1+Inter.)
= 1.02 / 1.04 = 0.9807

As the lifetime of the PV – Module is estimated 25 years; therefore the number of replacements are 3.

Table 5.31

Type of Battery	1600 Ah	615 Ah
Initial Amount	4 × 11496 = 45984 €	10 × 7000 = 70000 €
1st Replacement	$45984 \times (0.9807)^{6.16}$ = 40782.1 €	$70000 \times (0.9807)^{6.16}$ = 62081.3 €
2nd Replacement	$45984 \times (0.9807)^{12.32}$ = 36168.6 €	$70000 \times (0.9807)^{12.32}$ = 55058.4 €
3rd Replacement	$45984 \times (0.9807)^{18.48}$ = 32077.1 €	$70000 \times (0.9807)^{18.48}$ = 48829.9 €
Total	**155011.8 €**	**235969.6 €**

So, it is clear from the analysis that the batteries with high capacity are less expensive that the ones with low capacity.
This analysis will help us to decide on the type of the battery that has to be chosen.
Further, the normal average Price per Watt, including the encapsulation, is in a range of about, 5 – 6 €/W, taking an average of 5.5 €.

The total initial cost of the various PV-modules chosen for this study is:

1) 120W × 5.5 €/W = 660 € per module

2) 150W × 5.5 €/W = 825 € per module

3) 300W × 5.5 €/W =1650 € per module.

Total Cost of the PV-generator as chosen for Scenario III is:

1) 3 × 36 =108 × 660 € = 71280 €

2) 2 × 57 =114 × 825 € = 94050 €

3) 1 × 43 = 43 × 1650 €= 70950 €.

Cost of the Inverter is equal to: 2 × 1595 € = 3190 €.

Total Cost of the PV-Solar House is:

a.	PV-Generator	:	70950 €
b.	Batteries	:	45984 €
c.	Invertor	:	3190 €
			120124.00 €

d. Diesel Generator: 1700.00 €

121824.00 €

e. Installation Charges: 12182.4 €

(an estimation of 10% of Total Cost

Total: 134006.4 €

5.11 SUMMARY: Results on the PV-configurations

Winter

1. Load Profile: 72534 Wh/day

Load Correction:

a. Wh method: 1.4 × 72534 = 101547 Wh/day
b. Ah method: 1.2 × 72534 = 87040.8 Wh/day

2. Modules Chosen

a. Solarex MSX – 120 W.
b. Siemens SP – 150 W.
c. A.S.E. 300DGF – 300 W.

3. Correction to Field Conditions

a. 109 W
b. 136.2 W
c. 272.4 W

Wh method

P_w = 34776.5 W

N_{pv}

a) 319
b) 255
c) 127

Ah method

C_d = 1813 Ah.

mean daily current = 621 A

Voltage Transfer: 48 V

$N_{p,s}$

a) 3
b) 2
c) 1

$N_{p,p}$

a) 88
b) 142
c) 105

Sizing batteries:

d = 6 days

$f_{b,T}$ = 0.827, $f_{b,cd}$=0.85, dod = 0.85

C_{cor}= 15174.28 Ah

Batteries chosen are:

1) GNB 6 – 90A15 12V 615Ah
2) GNB 3 – 100A33 6V 1600Ah
3) GNB 1 – 100A99 2V 4800Ah.

Batteries in Series, $N_{b,s}$:

1) 4
2) 8
3) 24

Batteries in Parallel, $N_{b,p}$:

1) 25
2) 10
3) 3

Daily Discharge:

a. 9.8%
b. 9.4%
c. 10.05%

If the Batteries are discharged continuously for 6 days: i) 0.59, ii) 0.56, iii) 0.63 < 0.80

Summer

1. Load Profile: 27994 Wh/day

Load Correction:

a. Wh method: 1.4 × 27994 = 39191.6 Wh/day
b. Ah method: 1.2 × 27994 = 33592.8 Wh/day

2 Modules Chosen

a. Solarex MSX – 120 W.
b. Siemens SP – 150 W.
c. A.S.E. 300DGF – 300 W.

3 Correction to Field Conditions

a. 109 W
b. 136.2 W
c. 272.4 W

Wh method

P_w = 13421.7 W

N_{pv}

a) 123
b) 99
c) 50

Ah method

C_d = 700 Ah.

mean daily current

Voltage Transfer: 48 V

$N_{p,s}$

a) 3
b) 2
c) 1

$N_{p,p}$

a) 35
b) 55
c) 41

Sizing batteries:

d = 6 days

$f_{b,T}$ = 0.827, $f_{b,cd}$=0.85, dod = 0.85

C_{cor}= 5774 Ah

Batteries chosen are:

1) GNB 6 – 90A15 12V 615Ah
2) GNB 3 – 100A33 6V 1600Ah
3) GNB 1 – 100A99 2V 4800Ah.

Batteries in Series, $N_{b,s}$:

1) 4
2) 8
3) 24

Batteries in Parallel, $N_{b,p}$:

1) 10
2) 4
3) 2

Daily Discharge:

a. 9.4%
b. 9.1%
c. 6.05%

If the Batteries are discharged continuously for 6 days: i) 0.56, ii) 0.54, iii) 0.35 < 0.8

SUMMARY: Results on the PV- configurations

Common

1. Load Profile: 29334 Wh/day

Load Correction:

a. Wh method: 1.4 × 29334 = 41067.6 Wh/day
b. Ah method: 1.2 × 29334 = 35200.8 Wh/day

2. Modules Chosen

a. Solarex MSX – 120 W.
b. Siemens SP – 150 W.
c. A.S.E. 300DGF – 300 W.

3. Correction to Field Conditions

a. 109 W
b. 136.2 W
c. 272.4 W

Wh method	**Ah method**
P_w = 14064.2 W	C_d = 733 Ah.
N_{pv}	mean daily current
1. 129	= 251A
2. 103	
3. 52	

Voltage Transfer: 48 V

$N_{p,s}$	$N_{p,p}$
a) 3	a) 36
b) 2	b) 57
c) 1	c) 43

Sizing batteries:
d = 6 days
$f_{b,T}$ = 0.827, $f_{b,cd}$=0.85, dod = 0.85
C_{cor}= 6137 Ah

Batteries chosen are:

1) GNB 6 – 90A15 12V 615Ah
2) GNB 3 – 100A33 6V 1600Ah
3) GNB 1 – 100A99 2V 4800Ah.

Batteries in Series, $N_{b,s}$:

1) 4
2) 8
3) 24

Batteries in Parallel, $N_{b,p}$:

1) 10
2) 4
3) 2

Daily Discharge:

a. 9.8%
b. 9.5%
c. 6.3%

If the Batteries are discharged continuously for 6 days: i) 0.59, ii) 0.57, iii) 0.38 < 0.80

SUMMARY: Results on the PV- configurations

Using Concentrating PV-system

Winter

1 Load Profile: 72534 Wh/day

Load Correction:

a. Wh method: 1.4 × 72534 = 101547 Wh/day

b. Ah method: 1.2 × 72534 = 87040.8 Wh/day

2. Modules Chosen

a. Entech – 430 W

3. Correction to Field Conditions

a. 389 W

Wh method	**Ah method**
P_w = 34776.5 W	C_d = 1813 Ah.
N_{pv}	mean daily current
a) 319	= 621 A

Voltage Transfer: 48 V

$N_{p,s}$	$N_{p,p}$
a) 3	a) 29

Common

1. Load Profile: 29334 Wh/day

Load Correction:

Wh method: 1.4 × 29334 = 41067.6 Wh/day

Ah method: 1.2 × 29334 = 33592.8 Wh/day

2 Modules Chosen

a. Entech – 430 W

3 Correction to Field Conditions

a) 389 W

Wh method	**Ah method**
P_w = 13421.7 W	C_d = 700 Ah.
N_{pv}	mean daily current
a) 36	= 251 Ah

Voltage Transfer: 48 V

$N_{p,s}$	$N_{p,p}$
a) 3	a) 12

5.12 Results and Comments

1. Whereas, the lifetime of the concentrating Modules are 50% less than the normal modules,
2. Whereas, the inefficiency is not yet standardized due to the influence of the series resistance, and more important
3. If we take into account that these concentrating lenses use beam radiation (and not the diffused), while the site of installation in Jüelich which has through the year more diffused radiation, compared to beam radiation.

This solution is not worthwhile for installation, even though it produces high power and occupies less area.

- **OPTIMUM LOAD MATCHING:**

The matching efficiency was defined as the ratio of the load energy to the array maximum energy delivered.

The **Quality** of **Load Mismatching** is defined by two factors:

1. The Insolation – utilization efficiency
2. Time – utilization efficiency

So, **Load Mismatching Factor**: $\mu = E_L / E_{max}$

E_{max} is the Integral from t (sunrise) to t (sunset); that is total $P_{max} \times PSH$ (5.24)

E_{max} is calculated for the months of the highest and lowest insolation.

For a case of consideration let us take a mean day; the 15 of May (a month with the highest Insolation from Meteonorm Data), to demonstrate the Load Mismatching Factor.

PSH for this month is: 4.83h. Let us consider the A.S.E. modules. Then

$P_m = V_m \times i_m \times$No of strings, or

$P_{PV\text{-}Array}$ = 50 [V] × 5.9 [A] × 43 = 12685 [W]

From equation (5.24) we get

E_{max} = 12685 [W] × 4.83 [h] = 61269 [Wh]

Hence, μ = 41067.6 [Wh] / 61269 [Wh] = 0.67

This shows that the design of the complete system is near to a good design, as the Load Mismatching Factor will never be greater than 1, and the system which attains a value in range between 0.7 to 0.8 is a well designed system; not oversizing the PV-SYSTEM.

CASE STUDY 3

5.13 PV-SIZING. THE CASE OF A SOLAR HOUSE IN BUCHAREST.

The owners of a house in Bucharest decided to cover the energy needs of a house with R.E.S. technologies.
For hot water and space heating the solution was solar collector systems; while all the electric appliances are to be supplied from a stand-alone PV-system.

- The sizing of this PV-system will be done using two methods:

a) the method of Wh

b) the method of Ah

- **PART A**

Sizing the PV generator by the Wh method

Steps:

1. Determine the loads per day

Let it be 2500 Wh/day i.e. 1000 Wh/day in DC; that is: 40% DC
1500 Wh/day in AC; that is: 60% AC

2. Site's details:

The inclination (β) to horizontal be chosen as $\beta \approx \varphi = 45^0$, the METEO data of this site, are given in Appendix IV. Such an inclination was decided in order to achiever an optimum annual performance.
PSH per month and its mean annual value are given in the same Table in Appendix IV.

3. Elaboration for the daily load profile:

DC Load:

Let the **DC** Load split in a DC day load and DC night load with 40% during the day and 60% during the off operation hours for the PV-panels.

a. 40% during the day when PV is on operation:

$0.4 \times 1000Wh = 400Wh/day$

b. 60% during the time when PV-generator is off, at night; that is:

$0.6 \times 1000Wh = 600Wh/day$

AC Load:

Similarly as above.

a. 40% during the day directly PV to load via a DC/AC inverter:

$0.4 \times 1500Wh = 600Wh/day$

b. 60% during the night PV through batteries :
$0.6 \times 1500Wh = 900Wh/day$ and then DC/AC.

4. Rough / preliminary determination of the PV-configuration.

The PV configuration to be studied according to the description made, may have the following lay-out:

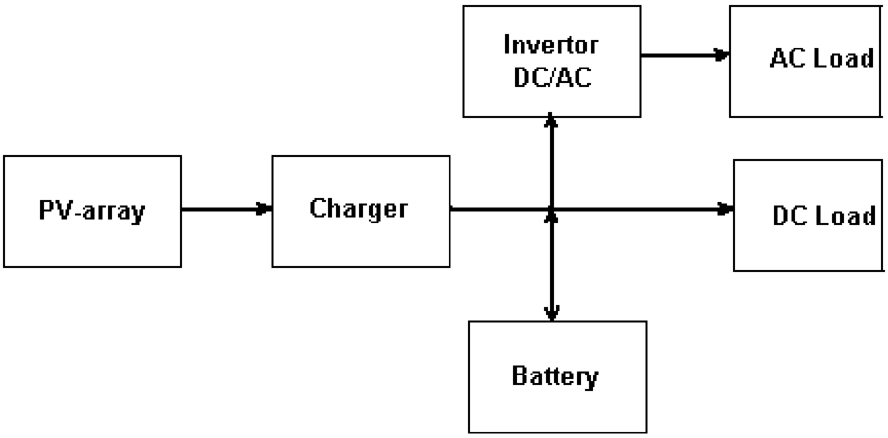


Figure 5.15: *A possible PV-lay-out to meet the loads of a Solar House*

5. Inclination to horizontal

Decide on PV-array: inclination, rotation axes etc, ground area required etc.

An investigation on various PV-inclination/rotation configurations has to be carried out for any inclination, in order to determine the most effective solution for the values of the parameters, e.g. when $\beta = \varphi$.

A detailed investigation was followed in Case Study no.1 in this Chapter.

6. Days of autonomy

Decide on days of energy autonomy of the system **d**.

Discuss on the Critical and non-Critical loads to determine **d**. Use the formulae below to estimate **d**.

Then re-discuss the PV-system-configuration to be adopted; fig.5.16.

$$d_{n-cr} = -1.9 \times (PSH)_{min} + 18.3 (days)$$

$$d_{n-cr} = -0.48 \times (PSH)_{min} + 4.58 (days)$$

For Bucharest (PSH) average is 3.63 while minimum is 1. So, **d** is to be 4. However, as seasonal storage or a supplement source may be used we keep **d=3** to decrease costs in batteries.

7. Correction in the loads due to losses

Table I

DC LOADS | **AC LOADS**

Losses	%		Losses	%
Cabling PV-directly to loads	5			5%
Charger/cables (when via battery)	5			5%
Battery efficiency 80%	20	ch / disch in the Wh method		0%
DC/AC invertor	15	invertor efficiency 85%	DC/AC inverter	15%

Application of the above values of the losses to Loads in Step 3, produce Table II below.

Table II: *Correction of Loads*

Load	**Route (see Figure 5.16)**	**Watt**	**Correction Factor**	**Final Load (correction value)**
DC	1.2.3	400	1.05	400×1.05=420Wh
DC	1.2.4.3	600	1.25	600×1.25=750Wh
AC	1.2.5.6.7	600	1.20	600×1.20=720Wh
AC	1.2.4.5.6.7	900	1.40	900×1.40=1260Wh
Total				**3150Wh = 3.15kWh Total Final Load** **2500Wh = 2.50kWh Total Initial Load**

After the analysis made so far the PV-system configuration may change to the following:

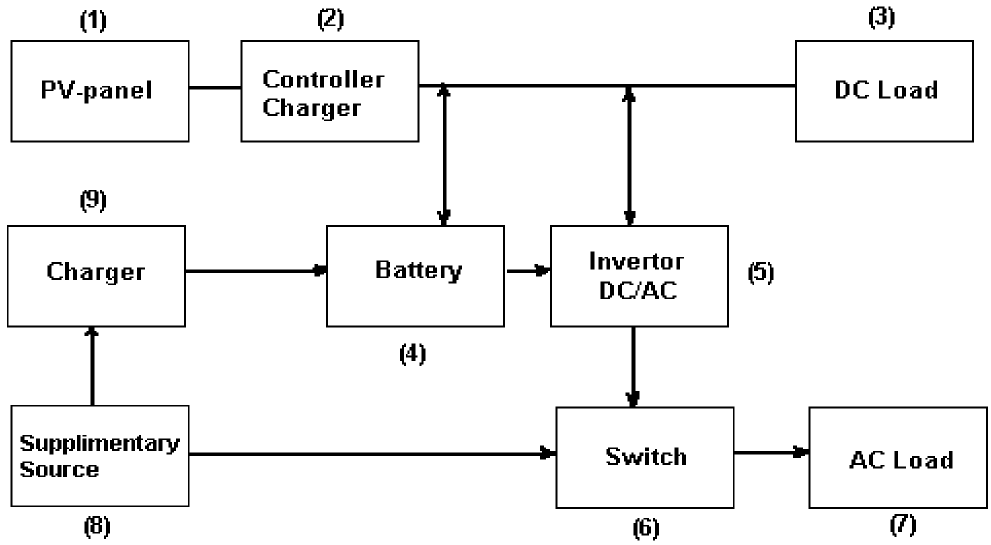


Figure 5.16: *PV-System: a Hybrid Solution*

8. **Initial / Rough W_p determination**

P_m = Load (corrected to losses): $(PSH)_{ann}$ = 3150 Wh / 5.68h = 554.6W_p

9. **Types of PV-panels to be installed.**

Decide on the PV-panels to be installed:
Let a PV type is chosen, whose characteristics are:

i_{sc} = 3.45A $\quad$ V_{sc} = 21.7Volts

i_m = 3.15A $\quad$ V_m = 17.4 Volts $\quad$ $P_m = i_m \times V_m = 54.8 \approx 55W_p$

10. **Correct P_m, V_m, i_m for the field values of the parameter, T_c.**

Lets take a PV-panel whose **NOCT** is equal to 46^{0}C.
Then, the operating temperature, $\mathbf{T_c}$, of the PV-panels is determined as follows:

$$\frac{\mathbf{T_c - T_a}}{\mathbf{I_T}} = \frac{\mathbf{NOCT - 20^0}}{\mathbf{0.8\,kW/m^2}}.$$

$\mathbf{I_T}$ should be 1kW/m^2 using **S.T.C.** as in §1.2.9.

Then, $$\mathbf{T_c = T_a + \frac{46^0C - 20^0C}{0.8\,kW/m^2} \times I_T = T + \frac{26^0C}{0.8\,kW/m^2} \times 1.0\,kW/m^2 = T_a + 32.5^0C}.$$

The ambient temperature for Bucharest for August is given in the relevant Table in Appendix II.

Assuming that for August the mean ambient temperature is $\mathbf{\overline{T}_{a,Au}} = 21.2^{\mathbf{0}}\mathbf{C.}$ for Bucharest

$\mathbf{T_c}$=21.2 ^{0}C+32.5 ^{0}C=53.7^{0}C

For this temperature we evaluate $\mathbf{i_{sc}}$, $\mathbf{V_{oc}}$, **FF** and from these new conditions, we get:

a. $\mathbf{i_{sc}}$ = 3.45A ; $\mathbf{i_{sc}}$ is assumed non-dependent on temperature.
b. $\mathbf{V_{oc}}$ = 21.7Volts – 36 × 0.0023 Volts/^{0}C × (53.7 – 25)^{0}C = 19.32Volts
c. $$\mathbf{FF} = \frac{55W}{3.15A \times 21.7Volts} = 0.735.$$

Notice: We assume that FF does not change substantially with T_c.
Finally,

P_m (10^3W/m^2, T_c=53^{0}C) = $i_{sc} \times V_{oc} \times FF$ = 3.45 × 19.32Volts × 0.735 = 49W, instead of 55 W_p under **S.T.C**.

11. **Determine the number of PV-panels, N_{pv}**

$$\mathbf{N_{pv} = \frac{P_w}{P_m} = \frac{554.6W_p}{49W_p} = 11.32PV - panels \approx 12PV - panels}$$

Notice: If we used $\mathbf{P_m}$ from the specifications (**S.T.C.**), then we would have:

$$\mathbf{N_{pv}} = \frac{\mathbf{P_w}}{\mathbf{P_m}} = \frac{\mathbf{554.6W_p}}{\mathbf{55W_p}} = \mathbf{10.1PV-panels \approx 10PV-panels}$$

12. Decide on the voltage value V_s, for Power transfer i.e. 24, 48, 120 Volts

The decision affects the PV-system elements and PV-panels electrical connections.
Consider 2 cases: V_s=48 Volts and 120 Volts
If, $\mathbf{V_s}$**=48 Volts**, then:

$$(\mathbf{N_{p,s}})_{48V} = \frac{\mathbf{V_s}}{\mathbf{V_m}} = \frac{\mathbf{48Volts}}{\mathbf{17.4Volts}} = \mathbf{3\ PV-panels\ in\ series}$$

so, $\mathbf{N_{p,p}}$ = 12 : 3 = 4 strings of PV-panels in parallel; each string has 3 PV-panels in series.
If, $\mathbf{V_s}$**=120 Volts**, then:

$$(\mathbf{N_{p,s}})_{120V} = \frac{\mathbf{V_s}}{\mathbf{V_m}} = \frac{\mathbf{120Volts}}{\mathbf{17.4Volts}} = \mathbf{8\,PV-panels\ in\ series}$$

so, $\mathbf{N_{p,p} = 2 \Rightarrow N_p = 16}$ **in total**

13. Confirmation
In step 11, we estimated N_p = 12 PV-panels
Hence, 12 × 49 W = 588 W_p
This has to be compared with the 554.6 W_p, estimated in step 8.

- **PART B**

Approach to the same sizing problem via the Ah methodology

Steps **1. – 6.** are the same as in the Wh method.

7′. Determination of the charge [Q(Ah)] delivered daily by the PV-generator

Assume that the power from the PV-generator is transferred at 48 Volts or 120 Volts**.**
So, then:

a. $\frac{2500Wh}{48Volts} = \frac{2500A \times V \times h}{48V} = 52.08Ah$, under 48 Volts, or

b. $\frac{2500Wh}{120Volts} == 20.83Ah$, under 120 Volts.

Let's follow both scenarios: **48 Volts** and **120 Volts**, to get analytic results**.**

A. DC Loads – directly met by the PV-generator:

1. $\dfrac{400Wh}{48Volts} = 8.33 Ah/day$

2. $\dfrac{400Wh}{120Volts} = 3.33 Ah/day$

Indirect coverage via batteries:

1. $\dfrac{600Wh}{48Volts} = 12.50 Ah/day$

2. $\dfrac{600Wh}{120Volts} = 5.00 Ah/day$

B. AC Loads – directly met by the PV-generator through the DC/AC charger:

1. $\dfrac{600Wh}{48Volts} = 12.50 Ah/day$

2. $\dfrac{600Wh}{120Volts} = 5.00 Ah/day$

Indirect coverage via batteries and the **DC/AC** charger:

1. $\dfrac{900Wh}{48Volts} = 18.75 Ah/day$

2. $\dfrac{900Wh}{120Volts} = 7.50 Ah/day$

So, the total Ah per day is: 52.08 Ah/day for DC voltage; 48 Volts.

Remark:

The same value would be obtained if we divided the load of 2500 Wh by the voltage of 48 Volts:

Q(Ah) = E : V_s = 2500Wh : 48Volts = 52.08Ah

8′. Correction to Ah due to losses in various PV-system elements

The correction is similar as in the Wh method.
The only difference is in the battery efficiency, which in this case, based on Ah, the efficiency is assumed much higher eg. near to 100%.

- **DC Loads** directly met by the PV-generator
  8.33Ah × 1.05 = 8.75Ah
- **DC Loads** via batteries
  12.50Ah × 1.05 = 13.13Ah
  (Notice: in the Wh method the correction factor was 1.25)

- **AC Loads** via inverter
  12.50Ah × 1.20 = 15Ah
- **AC Loads** via batteries and DC/AC
  18.75Ah × 1.20 = 22.5Ah

Total: 59.38Ah

9′. Determination of the mean annual current from the PV-generator, $\bar{i}_{pv}$.

Since, total daily load is 59.38Ah and $(PSH)_{ann}$ is 3.63h⇒
$\bar{i}_{pv}$ = annual mean current = 59.38Ah / 3.63h = 16.358A

10′. Determination of the PV-panels; $N_{p,p}$, $N_{p,s}$ in parallel, in series

The string in parallel **(N_p)**
N_p =16.358A / 3.15A = 5.19. Let us take **N_p=6.**

Question: How much is V_m in field conditions?

$V_m = P_m / I_m$ = 49W / 3.15A = 15.56 Volts, while in the Wh method, V_m was used equal to S.T.C. value: V_m=17.4 Volts

Remark: In the Wh method, in step 10, we estimated P_m=49Watts and V_m=15.56Volts
This leads to:
N_s= 48Volts / 15.56Volts = 3.08 ⇒ **N_s=3**

Total: $N_{pv} = N_p \times N_s = 6 \times 3 = 18$

So, we result to a higher number for **N_{pv}** as **N_p** was well oversized. This approach will provide a PV-generator which generates much more energy that required. It is recommended to keep **N_s=3** so that the system has **N_{pv} = 6× 3= 18** PV-panels and not oversize **N_s=3.08 → 4** as such a decision would drastically oversize the PV-generator resulting to very high costs and unused energy production .

- **PART C**

SIZING OF THE BATTERY BANKS

1. Determine the days of autonomy, d (see Wh and Ah method).
There is no difference either method is used.
Decide on d=3 based on the formulae in step 6 in Wh method.

2. Determination of the load storage for the days of autonomy, see § 3.2.

a. **Wh method**

The load as said is 2.5kWh/day to be transferred at 48Volts.

$$\mathbf{Q(Ah)} = \frac{2500kWh/day \times 3days}{48Volts} = 156.25Ah$$

b. **Ah method**

The loads per day to be delivered by batteries are 52.08Ah, so, for 3 days there must be stored: 52.08Ah × 3days = 156.25Ah.

3. Correction in the Ah value of the batteries due to temperature

Temperature of the batteries affects their efficiency. The capacity, **C**, decreases as **T** decreases below 25 – 27 ^{0}C.
For high charge – discharge rates, **C**, changes as in figure below.

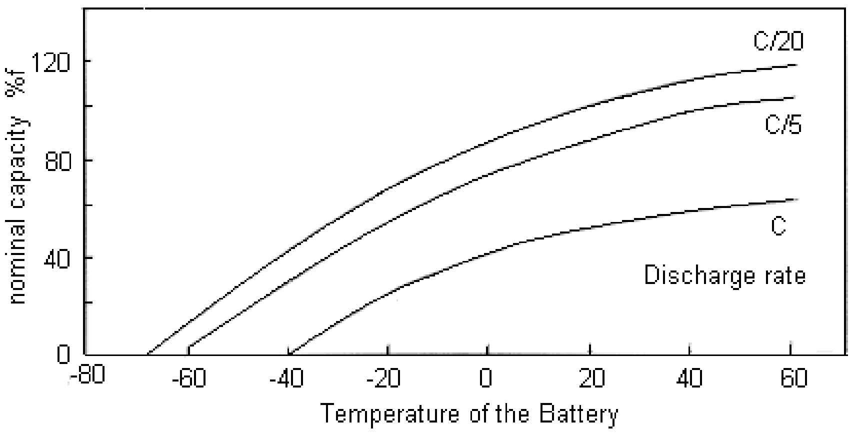


Figure 5.17: *Impact of temperature and of discharge rate to the energy delivered (come of a PV-acid battery).*

When **T** changes, **C** has to be corrected:

$$\mathbf{f_{b,T}} = \frac{\mathbf{C}}{\mathbf{C_0}} = \frac{\mathbf{C\,at\quad T^0C}}{\mathbf{C_0\,at\quad 25-27^0C}} = \mathbf{0.01035 \cdot T^0C + 0.724} \tag{5.25}$$

Lets take $\mathbf{f_{b,T}}$ **= 1**, for the case of Bucharest. Remember that for North Germany we estimated $f_{b,T}$ =0.8275.

If **T** in $^\mathbf{0}$**F**, then:

$$\frac{\mathbf{C}}{\mathbf{C_O}} = \mathbf{0.00575 \times T + 0.5A \quad (T\ in\ ^0F)} \tag{5.26}$$

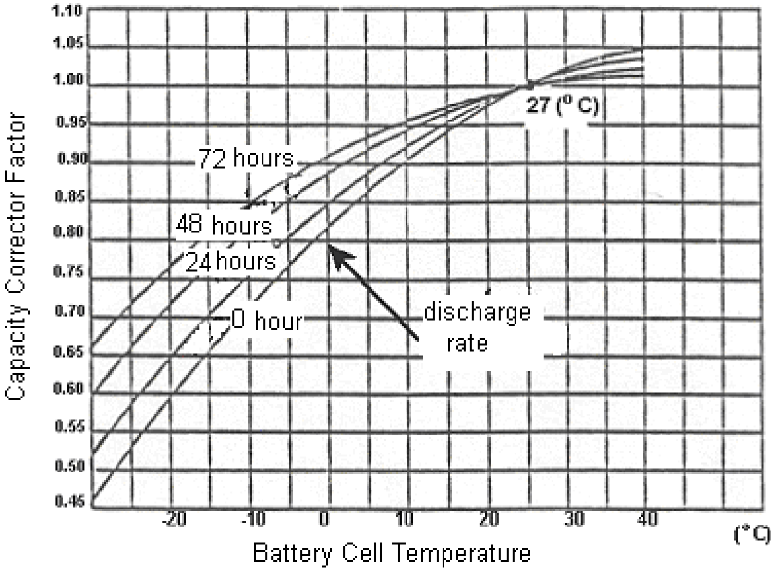


Figure 5.18: *Capacity correction factor of a Pb battery versus battery cell temperature (^0C).*

4. Determination of the correction coefficient due to the charge/discharge rate

A correction factor due to charge/discharge rate, $\mathbf{f_{b,cd}}$, has to be studied. $\mathbf{f_{b,cd}}$ is defined as follows:

$$f_{b,cd} = \frac{i_{ch/disch}\ \text{(as recommend)}}{i_{ch/disch}\ \text{(as in the case)}} \tag{5.27}$$

So, the correctied capacity, $\mathbf{C_{cor}}$, is given by a formula equivalent to (3.18).

$$C_{cor} = \frac{C(Ah/day)}{f_{b,T} \times f_{b,ch} \times DOD} \tag{5.28}$$

and for autonomy of **d** days

$$C_{cor} = \frac{C(Ah/day) \times d(days)}{f_{b,T} \times f_{b,ch} \times DOD} \tag{5.29}$$

Notice: if $\mathbf{i_{ch}}$ multiplied by **10h** i.e. $\mathbf{(i_{ch} \times 10h)Ah > C_{cor}}$ (from the above equation)

Then, $\mathbf{C_{cor} = (i_{ch} \times 10)Ah}$.

In our case:

$i = i_m \times 4$ strings = 3.15Ah × 6 = 18.9Ah

$\mathbf{(i_{ch} \times 10)Ah = 18.9A \times 10h = 189Ah}$

Compare $\mathbf{(i_{ch} \times 10)Ah}$ to $\mathbf{C_{cor}}$ where:

$$\mathbf{C_{cor}} = \frac{52.08\frac{Ah}{day} \times 3days}{1 \times 1 \times 0.8} = 195.3Ah$$

As $\mathbf{C_{cor} > (i_{ch} \times 10)Ah = 189Ah} \Rightarrow$ then we accept that batterie's capacity is 195.3Ah.

5. Determine the type of batteries to be used

One should choose the type of the battery to meet the requirements and the prerequisites of the problem as in the following:

a. Total capacity 195.3Ah i.e. about 200Ah
b. The voltage across batteries bank to be 48 Volts
c. The DOD value to be higher than 20%. In fact, DOD is related to **d**:

$$\frac{\mathbf{d}}{\mathbf{d+1}} = \mathbf{DOD} \Rightarrow \frac{\mathbf{3}}{\mathbf{4}} = \mathbf{DOD} \Rightarrow \frac{\mathbf{d}}{\mathbf{d+1}} = \mathbf{DOD_{max}}$$

$$\mathbf{DOD_{max}} = \frac{3}{7+1} = 0.75$$

d. The decision of the battery type is complex and depends not only in the above characteristics, but also on the unit price, the life cycles, duration, etc.
This has to be examined separately, as in § 3.3.3.

From the appropriate Table in Appendix III let's choose, at first, the battery type:
GNB Absolyte: C=59A, V=12Volts, DOD=0.8.

Hence, 4 batteries of this type in series are required to provide: 4 ×12Volts = 48Volts
The batteries in parallel are determined by the formula:

$$\mathbf{N_{b,p}} = \frac{\mathbf{Q_L \times d}}{\mathbf{DOD \times C}} = \frac{(2500Wh/48Volts) \times 3days}{0.8 \times 59Ah} = 3.13.$$

Therefore, we assume 4 strings of batteries, in parallel.

6. Confirm that during the discharge process DOD < $\mathbf{DOD_{specs}}$

We decided before, in step 5, to use 4 batteries of 59Ah with DOD=0.8.
Then, in step 7' of the Ah method the daily total charge Load is equal to 52.08Ah, while total capacity is 4 × 59Ah = 236Ah.
Therefore, the daily discharge is:

$\frac{52.08Ah}{236Ah} = 0.22$ or 22% < 80% as specified of the type of the battery chosen.

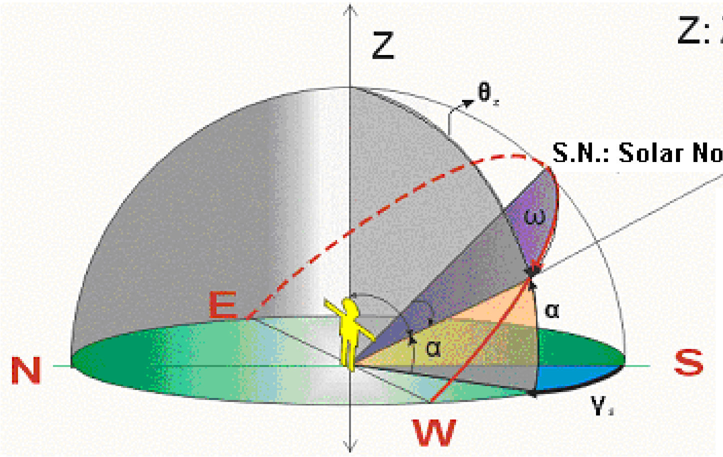
As total C=236Ah, DOD=0.8,
the total available capacity is: 0.8 × 236Ah = 188.8Ah

This is higher than the 156.23Ah required for the autonomy of the 3 days.
Finally, even if batteries would operate for all 3 days, the discharge level would be:
156.25Ah / 236Ah = 0.662 or 66.2% < 80%.

7. The decision on the battery type choise, provided that this type would meat the technical requirements and the pre-requisites as presented above, should be the outcome of a financial analysis as done in the previous Case studies.

Appendix I

1. Schematic configuration of the sun trajectory for a day. The important angles: **ω, α, γ_s, θ_z** to determine sun's position in the sky are shown.
Angles **γ_s** and **α** are enough to determine sun's position.



ω: angle hour: $\omega>0$ before solar noon
$\omega<0$ after solar noon
ω change 15^0 every hour
α: altitude
γ_s: solar azimuth angle
θ_z: zenith angle of the sun:
$\alpha+\theta_z=90^0$

Figure I.1: *The figure shows a daily orbit trajectory of the sun. The position S.N. is for the* ***S****olar* ***N****oon. We determine as the solar true time 12.00hours. Then, the hour angle,* ***ω****, is 0^0.*

2. Declination angle, δ, Solar Time, (S.T.), and Watch Time, (W.T.)

Declination angle, **δ**, is the angular position of the sun at solar noon with the respect to the plane of the equator. **δ** is positive from spring equinox (21.03) to autumn equinox (22.09). Generally, holds:
$-23.45^0 \leq \delta \leq +23.45^0$

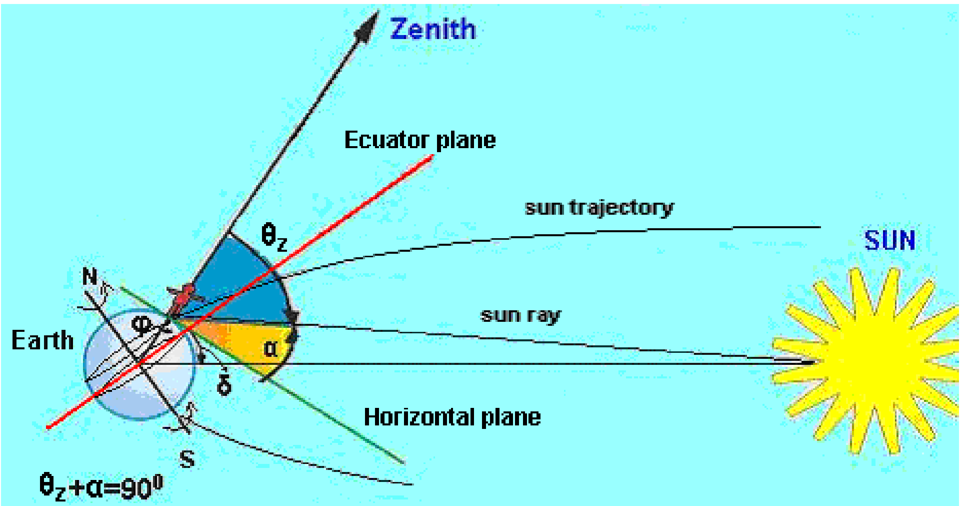


Figure I.2: *Schematically presentation of the sun, the earth, the site and its horizontal surface for the better understanding of the angles:* ***δ*** *(declination),* ***θ_z*** *(azimuth angle),* ***α*** *(altitude of the sun).*

Note:
1.The observer watches the sun aver the horizontal surface by the an angle which equals to ***α***
2. The figure shows the winter period for the north Hemisphere
3. ***δ****, the declination has a negative value, in figure I.2.*

Solar Time, **S.T.,** is the time based on the apparent angular motion of the sun across the sky, with **Solar Noon** (**S.N.**), the time the sun crosses the meridian of the observer.
Solar time is the time, which is measured according to the sun position, and the starting point is taken at solar noon. Then S.T.=12.00h
According to this, the hour angle,**ω**(negative in the morning, positive in the afternoon), which is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, measured from the S.N. It increases every hour with 15^0. For one full rotation (every/day): **ω**=(15^0/h)×24h=360^0, which is obvious.

Finally,
when **ω=0** the Solar Time is 12.00 h.

- **δ,** changes from **-23.45^0** in winter solstice (22nd of December) up to **$+23.45^0$** in summer solstice (22nd of June).

δ=0, in equinox (21st of March and 23rd of September).

$$\delta = 23.45^o \times \sin\left(360 \times \frac{284+n}{365}\right) \qquad (I.1)$$

Where **n,** is the day of the year counted from the 1st of January .

For example lets take 1st of April:
n=31+28+31+1=91 .

Table I.1: *Some typical dates and declination,* ***δ,*** *values*

Declination (δ)	*Dates*
+23.27°	22 June
+20°	21 March, 24 June
+15°	1 May, 12 August
+10°	16 April, 28 August
+5°	3 April, 10 September
0°	21 March, 23 September
-5°	8 march, 6 October
-10°	23 February, 20 October
-15°	9 February, 3 November
-20°	21 January, 22 November

It holds:

S.T. = W.T. –(4min/degree)×(L_{st} - L_{loc}) + E (I.2)

S.T.: Solar Time;
W.T.: Watch Time, which is conditioned by the Greenwich meridian; and the summer or winter conditioned time
L_{st}: is the standard meridian for the local time zone;
L_{loc}: is the longitude of the location in question in degrees;
E: is the equation of time:
Let us make a convention to measure **L** towards East, as positive.

E=9.87sin2B-7.53cosB-1.5sinB, (I.3)

where:
B=[360×(n-81)] / 364; **n** = the day of the year, 1≤ **n** ≤ 365 (I.4)
Note:*In solar studies the time used is the Solar Time, unless differently specified.*

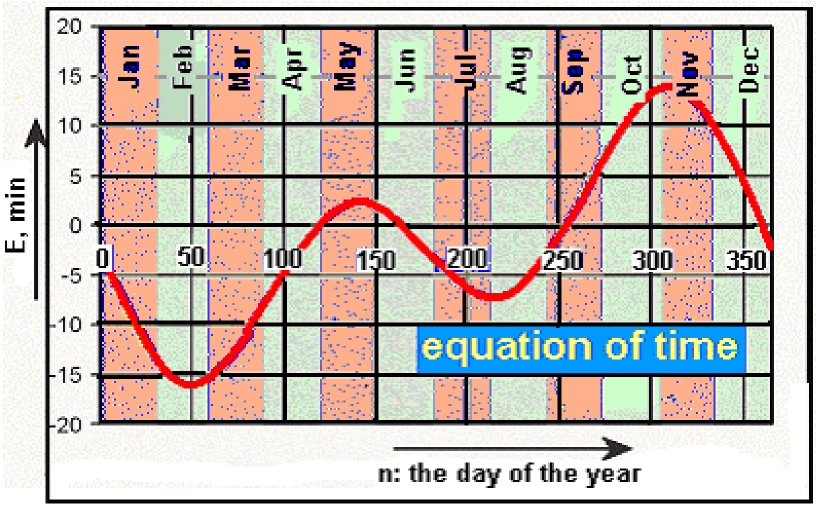


Figure I.3: *The equation of time, **E**, in minutes, as a function of time of year*

3. Important relationships between angles

Let's have a PV-panel with and angle, **β,** to the horizontal and its azimuth angle, **γ,** see figure below placed in a region with latitude, **φ.**
Task: Determine the angle of incidence, **θ,** of the sun direct beam on the PV-panel for the 10^{th} of June, at solar noon (solar time, **S.T**., is **12.00** and that hour angle **ω** is **0^0**).

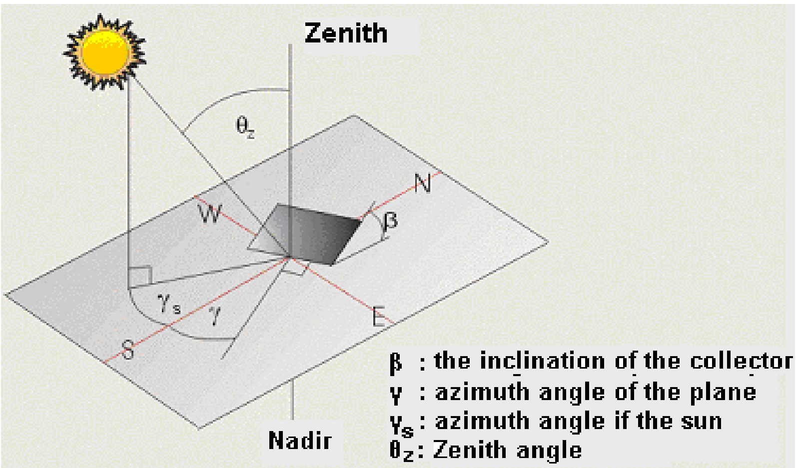


Figure I.4: *Figures shows the configuration of important angles*
Note: *see the difference between **γ** and **γ_s***

- The general equation which relates the angle of incidence, **θ,** to the plane and the other angles, is the following:

$$\cos\theta = \sin\delta \times \sin\varphi \times \cos\beta - \sin\delta \times \cos\varphi \times \sin\beta \times \cos\gamma + \cos\delta \times \cos\varphi \times \cos\beta \times \cos\omega + \cos\delta \times \sin\varphi \times \sin\beta \times \cos\gamma \times \cos\omega + \cos\delta \times \sin\beta \times \sin\gamma \times \sin\omega \quad (I.5)$$

- When **$\beta=0$,** then **$\theta=\theta_z$** and **for $\gamma=0$.** Then the above equation become:

$$\cos\theta_z = \cos\delta \times \cos\varphi \times \cos\omega + \sin\varphi \times \sin\delta \quad (I.6)$$

- The solar azimuth angle, γ_s, is given by the relationship below:

$$\gamma_s = \frac{\cos\delta \times \sin\omega}{\sin\theta_z} \qquad \text{(I.7)}$$

- When a surface is facing the south, $\gamma=0$, then the relationship (I.5) becomes:

$$\cos\theta=\cos(\varphi-\beta)\times\cos\delta\times\cos\omega+\sin(\varphi-\beta)\times\sin\delta \qquad \text{(I.8)}$$

- To determine the angle β for normal incidence of the direct sun beam to a tilted PV-panel, i.e. $\theta=0$, during the solar noon, $\omega=0$, equation (I.8) becomes:

$$\cos\theta=\cos(\varphi-\beta)\times\cos\delta\times\cos\omega+\sin(\varphi-\beta)\times\sin\delta$$

$$\Rightarrow \cos\theta=\cos(\varphi-\beta)\times\cos\delta\times1+\sin(\varphi-\beta)\times\sin\delta$$

$$\cos\theta=\cos[(\varphi-\beta)-\delta]$$

$$\Rightarrow \boxed{\theta=(\varphi-\beta)-\delta} \qquad \text{(I.9)}$$

Set $\theta=0$, and solve for β: $\boxed{\beta=\varphi-\delta}$

- To find the solar angle of the sunset or sunrise, we put $\theta_z=90^0$ or $\alpha=0^0$ in equation (I.6) which now becomes:

$$\cos\omega=-\tan\varphi\times\tan\delta \quad \Rightarrow \quad \omega_s=\cos^{-1}(-\tan\varphi\times\tan\delta) \qquad \text{(I.10)}$$

ω_s**:** is the sunset hour angle, in degrees, at horizontal.
The sunset hour angle, ω_s', for an inclined surface, is given by the relationship below:

$$\omega_s' = \min[\omega_s, \cos^{-1}(-\tan(\varphi-\beta)\times\tan\delta)] \qquad \text{(I.11)}$$

ω_s' is the smaller value chosen between the ω_s and $\cos^{-1}(-\tan(\varphi-\delta)\tan\delta)$.

Appendix II

Important formulae of the **(i,V)** characteristic of PV-cells & PV-panels

$$\mathbf{i} = \mathbf{i_{ph}} - \mathbf{I_r}\left\{\mathbf{exp}\left[\left(\mathbf{V} + \mathbf{iR_S} \Big/ \mathbf{AV_T}\right)\right] - \mathbf{1}\right\} \quad , \quad \begin{aligned} &\mathbf{i_{ph}} = \mathbf{i_{ph,c}} \cdot \mathbf{N_p} \\ &\mathbf{I_r} = \mathbf{I_{r,c}} \cdot \mathbf{N_p} \\ &\mathbf{R_S} = \mathbf{r_S} \cdot \mathbf{N_S}/\mathbf{N_p} \quad . \\ &\mathbf{V_T} = \mathbf{N_S} \cdot \mathbf{kT}/\mathbf{q} \\ &A : ideality..factor \end{aligned}$$

$$\mathbf{i_{ph}} = \mathbf{i_m} + \mathbf{I_r}\left\{\mathbf{e}^{2 \cdot i_m \cdot R_S \big/ AV_T + \frac{i_m}{i_{ph} - i_m + I_r}} - \mathbf{1}\right\} \quad .$$

• Solve via Newton - Raphson for $\mathbf{i_m}$

➢ $\mathbf{V_m}$=?

$$\mathbf{V_m} = \mathbf{A} \cdot \mathbf{V_T} \cdot \mathbf{ln}\left[\left(\mathbf{i_{ph}} - \mathbf{i_m} + \mathbf{I_r} \big/ \mathbf{I_r}\right)\right] - \mathbf{i_m} \cdot \mathbf{R}_S \quad ,$$

Then,

$$\mathbf{P} = \mathbf{i} \cdot \mathbf{A} \cdot \mathbf{V_T} \cdot \mathbf{ln}\left[\left(\mathbf{i_{ph}} - \mathbf{i} + \mathbf{I_r} \big/ \mathbf{I_r}\right)\right] - \mathbf{i}^2 \cdot \mathbf{R_S} \quad .$$

1. **(i ~ v)** from PV-generator is given by:

$$\mathbf{i} = \mathbf{i_{ph}} - \mathbf{I_S} \cdot \left[\mathbf{e}^{\frac{V + i \cdot R_S}{m \cdot V_T}} - \mathbf{1}\right] - \frac{\mathbf{V} + \mathbf{i} \cdot \mathbf{R_S}}{\mathbf{R_{sh}}} \qquad \mathbf{(1)},$$

Important parameters to be known for PV-generator are $\mathbf{i_{ph}}$, $\mathbf{I_S}$, $\mathbf{R_S}$, $\mathbf{R_{sh}}$, **m** and they may be determined from $\mathbf{V_{0C}}$, $\mathbf{i_{sh}}$, $\mathbf{V_m}$, $\mathbf{i_m}$, $\mathbf{R_{S,0}}$, $\mathbf{R_{sh}}$.

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2. Another way of expressing PV-generator

$$\mathbf{i} = \mathbf{i_{ph,STC}} \cdot \mathbf{I_T}\left(\mathbf{kW}/\mathbf{m}^2\right) - \mathbf{I_0}\left[\mathbf{e}^{\frac{V + i \cdot R_S}{V_T}} - \mathbf{1}\right] - \frac{\mathbf{V} + \mathbf{i} \cdot \mathbf{R_S}}{\mathbf{R_{sh}}} \qquad \mathbf{(2)},$$

$\mathbf{V_T}$ **:** Thermal Voltage of the PV-array

Here $\mathbf{i_{ph}}$ **&** $\mathbf{I_t}$ **,** $\mathbf{i_{ph,STC}}$ multiplied by $\mathbf{I_t}$ provides $\mathbf{i_{ph}}$ for $\mathbf{I_t}$ insolation.

Solar Energy vol.53 no.4 Oct. 1994 pp. 369-377

3.

$$\mathbf{i} = \mathbf{i_L} - \mathbf{I_0}\left[\mathbf{e}^{\frac{V + i \cdot R_S}{V_T}} - \mathbf{1}\right] - \frac{\mathbf{V}}{\mathbf{R_{sh}}} \qquad \mathbf{(3)},$$

$\mathbf{i_L}$= illumination

$$\mathbf{V_T} = \mathbf{kT} \big/ \mathbf{q}$$

Renewable Energy-An International Journal vol.18 no.3 Nov. 1999 pp. 383-392

4.

$$\mathbf{i} = \mathbf{i_L} - \left[\frac{\mathbf{i_L} - \dfrac{\mathbf{V_{0C}}}{\mathbf{R_p}}}{\exp(\mathbf{ektV_{0C}}) - \mathbf{1}} \right] \cdot \left[\mathbf{e}^{\mathbf{ekt}(\mathbf{V}+\mathbf{i}\cdot\mathbf{R_S})} - \mathbf{1} \right] - \frac{\mathbf{V} + \mathbf{i} \cdot \mathbf{R_S}}{\mathbf{R_p}} \qquad \textbf{(4),}$$

$$\mathbf{ekt} = \frac{\mathbf{q}}{\mathbf{m} \cdot \mathbf{k} \cdot \mathbf{T}} \quad , \quad \mathbf{R_p} \equiv \mathbf{R_{sh}}$$

Solar Energy vol.54 no.3 March 1995 pp. 165-171

5. PV-cells

$$\mathbf{i} = \mathbf{i_{ph}} - \mathbf{I_{0,1}} \cdot \left[\mathbf{e}^{\frac{\mathbf{V}+\mathbf{iR_S}}{n_1 \cdot V_T}} - \mathbf{1} \right] - \mathbf{I_{0,2}} \cdot \left[\mathbf{e}^{\frac{\mathbf{V}+\mathbf{iR_S}}{n_2 \cdot V_T}} - \mathbf{1} \right] - \frac{\mathbf{V}}{\mathbf{R_{sh}}} \quad , \qquad \textbf{(5),}$$

PV-array: let $\mathbf{iR_S} \ll \mathbf{1}$, then **(5)** gives:

$$\mathbf{i} = \mathbf{i_{ph}} - \mathbf{I_{0,1}} \cdot \left[\mathbf{e}^{\frac{\mathbf{V}}{N_S \cdot n_1 \cdot V_T}} - \mathbf{1} \right] - \mathbf{I_{0,2}} \cdot \left[\mathbf{e}^{\frac{\mathbf{V}}{N_2 \cdot n_2 \cdot V_T}} - \mathbf{1} \right] - \frac{\mathbf{V}}{\mathbf{R_{sh}}} \quad , \qquad \textbf{(6),}$$

Equation **(6)** is for an PV-array with $\mathbf{N_S}$: no. of cells in series

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6.

PV-array: let **i** be array's current

$$\mathbf{i} = \mathbf{M} \cdot \mathbf{i_{ph}} - \mathbf{M} \cdot \mathbf{I_0} \left[\mathbf{e}^{q \frac{N \cdot V + i_{ph} \cdot R_S \cdot N/M}{N \cdot A \cdot k \cdot T_p}} - \mathbf{1} \right] - \frac{\mathbf{N} \cdot \mathbf{V} + \mathbf{i_p} \cdot \mathbf{R_S} \cdot \mathbf{N/M}}{\mathbf{N} \cdot \mathbf{R_{sh}} / \mathbf{M}}, \qquad \textbf{(7),}$$

M: module's strings in parallel
N: no. of cells in series
i-v of an PV-generator

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7. PV-array
$\mathbf{N_S}$ PV-panels series
$\mathbf{N_P}$ PV-panels parallel
$\mathbf{R_{sh}} \longrightarrow$ neglect

$$\mathbf{V} = \mathbf{A} \cdot \mathbf{V_T} \cdot \mathbf{ln}\left[\left(\mathbf{i_{ph}} - \mathbf{i} + \mathbf{i_r} \right) / \mathbf{i_r} \right] - \mathbf{i} \cdot \mathbf{R_S}$$

$$\mathbf{i_{ph}} = \mathbf{i_{ph,1}} \cdot \mathbf{N_P} \quad , \qquad \textbf{(8),}$$

$$e^{\frac{V+i\cdot R_S}{A\cdot V_T}} = \frac{i_{ph}-i}{i_r}+1$$

$$I_r = I_S \cdot N_P$$

$$R_S = R_C \cdot N_S / N_P \quad , \qquad \frac{i_{ph}-i}{i_r} = \left[e^{\frac{V+i\cdot R_S}{A\cdot V_T}} - 1 \right] \quad ,$$

$$A \cdot V_T = N_S \cdot \frac{A \cdot k \cdot T}{q} \qquad i = i_{ph} - i_r \cdot \left[e^{\frac{V+i\cdot R_S}{A\cdot V_T}} - 1 \right]$$

neglect : $\dfrac{V + i \cdot R_S}{R_{sh}}$

$$i = i_{ph,1} \cdot N_P - I_0 \cdot N_P \cdot \left[e^{\frac{V+i\cdot R_S}{A\cdot V_T}} - 1 \right] \quad ,$$

$$R_S = R_C \cdot N$$

Solar Energy vol.53 no.5 1994 pp. 403-409

8.

$$V = -\frac{R_S \cdot N_S \cdot i}{N_P} + \frac{N_S \cdot A \cdot k \cdot T}{e} \cdot \ln \frac{N_P \cdot i_{ph} + N_P \cdot I_0 - i}{N_P \cdot I_0} \quad , \qquad (9).$$

Renewable Energy -An International Journal vol.6 no.1 1995 pp. 29-34

Appendix III

Table III.1: *Electrical characteristics of Siemens PV-panels*									
PV-type	SR100		SR90		SR50		SP75	SP70	
PV-cells in series	36	18	36	18	36	18	36	18	36
Peak power, Watts (W_p)	100	100	90	90	50	50	75	75	70
Mean power, Watts	90	90	80	80	45	45	70	70	65
V_{OC}	22.0	11 0	21.6	10.8	21.6	10.8	21.7	10.85	21.4
i_{sc}	6.3	12.6	61	12.2	3.2	6.4	4.8	9.6	4.7
V under load	17.7	8.85	17.0	8.5	17.0	8.5	17.0	8.5	16.5
i under load	5.6	11 2	5.4	10.8	2.95	5.9	4.4	8.8	4.25
Semiconductor type	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$	$Mono^+$
Max V_{OC} of the whole PV-system	600	600	600	600	600	600	600	600	600
Diode	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table III.2: *Types of Batteries*

Manufacturer and Type	Model	Nominal Capacity (Ah)	Nominal Voltage (V)	DOD (%)	Life Cycles	Total to be delivered Energy (kWh)
GNB Absolyte	638	42	6	50	1000	126
	1260	59	12	50	1000	359
	6 – 35A09	202	12	50	3000	3636
	3 – 75A25	1300	6	50	3000	1700
Exide Tubular Modular	6E120 – 5	192	12	15 20	4100 3900	1417 1797
	6E120 – 9	538	12	15 20	4100 3900	3970 5036
	3E120 – 21	1346	6	15 20	4100 3900	4967 6299
Delco – Remy Photovoltaic	2000	105	12	10 15 20	1800 1250 850	227 236 214
Global Solar Reserve gel Cell	3SSSSRC –125G	125	6	10	2000	150
	SRC – 250C	250	2	10	2000	100
	SRC – 375G	375	2	10	2000	150
Globe	GC12 – 800-38	80 80	12 12	20 80	1500 250	288 240
GNB Absolyte	638	40	6	80	500	96
	1260	56	12	80	500	269
	6 – 35A09	185	12	80	1500	2664
	3 – 75A25	1190	6	80	1500	8568

Table III.3: *Basic/Fundamental Loads-Demand for a typical house*					
LOAD	**Installed Power** (W) (1)	**Mean Daily operation time** (h) (2)	**Mean Daily consumption** Wh/day (3)=(2)×(1)	**Mean Montly consumption** kWh/month (4)=(3)×no of days	**Mean annual consumption** Wh/year (5)=(4)×12
Lighting Lamps 16 points×15W	240	2	480	14.4	170
TV color 24" TV B/W 17" Video	~100 ~40 ~30	1 5 1	100 200 30	3 6 1	36 72 12
Kitchen fan	~70	0.4	30	1	12
Fan	~50	1.4	70	2	24
Hot water pump	~70	2	140	4	48
PC	~180	0.55	100	3	36
Refrigeration with freezer	~150	9.3	1400	42	500
Washing machine	500	0.5	250	7.5	90
Vacuum cleaner	800	0.1	80	7.5	282
Electric kitchen	3700	0.4	1480	50	540
Iron	1100	0.3	1100×0.3×50%= 165	165×30.5=5	60
Oven	2600	0.5	2600×0.5h×25% =325	9.8	117.6
Air conditioning per room	860	10	10d/month (in summer)	86	1032
Total	**10490W**			**199.7kWh**	**2770.6 kWh**

Table III.4: *Characteristics of commercial PV-panels: mono or poly Si*					
No	Peak Power PV-panel with 30 up to 44 PV-cells in series (W) (1)	Mean Daily Charge Delivered Q (Ah) (2)	Mean Voltage (V_m) at MPP Volts (3)	Mean daily Delivered Energy (Wh) (4)=(3)×(2)	Mean annually delivered energy by the PV-panel (kWh) (5)=(4) ×365
1	~22	5.9	~15	88	32
2	~35	9.3	~15	140	51
3	~38	10.0	~16	160	58
4	~42	11.5	~15	170	62
5	~45	12.0	~15	180	65
6	~51	12.0	~17	200	73
7	~53	12.0	~17.5	210	75
8	~63	12.0	~20	240	87

Table III.5: *Best large-area thin film modules (standard conditions, aperture area) (Solar-photovoltaic: a 2001 device overview by Lawrence L. Kazmerski)*

Company	Device	Size (cm^2)	Efficiency (%)	Power (W)	Date
BP Solarex	CdS/CdTe	8670	10.6	91.5	5/'00
United Solar	a-Si/ a-SiGe/ a-SiGe/SS	9276	7.6 (stabilized)	70.8	9/'97
First Solar	CdTe/ CdS	6728	9.1	61.3	6/'96
Matsushita	CdS/CdTe	5413	11.0	59.0	6/'00
BP Solarex	a-Si/ a-SiGe	7417	7.6 (stabilised)	56.0	9/'96
BP Solarex	CdS/CdTe	4874	10.8	53.9	4/'00
Siemens Solar	CdS/CIS-alloy	3651	12.1	44.3	3/'99
KaneKa	a-Si/ x-Si/glass	3738	10.0 (est, stable)	38.0 (est.)	9/'00
Global Solar	CIS/SS	7495	4.9	36.5	2/'01
United Solar	a-Si triple	4519	7.9 (stabilized)	35.7	6/'97
Global Photon	CdS/CdTe	3366	9.2	31.0	4/'97

Appendix IV

Table IV.1: Cities from Romania, Europe
(Data from METEONORM program)

City	Code	Altitude [m]	Latitude φ [^{0}]	Longitude L [^{0}]	Type of site	Climatic zone	Situation
Bucuresti	15420	88	44.45	-26.09	City	III, 3	Open
Cluj - Napoca	15120	410	46.47	-23.34	Stations	III, 3	Open
Constanta	15480	13	44.13	-28.38	Stations	III, 9	Sea/lake
Craiova	15450	190	44.14	-23.52	Stations	III, 3	Open
Galati	15310	71	45.3	-28.01	Stations	III, 4	Open
Iasi	15090	104	47.1	-27.36	Stations	III, 4	Open
Timisoara	15247	86	45.46	-21.15	Stations	III, 3	Open

Figure IV.1: *The map of Romania.*

Table of formulae used to calculate the quantities and parametres in this Appendix

1. The data of the following quantities were taken from METEONORM (monthly values):

$\overline{\mathbf{H}}$: Irradiation of global radiation horizontal [**kWh / m²**] and [**MJ/m²**]

$\overline{\mathbf{H}}_d$: Irradiation of diffuse radiation horizontal [**kWh / m²**] and [**MJ/m²**]

$\overline{\mathbf{H}}_b$: Irradiation of direct radiation horizontal [**kWh / m²**] and [**MJ/m²**]

Ta: air temperature [**^{0}C**] **RH**: Relative humidity **WS**: Wind speed [**m/s**]

WD: Wind direction **RR**: Precipitation [**mm**]

2.

a. $\overline{\mathbf{H}}_{ext}$ - daily extraterrestrial radiation :

$$\overline{H}_{ext}(n) = \frac{24 \times 3600}{\pi \times 1000} \times I_{sc} \times \left[1 + 0.033 \times \cos\left(\frac{360 \times n}{365}\right)\right] \times \left[\cos\varphi \times \cos\delta \times \sin\omega_S + \frac{\pi \times \omega_S}{180} \times \sin\varphi \times \sin\delta\right]$$

where $\mathbf{I_{sc}}$ =1353 kW/m²

The results of the monthly extraterrestrial radiation, $\overline{\mathbf{H}}_{ext}$**,** shown in the tables hereafter were calculated using the mean day of the month (**n**; the representative day of the month: 17 Jan., 15 Feb., 16 Mar., 15 Apr., 15 May., 11 Jun., 17 Jul., 16 Aug., 16 Sep., 16 Oct., 15 Nov., 11 Dec.) in the above formula and then the result was multiplied by the number of days of the month.

b. The monthly extraterrestrial radiation, $\overline{\mathbf{H}}_{ext}$**,** can also be calculated by :

$$\sum_{n=1}^{N} \overline{H}_{ext} = \frac{24 \times 3600}{\pi \times 1000} \times I_{sc} \times \left[1 + 0.033 \times \cos\left(\frac{360 \times n}{365}\right)\right] \times \left[\cos\varphi \times \cos\delta \times \sin\omega_S + \frac{\pi \times \omega_S}{180} \times \sin\varphi \times \sin\delta\right]$$

where **N** is the number of days of the month; ω_s, δ and **n** depend on the day according to formulae in Appendix I.

c. $\overline{\mathbf{K}}_t$ - the monthly average clearness index : $\overline{K}_t = \overline{H}/\overline{H}_{ext}$; $\overline{\mathbf{H}}$ was taken from METEONORM.

d. $\overline{\mathbf{H}}_d/\overline{\mathbf{H}}$ was calculated using data from METEONORM.

e. **PSH**: Peak Solar Hour: $\overline{H}(kWh/m^2)/[(1kW/m^2) \times N(no.\ \ days\ \ of\ \ the\ \ month)]$

f. $$R_b = \frac{\cos\theta}{\cos\theta_z}$$

$\mathbf{R_b}$-ratio of beam solar insolation on tilted surface ($\mathbf{I_T}$) to that on horizontal surface ($\mathbf{I_h}$): $\mathbf{I_T/I_h}$

This is the instant $\mathbf{R_b}$

g. $$\overline{R}_b = \frac{\cos(\varphi - \beta) \times \cos(\delta) \times \sin(\omega'_s) + (\pi/180) \times \omega'_s \times \sin(\varphi - \beta) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta) \times \sin(\omega_s) + (\pi/180) \times \omega_s \times \sin(\varphi) \times \sin(\delta)}$$

ω'_s, ω_s, δ are defined in Appendix I.

Table IV.2: Monthly Average Daily Extraterrestrial Radiation, $\bar{H}_o$, MJ/m², for I_{sc} = 1353 W/m²

	Average Daily Extraterrestrial Radiation											
Latitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
60	3.5	8.2	16.7	27.3	36.3	40.6	38.4	30.6	20.3	10.7	4.5	2.3
55	6.1	11.2	19.6	29.3	37.2	40.8	39.0	32.2	22.9	13.6	7.2	4.8
50	9.1	14.2	22.3	31.2	38.1	41.1	39.6	33.7	25.3	16.6	10.2	7.6
45	12.1	17.2	24.8	32.9	38.8	41.3	40.0	35.0	27.5	19.4	13.2	10.5
40	15.1	20.1	27.2	34.3	39.3	41.3	40.2	36.1	29.5	22.1	16.2	13.6
35	18.1	22.8	29.3	35.5	39.5	41.1	40.2	36.9	31.3	24.7	19.1	16.7
30	21.1	25.5	31.2	36.4	39.6	40.7	40.0	37.5	32.9	27.1	22.0	19.7
25	23.9	27.9	32.9	37.1	39.4	40.0	39.6	37.8	34.2	29.3	24.8	22.6
20	26.7	30.2	34.4	37.5	38.9	39.1	38.9	37.8	35.3	31.3	27.4	25.5
15	29.3	32.3	35.5	37.6	38.1	38.0	37.9	37.6	36.1	33.1	29.8	28.2
10	31.7	34.1	36.4	37.5	37.1	36.6	36.7	37.1	36.6	34.6	32.1	30.8
5	33.9	35.7	37.1	37.1	35.9	35.0	35.3	36.3	36.8	35.9	34.1	33.1
0	35.9	37.0	37.4	36.4	34.4	33.2	33.6	35.3	36.8	36.9	36.0	35.3
−5	37.6	38.1	37.5	35.4	32.7	31.1	31.7	34.1	36.5	37.7	37.5	37.3
−10	39.1	38.9	37.3	34.2	30.7	28.9	29.6	32.6	35.9	38.1	38.9	39.0
−15	40.4	39.4	36.8	32.7	28.6	26.5	27.4	30.8	35.0	38.3	39.9	40.4
−20	41.4	39.6	36.0	31.0	26.3	23.9	24.9	28.8	33.9	38.2	40.7	41.7
−25	42.1	39.6	35.0	29.0	23.8	21.3	22.3	26.7	32.5	37.8	41.3	42.6
−30	42.5	39.3	33.7	26.9	21.2	18.5	19.7	24.3	30.9	37.2	41.5	43.3
−35	42.7	38.7	32.1	24.5	18.4	15.7	16.9	21.8	29.0	36.3	41.5	43.8
−40	42.7	37.8	30.3	22.0	15.6	12.8	14.0	19.2	27.0	35.1	41.3	44.0
−45	42.4	36.7	28.3	19.4	12.8	9.9	11.2	16.5	24.7	33.7	40.8	44.0
−50	41.9	35.3	26.1	16.6	9.9	7.1	8.3	13.6	22.2	32.0	40.1	43.8
−55	41.3	33.8	23.6	13.7	7.1	4.5	5.6	10.8	19.6	30.2	39.2	43.5
−60	40.6	32.1	21.0	10.8	4.4	2.1	3.1	7.9	16.8	28.1	38.3	43.2

METEO DATA "Bucuresti"

Latitude:44.4536^0,
Longitude:-26.0978^0,
Altitude :88 m,

Table IV.3

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2		h
Jan	41	147.6	18	64.8	23	82.8	106.3	382.8	0.39	1.32
Feb	55	198.0	25	90.0	30	108.0	138.0	496.9	0.40	1.96
Mar	89	320.4	41	147.6	48	172.8	215.5	775.6	0.41	2.87
Apr	133	478.8	71	255.6	63	226.8	274.8	989.3	0.48	4.43
May	168	604.8	91	327.6	76	273.6	334.5	1204.2	0.50	5.41
Jun	192	691.2	115	414.0	77	277.2	344.4	1239.8	0.56	6.40
Jul	196	705.6	118	424.8	78	280.8	345.3	1243.2	0.57	6.32
Aug	176	633.6	108	388.8	68	244.8	304.1	1094.8	0.58	5.68
Sep	122	439.2	69	248.4	54	194.4	233.4	840.2	0.52	4.06
Oct	84	302.4	44	158.4	40	144.0	172.1	619.4	0.49	2.71
Nov	42	151.2	18	64.8	24	86.4	114.0	410.4	0.37	1.40
Dec	28	100.8	11	39.6	18	64.8	94.2	339.3	0.30	0.90
Year	1322	4773.6	726	2613.6	597	2149.2	2676.7	9635.9	0.50	3.63

Table IV.4

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	88	2.4	225	40	0.56	-2.4
Feb	85	2.7	36	36	0.55	-0.1
Mar	78	2.8	36	38	0.54	4.8
Apr	75	2.6	36	46	0.47	11.3
May	74	2.1	36	70	0.45	16.7
Jun	76	1.7	36	77	0.40	20.2
Jul	74	1.6	36	64	0.40	22.0
Aug	73	1.4	36	58	0.39	21.2
Sep	73	1.5	36	42	0.44	16.9
Oct	78	1.7	36	32	0.48	10.8
Nov	87	2.2	225	49	0.57	5.2
Dec	90	2.2	225	43	0.64	0.2
Year	79	2.1	31	595	5.89	10.6

METEO DATA "Cluj-Napoca"

Latitude:46.47^0,
Longitude:-23.34^0,
Altitude :410 m,

Table IV.5

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m^2	KWh/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2		h
Jan	40	144.0	15	54.0	25	90.0	95.8	344.8	0.42	1.29
Feb	63	226.8	31	111.6	32	115.2	128.8	463.7	0.49	2.25
Mar	105	378.0	54	194.4	51	183.6	207.1	745.5	0.51	3.39
Apr	138	496.8	73	262.8	65	234.0	269.4	969.8	0.51	4.60
May	174	626.4	95	341.0	79	284.4	332.3	1196.4	0.52	5.61
Jun	143	514.8	54	194.4	88	316.8	344.1	1238.8	0.42	4.76
Jul	195	702.0	119	428.4	76	273.6	344.1	1238.8	0.57	6.29
Aug	175	630.0	111	399.6	63	226.8	299.8	1079.2	0.58	5.65
Sep	117	421.2	62	223.2	55	198.0	226.2	814.3	0.52	3.90
Oct	86	309.6	46	165.6	40	144.0	162.4	584.8	0.53	2.77
Nov	39	140.4	12	43.2	27	97.2	103.8	373.7	0.38	1.30
Dec	25	90.0	5	18.0	20	72.0	83.7	301.3	0.30	0.81
Year	1296	4665.6	676	2433.6	619	2228.4	2597.5	9351.0	0.50	3.55

Table IV.6

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	86	2.6	45	41	0.63	-3.3
Feb	80	2.6	45	30	0.51	-1.7
Mar	72	2.6	45	33	0.49	4.4
Apr	72	4.6	315	55	0.47	9.4
May	75	2.6	225	75	0.45	14.4
Jun	78	2.6	225	96	0.62	16.7
Jul	76	2.6	225	85	0.39	18.3
Aug	75	2.1	225	67	0.36	18.3
Sep	76	2.1	225	45	0.47	15.0
Oct	78	2.6	45	41	0.47	9.4
Nov	85	2.6	45	44	0.69	2.8
Dec	88	2.6	45	45	0.80	-1.1
Year	78	2.7	353	660	6.34	8.6

METEO DATA "Constanta"

Latitude: 44.13^0,
Longitude:- 28.38^0,
Altitude :13 m,

Table IV.7

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m²	KWh/m²	KWh/m²	MJ/m²	KWh/m²	MJ/m²	KWh/m²	MJ/m²		h
Jan	41	147.6	14	50.4	27	97.2	107.9	388.4	0.38	1.32
Feb	58	208.8	23	82.8	35	126.0	139.4	502.0	0.42	2.07
Mar	102	367.2	47	169.2	55	198.0	217.0	781.2	0.47	3.29
Apr	150	540.0	86	309.6	65	234.0	275.4	991.4	0.54	5.00
May	194	698.4	120	432.0	74	266.4	334.8	1205.3	0.58	6.26
Jun	204	734.4	130	468.0	74	266.4	344.4	1239.8	0.59	6.80
Jul	213	766.8	142	511.2	71	255.6	345.3	1243.2	0.62	6.87
Aug	188	676.8	125	450.0	63	226.8	304.7	1097.0	0.62	6.06
Sep	132	475.2	77	277.2	55	198.0	234.3	843.5	0.56	4.40
Oct	89	320.4	45	162.0	43	154.8	173.6	625.0	0.51	2.87
Nov	47	169.2	18	64.8	29	104.4	115.5	415.8	0.41	1.57
Dec	32	115.2	9	32.4	23	82.8	95.8	344.8	0.33	1.03
Year	1445	5202.0	833	2998.8	613	2206.8	2688.2	9677.4	0.54	3.96

Table IV.8

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	85	5.5	270	30	0.66	0.5
Feb	84	5.5	36	29	0.60	1.6
Mar	85	5.0	45	26	0.54	4.6
Apr	83	4.4	135	30	0.43	9.9
May	81	3.9	135	38	0.38	15.5
Jun	79	3.8	270	40	0.36	20.0
Jul	78	3.7	270	30	0.33	22.0
Aug	78	3.7	270	33	0.34	21.8
Sep	79	4.2	270	29	0.42	18.3
Oct	82	4.8	36	31	0.48	13.1
Nov	86	4.8	270	42	0.62	8.0
Dec	88	5.3	270	38	0.72	3.2
Year	82	4.6	291	396	5.88	11.5

METEO DATA "Craiova"

Latitude: 44.14^0,
Longitude:- 23.52^0,
Altitude :190 m,

Table IV.9

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m^2	KWh/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2		h
Jan	48	172.8	20	72.0	28	100.8	107.9	388.4	0.44	1.55
Feb	61	219.6	26	93.6	35	126.0	139.4	502.0	0.44	2.18
Mar	106	381.6	51	183.6	54	194.4	217.0	781.2	0.49	3.42
Apr	148	532.8	83	298.8	65	234.0	275.4	991.4	0.54	4.93
May	190	684.0	115	414.0	76	273.6	334.8	1205.3	0.57	6.13
Jun	173	622.8	89	320.4	84	302.4	344.4	1239.8	0.50	5.77
Jul	206	741.6	132	475.2	74	266.4	345.3	1243.2	0.60	6.65
Aug	165	594.0	94	338.4	72	259.2	304.7	1097.0	0.54	5.32
Sep	119	428.4	61	219.6	58	208.8	234.3	843.5	0.51	3.97
Oct	89	320.4	46	165.6	43	154.8	173.6	625.0	0.51	2.87
Nov	51	183.6	22	79.2	29	104.4	115.5	415.8	0.44	1.70
Dec	38	136.8	14	50.4	24	86.4	95.8	344.8	0.40	1.23
Year	1393	5014.8	749	2696.4	641	2307.6	2688.2	9677.4	0.52	3.98

Table IV.10

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	89	3.1	270	38	0.58	-2.3
Feb	85	3.6	90	39	0.57	-0.1
Mar	79	4.0	90	41	0.51	4.7
Apr	75	4.3	90	52	0.44	11.1
May	75	3.7	90	64	0.40	16.6
Jun	77	3.4	270	74	0.49	19.8
Jul	74	3.1	270	55	0.36	21.9
Aug	73	3.2	90	46	0.44	21.3
Sep	72	3.0	90	37	0.49	17.4
Oct	78	3.1	90	36	0.48	11.1
Nov	87	3.2	270	53	0.57	5.0
Dec	91	2.9	270	47	0.63	0.1
Year	80	3.4	90	582	5.96	10.6

METEO DATA "Galati"

Latitude: 45.3^0,
Longitude:- 28.01^0,
Altitude :71 m,

Table IV.11

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2		h
Jan	39	140.4	17	61.2	22	79.2	102.0	367.2	0.38	1.29
Feb	54	194.4	25	90.0	29	104.4	134.1	482.8	0.40	1.93
Mar	84	302.4	38	136.8	46	165.6	212.0	763.3	0.40	2.71
Apr	132	475.2	70	252.0	62	223.2	272.4	980.6	0.48	4.40
May	165	594.0	89	320.4	76	273.6	333.6	1200.8	0.49	5.32
Jun	187	673.2	109	392.4	78	280.8	344.4	1239.8	0.54	6.23
Jul	195	702.0	117	421.2	77	277.2	344.7	1241.0	0.57	6.29
Aug	176	633.6	109	392.4	67	241.2	302.3	1088.1	0.58	5.68
Sep	121	435.6	68	244.8	53	190.8	230.4	829.4	0.53	4.03
Oct	86	309.6	47	169.2	39	140.4	168.0	604.9	0.51	2.77
Nov	41	147.6	18	64.8	23	82.8	109.8	395.3	0.37	1.37
Dec	26	93.6	9	32.4	17	61.2	89.9	323.6	0.29	0.83
Year	1305	4701.6	715	2574	590	2124	2643.6	9517.0	0.50	42.8

Table IV.12

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d / \overline{H}$	Ta (^{0}C)
Jan	87	5.2	225	29	0.56	-2.5
Feb	84	5.3	36	32	0.54	-0.6
Mar	79	5.1	36	27	0.55	4.0
Apr	74	5.1	36	38	0.47	10.8
May	74	4.5	36	51	0.46	16.6
Jun	75	4.3	36	68	0.42	20.2
Jul	73	4.3	36	46	0.39	22.0
Aug	72	4.0	36	46	0.38	21.4
Sep	74	3.8	36	42	0.44	17.2
Oct	77	4.1	36	27	0.45	11.1
Nov	86	4.5	225	36	0.56	5.3
Dec	89	4.9	225	35	0.65	0.2
Year	79	4.6	31	477	5.88	10.5

METEO DATA "Iasi"

Latitude: 47.1^0,
Longitude:- 27.36^0,
Altitude :104 m,

Table IV.13

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m^2	KWh/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2	KWh/m^2	MJ/m^2		h
Jan	34	122.4	14	50.4	20	72.0	92.4	332.6	0.37	1.10
Feb	50	180.0	23	82.8	28	100.8	126.0	453.6	0.40	1.79
Mar	82	295.2	37	133.2	45	162.0	204.3	735.4	0.40	2.65
Apr	128	460.8	67	241.2	61	219.6	267.6	963.4	0.48	4.27
May	165	594.0	90	324.0	75	270.0	331.4	1193.0	0.50	5.32
Jun	189	680.4	111	399.6	78	280.8	343.8	1237.7	0.55	6.30
Jul	187	673.2	109	392.4	78	280.8	343.8	1237.6	0.54	6.03
Aug	174	626.4	107	385.2	67	241.2	298.5	1074.7	0.58	5.61
Sep	112	403.2	61	219.6	52	187.2	223.8	805.7	0.50	3.73
Oct	77	277.2	40	144.0	37	133.2	159.3	573.6	0.48	2.48
Nov	35	126.0	14	50.4	21	75.6	100.5	361.8	0.35	1.16
Dec	23	82.8	8	28.8	15	54.0	80.6	290.2	0.29	0.74
Year	1253	4510.8	679	2444.4	575	2070	2572.0	9259.3	0.49	3.43

Table IV.14

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	85	3.8	315	32	0.59	-3.7
Feb	85	4.2	315	31	0.56	-1.8
Mar	78	4.0	315	31	0.55	3.0
Apr	66	4.1	315	53	0.48	10.3
May	71	3.4	315	63	0.45	16.1
Jun	71	3.1	315	101	0.41	19.2
Jul	66	2.9	315	83	0.42	20.5
Aug	71	2.8	315	56	0.39	19.9
Sep	71	2.7	315	48	0.46	15.9
Oct	75	2.9	315	25	0.48	10.0
Nov	86	3.3	315	35	0.60	4.3
Dec	88	3.5	315	31	0.65	-0.6
Year	76	3.4	315	589	6.04	9.4

METEO DATA "Timisoara"

Latitude: 45.46^0,
Longitude:- 21.15^0,
Altitude: 86 m,

Table IV.15

Month	$\overline{H}$		$\overline{H}_b$		$\overline{H}_d$		$\overline{H}_{ext}$		$\overline{K}_t$	PSH
	KWh/m²	MJ/m²	KWh/m²	MJ/m²	KWh/m²	MJ/m²	KWh/m²	MJ/m²		h
Jan	33	118.8	13	46.8	20	72.0	101.1	363.8	0.33	1.07
Feb	53	190.8	24	86.4	29	104.4	133.6	480.8	0.40	1.89
Mar	99	356.4	51	183.6	48	172.8	211.4	761.1	0.47	3.19
Apr	134	482.4	72	259.2	62	223.2	272.1	979.6	0.49	4.47
May	178	640.8	102	367.2	76	273.6	333.3	1199.7	0.53	5.74
Jun	176	633.6	98	352.8	78	280.8	344.4	1239.8	0.51	5.87
Jul	193	694.8	115	414.0	78	280.8	344.7	1241.0	0.56	6.23
Aug	170	612.0	102	367.2	68	244.8	301.9	1087.0	0.56	5.48
Sep	120	432.0	67	241.2	53	190.8	229.8	827.3	0.52	4.00
Oct	78	280.8	40	144.0	38	136.8	167.4	602.6	0.47	2.51
Nov	39	140.4	16	57.6	23	82.8	108.9	392.0	0.36	1.30
Dec	29	104.4	11	39.6	18	64.8	89.0	320.3	0.33	0.94
Year	1296	4665.6	709	2552.4	890	3204	2637.5	9495.1	0.50	42.7

Table IV.16

Month	RH	WS (m/s)	WD (degrees)	RR (mm)	$\overline{H}_d/\overline{H}$	Ta (^{0}C)
Jan	91	2.0	315	40	0.61	-1.6
Feb	87	2.3	180	36	0.55	1.2
Mar	81	2.6	315	37	0.48	5.8
Apr	80	2.6	315	48	0.46	11.2
May	77	2.3	315	65	0.43	16.3
Jun	79	2.2	315	76	0.44	19.4
Jul	74	2.1	315	64	0.40	21.1
Aug	75	1.9	315	50	0.40	20.4
Sep	76	1.8	315	40	0.44	16.5
Oct	85	1.9	315	39	0.49	11.0
Nov	92	2.2	180	48	0.59	5.6
Dec	89	2.1	180	50	0.62	0.8
Year	82	2.2	297	593	5.91	10.6

Iasi

Latitude:47.1^0

Longitude: 27.36^0

Altitude: 104 m

Calculations for: a. the 22nd June: WT is from 6^{30}to 22^{30} for summer time or equivalent 5^{30} to 21^{30} for winter time which is the proper time to be used for WT

b. the 22nd December: WT is from 6^{30} to 18^{30}.

For 22.06 ⇒ n=173 and for 22.12 ⇒ n=356.

B	E	L_{st}	L_{loc}	WT*	WT	ST	ω	δ
For 22.06	(minutes)			Summer Time	Winter Time			
90.99	-1.70	30	27.36	6h30’	5h30’	5h18’	-100.50	23.45
90.99	-1.70	30	27.36	7h30’	6h30’	6h18’	-85.50	23.45
90.99	-1.70	30	27.36	8h30’	7h30’	7h18’	-70.50	23.45
90.99	-1.70	30	27.36	9h30’	8h30’	8h18’	-55.50	23.45
90.99	-1.70	30	27.36	10h30’	9h30’	9h18’	-40.50	23.45
90.99	-1.70	30	27.36	11h30’	10h30’	10h18’	-25.50	23.45
90.99	-1.70	30	27.36	12h30’	11h30’	11h18’	-10.50	23.45
90.99	-1.70	30	27.36	13h30’	12h30’	12h18’	4.50	23.45
90.99	-1.70	30	27.36	14h30’	13h30’	13h18’	19.50	23.45
90.99	-1.70	30	27.36	15h30’	14h30’	14h18’	34.50	23.45
90.99	-1.70	30	27.36	16h30’	15h30’	15h18’	49.50	23.45
90.99	-1.70	30	27.36	17h30’	16h30’	16h18’	64.50	23.45
90.99	-1.70	30	27.36	18h30’	17h30’	17h18’	79.50	23.45
90.99	-1.70	30	27.36	19h30’	18h30’	18h18’	94.50	23.45
90.99	*-1.70*	*30*	*27.36*	*20h30’*	*19h30’*	*19h18’*	*109.50*	*23.45*
90.99	*-1.70*	*30*	*27.36*	*21h30’*	*20h30’*	*20h18’*	*124.50*	*23.45*
90.99	*-1.70*	*30*	*27.36*	*22h30’*	*21h30’*	*21h18’*	*139.50*	*23.45*
For 22.12								
271.98	*0.62*	*30*	*27.36*		*6h30’*	*6h20’*	*-85.00*	*-23.45*
271.98	*0.62*	*30*	*27.36*		*7h30’*	*7h20’*	*-70.00*	*-23.45*
271.98	0.62	30	27.36		8h30’	8h20’	-55.00	-23.45
271.98	0.62	30	27.36		9h30’	9h20’	-40.00	-23.45
271.98	0.62	30	27.36		10h30’	10h20’	-25.00	-23.45
271.98	0.62	30	27.36		11h30’	11h20’	-10.00	-23.45
271.98	0.62	30	27.36		12h30’	12h20’	5.00	-23.45
271.98	0.62	30	27.36		13h30’	13h20’	20.00	-23.45
271.98	0.62	30	27.36		14h30’	14h20’	35.00	-23.45
271.98	0.62	30	27.36		15h30’	15h20’	50.00	-23.45
271.98	*0.62*	*30*	*27.36*		*16h30’*	*16h20’*	*65.00*	*-23.45*
271.98	*0.62*	*30*	*27.36*		*17h30’*	*17h20’*	*80.00*	*-23.45*
271.98	*0.62*	*30*	*27.36*		*18h30’*	*18h20’*	*95.00*	*-23.45*

* WT: Watch Time: the conventional time the watch shows.

For **β=0:** **$\cos\theta \equiv \cos\theta_z$**

$\omega_s \equiv \omega'_s$

$R_b=1$

φ	β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06								
47.1	10	117.84	109.18	6h30’	5h18’	0.1071	0.1779	0.6018
47.1	10	117.84	109.18	7h30’	6h18’	0.2978	0.3408	0.8740
47.1	10	117.84	109.18	8h30’	7h18’	0.4846	0.5002	0.9688
47.1	10	117.84	109.18	9h30’	8h18’	0.6547	0.6454	1.0144
47.1	10	117.84	109.18	10h30’	9h18’	0.7966	0.7665	1.0392
47.1	10	117.84	109.18	11h30’	10h18’	0.9006	0.8553	1.0529
47.1	10	117.84	109.18	12h30’	11h18’	0.9595	0.9056	1.0595
47.1	10	117.84	109.18	13h30’	12h18’	0.9695	0.9142	1.0606
47.1	10	117.84	109.18	14h30’	13h18’	0.9298	0.8803	1.0563
47.1	10	117.84	109.18	15h30’	14h18’	0.8432	0.8063	1.0457
47.1	10	117.84	109.18	16h30’	15h18’	0.7154	0.6973	1.0261
47.1	10	117.84	109.18	17h30’	16h18’	0.5553	0.5606	0.9906
47.1	10	117.84	109.18	18h30’	17h18’	0.3737	0.4056	0.9215
47.1	10	117.84	109.18	19h30’	18h18’	0.1830	0.2428	0.7539
47.1	10	117.84	109.18	20h30’	19h18’	-0.0038	0.0833	-0.0461*
47.1	10	117.84	109.18	21h30’	20h18’	-0.1741	-0.0621	2.8043**
47.1	10	117.84	109.18	22h30’	21h18’	-0.3162	-0.1834	1.7243**
For 22.12								
47.1	10	62.25	62.25	6h30’	6h20’	-0.1755	-0.2363	0.7425**
47.1	10	62.25	62.25	7h30’	7h20’	0.0109	-0.0772	-0.1418***
47.1	10	62.25	62.25	8h30’	8h20’	0.1803	0.0674	2.6759
47.1	10	62.25	62.25	9h30’	9h20’	0.3211	0.1875	1.7120
47.1	10	62.25	62.25	10h30’	10h20’	0.4236	0.2751	1.5399
47.1	10	62.25	62.25	11h30’	11h20’	0.4810	0.3241	1.4842
47.1	10	62.25	62.25	12h30’	12h20’	0.4893	0.3312	1.4775
47.1	10	62.25	62.25	13h30’	13h20’	0.4480	0.2959	1.5140
47.1	10	62.25	62.25	14h30’	14h20’	0.3599	0.2207	1.6308
47.1	10	62.25	62.25	15h30’	15h20’	0.2309	0.1106	2.0881
47.1	10	62.25	62.25	16h30’	16h20’	0.0699	-0.0269	-2.6012***
47.1	10	62.25	62.25	17h30’	17h20’	-0.1122	-0.1823	0.6155**
47.1	10	62.25	62.25	18h30’	18h20’	-0.3030	-0.3452	0.8778**

Cases	**cosθ**	**$\cos\theta_z$**	Observations
*	-	+	The sun is above the horizon. This combination implies that the sun faces the collector/PV-panel from the back surface. There is no sense to consider **R_b**.
**	-	-	The sun is below the horizon. **R_b** should not be taken into account.
***	+	-	The sun is below the horizon. Theoretically, the “sun beam” faces the collector since **cosθ>0.** **R_b** has no sense as no real beam impinges on.

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
15	117.84	105.82	6h30’	5h18’	0.0703	0.1779	0.3950
15	117.84	105.82	7h30’	6h18’	0.2729	0.3408	0.8007
15	117.84	105.82	8h30’	7h18’	0.4712	0.5002	0.9421
15	117.84	105.82	9h30’	8h18’	0.6519	0.6454	1.0100
15	117.84	105.82	10h30’	9h18’	0.8026	0.7665	1.0470
15	117.84	105.82	11h30’	10h18’	0.9130	0.8553	1.0675
15	117.84	105.82	12h30’	11h18’	0.9756	0.9056	1.0773
15	117.84	105.82	13h30’	12h18’	0.9862	0.9142	1.0788
15	117.84	105.82	14h30’	13h18’	0.9441	0.8803	1.0725
15	117.84	105.82	15h30’	14h18’	0.8521	0.8063	1.0567
15	117.84	105.82	16h30’	15h18’	0.7164	0.6973	1.0274
15	117.84	105.82	17h30’	16h18’	0.5463	0.5606	0.9746
15	117.84	105.82	18h30’	17h18’	0.3535	0.4056	0.8716
15	117.84	105.82	19h30’	18h18’	0.1509	0.2428	0.6217
15	*117.84*	*105.82*	*20h30’*	*19h18’*	*-0.0475*	*0.0833*	*-0.5706**
15	*117.84*	*105.82*	*21h30’*	*20h18’*	*-0.2283*	*-0.0621*	*3.6779***
15	*117.84*	*105.82*	*22h30’*	*21h18’*	*-0.3792*	*-0.1834*	*2.0681***
For 22.12							
15	*62.25*	*62.25*	*6h30’*	*6h20’*	*-0.1429*	*-0.2363*	*0.6048***
15	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.0551*	*-0.0772*	*-0.7132****
15	62.25	62.25	8h30’	8h20’	0.2349	0.0674	3.4866
15	62.25	62.25	9h30’	9h20’	0.3844	0.1875	2.0498
15	62.25	62.25	10h30’	10h20’	0.4933	0.2751	1.7934
15	62.25	62.25	11h30’	11h20’	0.5543	0.3241	1.7103
15	62.25	62.25	12h30’	12h20’	0.5631	0.3312	1.7003
15	62.25	62.25	13h30’	13h20’	0.5193	0.2959	1.7547
15	62.25	62.25	14h30’	14h20’	0.4256	0.2207	1.9288
15	62.25	62.25	15h30’	15h20’	0.2887	0.1106	2.6104
15	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.1177*	*-0.0269*	*-4.3789****
15	*62.25*	*62.25*	*17h30’*	*17h20’*	*-0.0757*	*-0.1823*	*0.4154***
15	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.2784*	*-0.3452*	*0.8064***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
20	117.84	102.86	6h30’	5h18’	0.0330	0.1779	0.1853
20	117.84	102.86	7h30’	6h18’	0.2458	0.3408	0.7214
20	117.84	102.86	8h30’	7h18’	0.4543	0.5002	0.9082
20	117.84	102.86	9h30’	8h18’	0.6441	0.6454	0.9980
20	117.84	102.86	10h30’	9h18’	0.8024	0.7665	1.0469
20	117.84	102.86	11h30’	10h18’	0.9185	0.8553	1.0739
20	117.84	102.86	12h30’	11h18’	0.9843	0.9056	1.0869
20	117.84	102.86	13h30’	12h18’	0.9955	0.9142	1.0889
20	117.84	102.86	14h30’	13h18’	0.9512	0.8803	1.0805
20	117.84	102.86	15h30’	14h18’	0.8545	0.8063	1.0597

continued

20	117.84	102.86	16h30’	15h18’	0.7119	0.6973	1.0210
20	117.84	102.86	17h30’	16h18’	0.5332	0.5606	0.9512
20	117.84	102.86	18h30’	17h18’	0.3305	0.4056	0.8150
20	117.84	102.86	19h30’	18h18’	0.1177	0.2428	0.4849
20	117.84	102.86	20h30’	19h18’	-0.0908	0.0833	-1.0908*
20	117.84	102.86	21h30’	20h18’	-0.2808	-0.0621	4.5235**
20	117.84	102.86	22h30’	21h18’	-0.4394	-0.1834	2.3962**
For 22.12							
20	62.25	62.25	6h30’	6h20’	-0.1093	-0.2363	0.4625**
20	62.25	62.25	7h30’	7h20’	0.0987	-0.0772	-1.2792***
20	62.25	62.25	8h30’	8h20’	0.2877	0.0674	4.2707
20	62.25	62.25	9h30’	9h20’	0.4448	0.1875	2.3720
20	62.25	62.25	10h30’	10h20’	0.5593	0.2751	2.0331
20	62.25	62.25	11h30’	11h20’	0.6234	0.3241	1.9234
20	62.25	62.25	12h30’	12h20’	0.6326	0.3312	1.9102
20	62.25	62.25	13h30’	13h20’	0.5865	0.2959	1.9820
20	62.25	62.25	14h30’	14h20’	0.4882	0.2207	2.2121
20	62.25	62.25	15h30’	15h20’	0.3442	0.1106	3.1128
20	62.25	62.25	16h30’	16h20’	0.1645	-0.0269	-6.1234***
20	62.25	62.25	17h30’	17h20’	-0.0387	-0.1823	0.2122**
20	62.25	62.25	18h30’	18h20’	-0.2516	-0.3452	0.7289**

β	ω_s	ω'_s	WT	ST	$\cos\theta$	$\cos\theta_z$	R_b
For 22.06							
25	117.84	100.18	6h30’	5h18’	-0.0046	0.1779	-0.0259*
25	117.84	100.18	7h30’	6h18’	0.2169	0.3408	0.6366
25	117.84	100.18	8h30’	7h18’	0.4339	0.5002	0.8674
25	117.84	100.18	9h30’	8h18’	0.6314	0.6454	0.9783
25	117.84	100.18	10h30’	9h18’	0.7962	0.7665	1.0387
25	117.84	100.18	11h30’	10h18’	0.9170	0.8553	1.0721
25	117.84	100.18	12h30’	11h18’	0.9855	0.9056	1.0882
25	117.84	100.18	13h30’	12h18’	0.9971	0.9142	1.0907
25	117.84	100.18	14h30’	13h18’	0.9510	0.8803	1.0803
25	117.84	100.18	15h30’	14h18’	0.8504	0.8063	1.0546
25	117.84	100.18	16h30’	15h18’	0.7020	0.6973	1.0068
25	117.84	100.18	17h30’	16h18’	0.5160	0.5606	0.9205
25	117.84	100.18	18h30’	17h18’	0.3051	0.4056	0.7523
25	117.84	100.18	19h30’	18h18’	0.0836	0.2428	0.3443
25	117.84	100.18	20h30’	19h18’	-0.1334	0.0833	-1.6026*
25	117.84	100.18	21h30’	20h18’	-0.3312	-0.0621	5.3347**
25	117.84	100.18	22h30’	21h18’	-0.4962	-0.1834	2.7061**
For 22.12							
25	62.25	62.25	6h30’	6h20’	-0.0748	-0.2363	0.3167**

continued

25	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.1417*	*-0.0772*	*-1.8355****
25	62.25	62.25	8h30’	8h20’	0.3384	0.0674	5.0223
25	62.25	62.25	9h30’	9h20’	0.5019	0.1875	2.6762
25	62.25	62.25	10h30’	10h20’	0.6210	0.2751	2.2575
25	62.25	62.25	11h30’	11h20’	0.6877	0.3241	2.1219
25	62.25	62.25	12h30’	12h20’	0.6973	0.3312	2.1055
25	62.25	62.25	13h30’	13h20’	0.6494	0.2959	2.1943
25	62.25	62.25	14h30’	14h20’	0.5470	0.2207	2.4786
25	62.25	62.25	15h30’	15h20’	0.3972	0.1106	3.5916
25	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.2102*	*-0.0269*	*-7.8213****
25	*62.25*	*62.25*	*17h30’*	*17h20’*	*-0.0014*	*-0.1823*	*0.0074***
25	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.2230*	*-0.3452*	*0.6459***

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
30	*117.84*	*97.71*	*6h30’*	*5h18’*	*-0.0421*	*0.1779*	*-0.2369**
30	117.84	97.71	7h30’	6h18’	0.1864	0.3408	0.5469
30	117.84	97.71	8h30’	7h18’	0.4102	0.5002	0.8200
30	117.84	97.71	9h30’	8h18’	0.6140	0.6454	0.9513
30	117.84	97.71	10h30’	9h18’	0.7840	0.7665	1.0227
30	117.84	97.71	11h30’	10h18’	0.9085	0.8553	1.0622
30	117.84	97.71	12h30’	11h18’	0.9792	0.9056	1.0812
30	117.84	97.71	13h30’	12h18’	0.9912	0.9142	1.0842
30	117.84	97.71	14h30’	13h18’	0.9436	0.8803	1.0719
30	117.84	97.71	15h30’	14h18’	0.8398	0.8063	1.0415
30	117.84	97.71	16h30’	15h18’	0.6867	0.6973	0.9849
30	117.84	97.71	17h30’	16h18’	0.4949	0.5606	0.8828
30	117.84	97.71	18h30’	17h18’	0.2773	0.4056	0.6838
30	117.84	97.71	19h30’	18h18’	0.0488	0.2428	0.2011
30	*117.84*	*97.71*	*20h30’*	*19h18’*	*-0.1750*	*0.0833*	*-2.1023**
30	*117.84*	*97.71*	*21h30’*	*20h18’*	*-0.3790*	*-0.0621*	*6.1054***
30	*117.84*	*97.71*	*22h30’*	*21h18’*	*-0.5493*	*-0.1834*	*2.9954***
For 22.12							
30	*62.25*	*62.25*	*6h30’*	*6h20’*	*-0.0398*	*-0.2363*	*0.1684***
30	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.1836*	*-0.0772*	*-2.3779****
30	62.25	62.25	8h30’	8h20’	0.3865	0.0674	5.7358
30	62.25	62.25	9h30’	9h20’	0.5551	0.1875	2.9600
30	62.25	62.25	10h30’	10h20’	0.6780	0.2751	2.4646
30	62.25	62.25	11h30’	11h20’	0.7468	0.3241	2.3042
30	62.25	62.25	12h30’	12h20’	0.7567	0.3312	2.2849
30	62.25	62.25	13h30’	13h20’	0.7072	0.2959	2.3899
30	62.25	62.25	14h30’	14h20’	0.6016	0.2207	2.7262
30	62.25	62.25	15h30’	15h20’	0.4471	0.1106	4.0431
30	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.2542*	*-0.0269*	*-9.4597****
30	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.0360*	*-0.1823*	*-0.1974****

30	*62.25*	*62.25*	*18h30'*	*18h20'*	*-0.1926*	*-0.3452*	*0.5579***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
35	*117.84*	*95.38*	*6h30'*	*5h18'*	*-0.0794*	*0.1779*	*-0.4460**
35	117.84	95.38	7h30'	6h18'	0.1544	0.3408	0.4531
35	117.84	95.38	8h30'	7h18'	0.3833	0.5002	0.7663
35	117.84	95.38	9h30'	8h18'	0.5918	0.6454	0.9170
35	117.84	95.38	10h30'	9h18'	0.7657	0.7665	0.9989
35	117.84	95.38	11h30'	10h18'	0.8932	0.8553	1.0443
35	117.84	95.38	12h30'	11h18'	0.9655	0.9056	1.0660
35	117.84	95.38	13h30'	12h18'	0.9777	0.9142	1.0695
35	117.84	95.38	14h30'	13h18'	0.9291	0.8803	1.0554
35	117.84	95.38	15h30'	14h18'	0.8228	0.8063	1.0205
35	117.84	95.38	16h30'	15h18'	0.6663	0.6973	0.9555
35	117.84	95.38	17h30'	16h18'	0.4700	0.5606	0.8385
35	117.84	95.38	18h30'	17h18'	0.2474	0.4056	0.6101
35	117.84	95.38	19h30'	18h18'	0.0137	0.2428	0.0564
35	*117.84*	*95.38*	*20h30'*	*19h18'*	*-0.2153*	*0.0833*	*-2.5861**
35	*117.84*	*95.38*	*21h30'*	*20h18'*	*-0.4240*	*-0.0621*	*6.8296***
35	*117.84*	*95.38*	*22h30'*	*21h18'*	*-0.5981*	*-0.1834*	*3.2619***
For 22.12							
35	*62.25*	*62.25*	*6h30'*	*6h20'*	*-0.0045*	*-0.2363*	*0.0189***
35	*62.25*	*62.25*	*7h30'*	*7h20'*	*0.2240*	*-0.0772*	*-2.9021****
35	62.25	62.25	8h30'	8h20'	0.4316	0.0674	6.4056
35	62.25	62.25	9h30'	9h20'	0.6041	0.1875	3.2214
35	62.25	62.25	10h30'	10h20'	0.7298	0.2751	2.6530
35	62.25	62.25	11h30'	11h20'	0.8002	0.3241	2.4690
35	62.25	62.25	12h30'	12h20'	0.8104	0.3312	2.4468
35	62.25	62.25	13h30'	13h20'	0.7597	0.2959	2.5673
35	62.25	62.25	14h30'	14h20'	0.6517	0.2207	2.9531
35	62.25	62.25	15h30'	15h20'	0.4936	0.1106	4.4638
35	*62.25*	*62.25*	*16h30'*	*16h20'*	*0.2963*	*-0.0269*	*-11.0262****
35	*62.25*	*62.25*	*17h30'*	*17h20'*	*0.0731*	*-0.1823*	*-0.4008****
35	*62.25*	*62.25*	*18h30'*	*18h20'*	*-0.1608*	*-0.3452*	*0.4657***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
40	*117.84*	*93.14*	*6h30'*	*5h18'*	*-0.1160*	*0.1779*	*-0.6518**
40	117.84	93.14	7h30'	6h18'	0.1213	0.3408	0.3559
40	117.84	93.14	8h30'	7h18'	0.3536	0.5002	0.7069
40	117.84	93.14	9h30'	8h18'	0.5652	0.6454	0.8757
40	117.84	93.14	10h30'	9h18'	0.7417	0.7665	0.9676
40	117.84	93.14	11h30'	10h18'	0.8710	0.8553	1.0184
40	117.84	93.14	12h30'	11h18'	0.9444	0.9056	1.0428
40	117.84	93.14	13h30'	12h18'	0.9568	0.9142	1.0466

continued

40	117.84	93.14	14h30’	13h18’	0.9074	0.8803	1.0308
40	117.84	93.14	15h30’	14h18’	0.7996	0.8063	0.9917
40	117.84	93.14	16h30’	15h18’	0.6407	0.6973	0.9189
40	117.84	93.14	17h30’	16h18’	0.4416	0.5606	0.7877
40	117.84	93.14	18h30’	17h18’	0.2157	0.4056	0.5318
40	*117.84*	*93.14*	*19h30’*	*18h18’*	*-0.0215*	*0.2428*	*-0.0887**
40	*117.84*	*93.14*	*20h30’*	*19h18’*	*-0.2539*	*0.0833*	*-3.0501**
40	*117.84*	*93.14*	*21h30’*	*20h18’*	*-0.4657*	*-0.0621*	*7.5019***
40	*117.84*	*93.14*	*22h30’*	*21h18’*	*-0.6425*	*-0.1834*	*3.5037***
For 22.12							
40	*62.25*	*62.25*	*6h30’*	*6h20’*	*0.0309*	*-0.2363*	*-0.1307****
40	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.2628*	*-0.0772*	*-3.4043****
40	62.25	62.25	8h30’	8h20’	0.4734	0.0674	7.0267
40	62.25	62.25	9h30’	9h20’	0.6485	0.1875	3.4582
40	62.25	62.25	10h30’	10h20’	0.7761	0.2751	2.8213
40	62.25	62.25	11h30’	11h20’	0.8475	0.3241	2.6150
40	62.25	62.25	12h30’	12h20’	0.8579	0.3312	2.5902
40	62.25	62.25	13h30’	13h20’	0.8065	0.2959	2.7252
40	62.25	62.25	14h30’	14h20’	0.6968	0.2207	3.1576
40	62.25	62.25	15h30’	15h20’	0.5364	0.1106	4.8506
40	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.3361*	*-0.0269*	*-12.5089****
40	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.1096*	*-0.1823*	*-0.6011****
40	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.1277*	*-0.3452*	*0.3700***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
45	*117.84*	*90.96*	*6h30’*	*5h18’*	*-0.1517*	*0.1779*	*-0.8526**
45	117.84	90.96	7h30’	6h18’	0.0872	0.3408	0.2559
45	117.84	90.96	8h30’	7h18’	0.3212	0.5002	0.6421
45	117.84	90.96	9h30’	8h18’	0.5343	0.6454	0.8278
45	117.84	90.96	10h30’	9h18’	0.7120	0.7665	0.9288
45	117.84	90.96	11h30’	10h18’	0.8422	0.8553	0.9847
45	117.84	90.96	12h30’	11h18’	0.9161	0.9056	1.0116
45	117.84	90.96	13h30’	12h18’	0.9286	0.9142	1.0158
45	117.84	90.96	14h30’	13h18’	0.8789	0.8803	0.9984
45	117.84	90.96	15h30’	14h18’	0.7703	0.8063	0.9554
45	117.84	90.96	16h30’	15h18’	0.6103	0.6973	0.8753
45	117.84	90.96	17h30’	16h18’	0.4098	0.5606	0.7310
45	117.84	90.96	18h30’	17h18’	0.1823	0.4056	0.4495
45	*117.84*	*90.96*	*19h30’*	*18h18’*	*-0.0566*	*0.2428*	*-0.2332**
45	*117.84*	*90.96*	*20h30’*	*19h18’*	*-0.2907*	*0.0833*	*-3.4910**
45	*117.84*	*90.96*	*21h30’*	*20h18’*	*-0.5039*	*-0.0621*	*8.1172***
45	*117.84*	*90.96*	*22h30’*	*21h18’*	*-0.6819*	*-0.1834*	*3.7188***
For 22.12							
45	*62.25*	*62.25*	*6h30’*	*6h20’*	*0.0660*	*-0.2363*	*-0.2794****

45	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.2996*	*-0.0772*	*-3.8806****

continued

45	62.25	62.25	8h30’	8h20’	0.5117	0.0674	7.5945
45	62.25	62.25	9h30’	9h20’	0.6880	0.1875	3.6688
45	62.25	62.25	10h30’	10h20’	0.8165	0.2751	2.9681
45	62.25	62.25	11h30’	11h20’	0.8884	0.3241	2.7412
45	62.25	62.25	12h30’	12h20’	0.8988	0.3312	2.7139
45	62.25	62.25	13h30’	13h20’	0.8471	0.2959	2.8624
45	62.25	62.25	14h30’	14h20’	0.7367	0.2207	3.3381
45	62.25	62.25	15h30’	15h20’	0.5751	0.1106	5.2005
45	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.3734*	*-0.0269*	*-13.8965***
45	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.1453*	*-0.1823*	*-0.7968****
45	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.0937*	*-0.3452*	*0.2715***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
50	*117.84*	*88.79*	*6h30’*	*5h18’*	*-0.1863*	*0.1779*	*-1.0470**
50	117.84	88.79	7h30’	6h18’	0.0525	0.3408	0.1540
50	117.84	88.79	8h30’	7h18’	0.2863	0.5002	0.5724
50	117.84	88.79	9h30’	8h18’	0.4993	0.6454	0.7735
50	117.84	88.79	10h30’	9h18’	0.6769	0.7665	0.8830
50	117.84	88.79	11h30’	10h18’	0.8070	0.8553	0.9436
50	117.84	88.79	12h30’	11h18’	0.8809	0.9056	0.9726
50	117.84	88.79	13h30’	12h18’	0.8934	0.9142	0.9773
50	117.84	88.79	14h30’	13h18’	0.8437	0.8803	0.9584
50	117.84	88.79	15h30’	14h18’	0.7352	0.8063	0.9118
50	117.84	88.79	16h30’	15h18’	0.5753	0.6973	0.8251
50	117.84	88.79	17h30’	16h18’	0.3748	0.5606	0.6687
50	117.84	88.79	18h30’	17h18’	0.1475	0.4056	0.3637
50	*117.84*	*88.79*	*19h30’*	*18h18’*	*-0.0912*	*0.2428*	*-0.3759**
50	*117.84*	*88.79*	*20h30’*	*19h18’*	*-0.3251*	*0.0833*	*-3.9053**
50	*117.84*	*88.79*	*21h30’*	*20h18’*	*-0.5383*	*-0.0621*	*8.6708***
50	*117.84*	*88.79*	*22h30’*	*21h18’*	*-0.7162*	*-0.1834*	*3.9056***
For 22.12							
50	*62.25*	*62.25*	*6h30’*	*6h20’*	*0.1007*	*-0.2363*	*-0.4259****
50	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.3340*	*-0.0772*	*-4.3274****
50	62.25	62.25	8h30’	8h20’	0.5461	0.0674	8.1044
50	62.25	62.25	9h30’	9h20’	0.7223	0.1875	3.8514
50	62.25	62.25	10h30’	10h20’	0.8507	0.2751	3.0923
50	62.25	62.25	11h30’	11h20’	0.9225	0.3241	2.8465
50	62.25	62.25	12h30’	12h20’	0.9329	0.3312	2.8169
50	62.25	62.25	13h30’	13h20’	0.8812	0.2959	2.9778
50	62.25	62.25	14h30’	14h20’	0.7709	0.2207	3.4931
50	62.25	62.25	15h30’	15h20’	0.6094	0.1106	5.5108

50	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.4078*	*-0.0269*	*-15.1784****
50	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.1799*	*-0.1823*	*-0.9865****
50	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.0590*	*-0.3452*	*0.1709***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
55	*117.84*	*86.60*	*6h30’*	*5h18’*	*-0.2195*	*0.1779*	*-1.2333**
55	117.84	86.60	*7h30’*	6h18’	0.0173	0.3408	0.0509
55	117.84	86.60	8h30’	7h18’	0.2493	0.5002	0.4983
55	117.84	86.60	9h30’	8h18’	0.4605	0.6454	0.7134
55	117.84	86.60	10h30’	9h18’	0.6366	0.7665	0.8305
55	117.84	86.60	11h30’	10h18’	0.7657	0.8553	0.8953
55	117.84	86.60	12h30’	11h18’	0.8389	0.9056	0.9264
55	117.84	86.60	13h30’	12h18’	0.8514	0.9142	0.9313
55	117.84	86.60	14h30’	13h18’	0.8021	0.8803	0.9111
55	117.84	86.60	15h30’	14h18’	0.6945	0.8063	0.8613
55	117.84	86.60	16h30’	15h18’	0.5359	0.6973	0.7685
55	117.84	86.60	17h30’	16h18’	0.3371	0.5606	0.6013
55	117.84	86.60	18h30’	17h18’	0.1116	0.4056	0.2752
55	*117.84*	*86.60*	*19h30’*	*18h18’*	*-0.1252*	*0.2428*	*-0.5157**
55	*117.84*	*86.60*	*20h30’*	*19h18’*	*-0.3572*	*0.0833*	*-4.2899**
55	*117.84*	*86.60*	*21h30’*	*20h18’*	*-0.5686*	*-0.0621*	*9.1584***
55	*117.84*	*86.60*	*22h30’*	*21h18’*	*-0.7450*	*-0.1834*	*4.0627***
For 22.12							
55	*62.25*	*62.25*	*6h30’*	*6h20’*	*0.1345*	*-0.2363*	*-0.5692****
55	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.3660*	*-0.0772*	*-4.7413****
55	62.25	62.25	8h30’	8h20’	0.5763	0.0674	8.5528
55	62.25	62.25	9h30’	9h20’	0.7510	0.1875	4.0048
55	62.25	62.25	10h30’	10h20’	0.8784	0.2751	3.1930
55	62.25	62.25	11h30’	11h20’	0.9496	0.3241	2.9302
55	62.25	62.25	12h30’	12h20’	0.9600	0.3312	2.8985
55	62.25	62.25	13h30’	13h20’	0.9087	0.2959	3.0706
55	62.25	62.25	14h30’	14h20’	0.7992	0.2207	3.6217
55	62.25	62.25	15h30’	15h20’	0.6391	0.1106	5.7793
55	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.4392*	*-0.0269*	*-16.3450****
55	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.2131*	*-0.1823*	*-1.1687****
55	*62.25*	*62.25*	*18h30’*	*18h20’*	*-0.0238*	*-0.3452*	*0.0690***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
60	*117.84*	*84.35*	*6h30’*	*5h18’*	*-0.2510*	*0.1779*	*-1.4103**
60	*117.84*	*84.35*	*7h30’*	*6h18’*	*-0.0179*	*0.3408*	*-0.0526**
60	117.84	84.35	8h30’	7h18’	0.2103	0.5002	0.4205
60	117.84	84.35	9h30’	8h18’	0.4182	0.6454	0.6479
60	117.84	84.35	10h30’	9h18’	0.5915	0.7665	0.7717

60	117.84	84.35	11h30’	10h18’	0.7186	0.8553	0.8401
60	117.84	84.35	12h30’	11h18’	0.7906	0.9056	0.8730
60	117.84	84.35	13h30’	12h18’	0.8028	0.9142	0.8782
60	117.84	84.35	14h30’	13h18’	0.7544	0.8803	0.8569

continued

60	117.84	84.35	15h30’	14h18’	0.6485	0.8063	0.8042
60	117.84	84.35	16h30’	15h18’	0.4924	0.6973	0.7062
60	117.84	84.35	17h30’	16h18’	0.2967	0.5606	0.5293
60	117.84	84.35	18h30’	17h18’	0.0748	0.4056	0.1846
60	117.84	84.35	19h30’	18h18’	-0.1582	0.2428	-0.6516*
60	117.84	84.35	20h30’	19h18’	-0.3865	0.0833	-4.6419*
60	117.84	84.35	21h30’	20h18’	-0.5945	-0.0621	9.5764**
60	117.84	84.35	22h30’	21h18’	-0.7681	-0.1834	4.1890**
For 22.12							
60	62.25	62.25	6h30’	6h20’	0.1674	-0.2363	-0.7082***
60	62.25	62.25	7h30’	7h20’	0.3952	-0.0772	-5.1192***
60	62.25	62.25	8h30’	8h20’	0.6021	0.0674	8.9361
60	62.25	62.25	9h30’	9h20’	0.7741	0.1875	4.1277
60	62.25	62.25	10h30’	10h20’	0.8994	0.2751	3.2695
60	62.25	62.25	11h30’	11h20’	0.9695	0.3241	2.9916
60	62.25	62.25	12h30’	12h20’	0.9797	0.3312	2.9581
60	62.25	62.25	13h30’	13h20’	0.9292	0.2959	3.1401
60	62.25	62.25	14h30’	14h20’	0.8215	0.2207	3.7227
60	62.25	62.25	15h30’	15h20’	0.6639	0.1106	6.0039
60	62.25	62.25	16h30’	16h20’	0.4672	-0.0269	-17.3872**
60	62.25	62.25	17h30’	17h20’	0.2447	-0.1823	-1.3420**
60	62.25	62.25	18h30’	18h20’	0.0116	-0.3452	-0.0335**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
70	117.84	79.49	6h30’	5h18’	-0.3080	0.1779	-1.7309*
70	117.84	79.49	7h30’	6h18’	-0.0877	0.3408	-0.2575*
70	117.84	79.49	8h30’	7h18’	0.1279	0.5002	0.2558
70	117.84	79.49	9h30’	8h18’	0.3244	0.6454	0.5026
70	117.84	79.49	10h30’	9h18’	0.4882	0.7665	0.6369
70	117.84	79.49	11h30’	10h18’	0.6083	0.8553	0.7112
70	117.84	79.49	12h30’	11h18’	0.6764	0.9056	0.7469
70	117.84	79.49	13h30’	12h18’	0.6879	0.9142	0.7525
70	117.84	79.49	14h30’	13h18’	0.6421	0.8803	0.7294
70	117.84	79.49	15h30’	14h18’	0.5420	0.8063	0.6722
70	117.84	79.49	16h30’	15h18’	0.3945	0.6973	0.5658
70	117.84	79.49	17h30’	16h18’	0.2096	0.5606	0.3739
70	117.84	79.49	18h30’	17h18’	-0.0001	0.4056	-0.0002*
70	117.84	79.49	19h30’	18h18’	-0.2203	0.2428	-0.9076*
70	117.84	79.49	20h30’	19h18’	-0.4361	0.0833	-5.2377*
70	117.84	79.49	21h30’	20h18’	-0.6327	-0.0621	10.1914**

70	117.84	79.49	22h30’	21h18’	-0.7968	-0.1834	4.3452**
For 22.12							
70	62.25	62.25	6h30’	6h20’	0.2290	-0.2363	-0.9690***
70	62.25	62.25	7h30’	7h20’	0.4443	-0.0772	-5.7556***

continued

70	62.25	62.25	8h30’	8h20’	0.6399	0.0674	9.4966
70	62.25	62.25	9h30’	9h20’	0.8024	0.1875	4.2787
70	62.25	62.25	10h30’	10h20’	0.9208	0.2751	3.3474
70	62.25	62.25	11h30’	11h20’	0.9871	0.3241	3.0458
70	62.25	62.25	12h30’	12h20’	0.9967	0.3312	3.0095
70	62.25	62.25	13h30’	13h20’	0.9490	0.2959	3.2070
70	62.25	62.25	14h30’	14h20’	0.8472	0.2207	3.8392
70	62.25	62.25	15h30’	15h20’	0.6983	0.1106	6.3146
70	62.25	62.25	16h30’	16h20’	0.5124	-0.0269	-19.0683***
70	62.25	62.25	17h30’	17h20’	0.3021	-0.1823	-1.6568***
70	62.25	62.25	18h30’	18h20’	0.0817	-0.3452	-0.2368***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
80	117.84	73.76	6h30’	5h18’	-0.3557	0.1779	-1.9989*
80	117.84	73.76	7h30’	6h18’	-0.1549	0.3408	-0.4546*
80	117.84	73.76	8h30’	7h18’	0.0417	0.500 2	0.0834
80	117.84	73.76	9h30’	8h18’	0.2208	0.645 4	0.3420
80	117.84	73.76	10h30’	9h18’	0.3701	0.766 5	0.4828
80	117.84	73.76	11h30’	10h18’	0.4796	0.855 3	0.5607
80	117.84	73.76	12h30’	11h18’	0.5416	0.905 6	0.5981
80	117.84	73.76	13h30’	12h18’	0.5522	0.9142	0.6040
80	117.84	73.76	14h30’	13h18’	0.5104	0.880 3	0.5798
80	117.84	73.76	15h30’	14h18’	0.4192	0.806 3	0.5198
80	117.84	73.76	16h30’	15h18’	0.2847	0.697 3	0.4083
80	117.84	73.76	17h30’	16h18’	0.1161	0.560 6	0.2072
80	117.84	73.76	18h30’	17h18’	-0.0750	0.4056	-0.1850*
80	117.84	73.76	19h30’	18h18’	-0.2758	0.2428	-1.1360*
80	117.84	73.76	20h30’	19h18’	-0.4724	0.0833	-5.6744*
80	117.84	73.76	21h30’	20h18’	-0.6517	-0.0621	10.4970**
80	117.84	73.76	22h30’	21h18’	-0.8012	-0.1834	4.3695**
For 22.12							
80	62.25	62.25	6h30’	6h20’	0.2837	-0.2363	-1.2003***
80	62.25	62.25	7h30’	7h20’	0.4799	-0.0772	-6.2173***

80	62.25	62.25	8h30’	8h20’	0.6582	0.0674	9.7688
80	62.25	62.25	9h30’	9h20’	0.8064	0.1875	4.2999
80	62.25	62.25	10h30’	10h20’	0.9143	0.2751	3.3237
80	62.25	62.25	11h30’	11h20’	0.9747	0.3241	3.0077
80	62.25	62.25	12h30’	12h20’	0.9835	0.3312	2.9696
80	62.25	62.25	13h30’	13h20’	0.9400	0.2959	3.1765
80	62.25	62.25	14h30’	14h20’	0.8472	0.2207	3.8392
80	62.25	62.25	15h30’	15h20’	0.7115	0.1106	6.4337
80	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.5420*	*-0.0269*	*-20.1705****
80	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.3503*	*-0.1823*	*-1.9212****
80	*62.25*	*62.25*	*18h30’*	*18h20’*	*0.1494*	*-0.3452*	*-0.4329****

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
90	*117.84*	*66.30*	*6h30’*	*5h18’*	*-0.3926*	*0.1779*	*-2.2063**
90	*117.84*	*66.30*	*7h30’*	*6h18’*	*-0.2174*	*0.3408*	*-0.6380**
90	*117.84*	*66.30*	*8h30’*	*7h18’*	*-0.0458*	*0.5002*	*-0.0916**
90	117.84	66.30	9h30’	8h18’	0.1104	0.6454	0.1711
90	117.84	66.30	10h30’	9h18’	0.2408	0.7665	0.3141
90	117.84	66.30	11h30’	10h18’	0.3363	0.8553	0.3931
90	117.84	66.30	12h30’	11h18’	0.3904	0.9056	0.4311
90	117.84	66.30	13h30’	12h18’	0.3996	0.9142	0.4371
90	117.84	66.30	14h30’	13h18’	0.3632	0.8803	0.4125
90	117.84	66.30	15h30’	14h18’	0.2836	0.8063	0.3517
90	117.84	66.30	16h30’	15h18’	0.1662	0.6973	0.2384
90	117.84	66.30	17h30’	16h18’	0.0191	0.5606	0.0341
90	*117.84*	*66.30*	*18h30’*	*17h18’*	*-0.1477*	*0.4056*	*-0.3641**
90	*117.84*	*66.30*	*19h30’*	*18h18’*	*-0.3228*	*0.2428*	*-1.3299**
90	*117.84*	*66.30*	*20h30’*	*19h18’*	*-0.4945*	*0.0833*	*-5.9389**
90	*117.84*	*66.30*	*21h30’*	*20h18’*	*-0.6509*	*-0.0621*	*10.4841***
90	*117.84*	*66.30*	*22h30’*	*21h18’*	*-0.7814*	*-0.1834*	*4.2612***
For 22.12							
90	*62.25*	*62.25*	*6h30’*	*6h20’*	*0.3298*	*-0.2363*	*-1.3953****
90	*62.25*	*62.25*	*7h30’*	*7h20’*	*0.5010*	*-0.0772*	*-6.4902****
90	62.25	62.25	8h30’	8h20’	0.6566	0.0674	9.7445
90	62.25	62.25	9h30’	9h20’	0.7858	0.1875	4.1905
90	62.25	62.25	10h30’	10h20’	0.8801	0.2751	3.1992
90	62.25	62.25	11h30’	11h20’	0.9328	0.3241	2.8782
90	62.25	62.25	12h30’	12h20’	0.9404	0.3312	2.8395
90	62.25	62.25	13h30’	13h20’	0.9025	0.2959	3.0497
90	62.25	62.25	14h30’	14h20’	0.8215	0.2207	3.7226
90	62.25	62.25	15h30’	15h20’	0.7031	0.1106	6.3575
90	*62.25*	*62.25*	*16h30’*	*16h20’*	*0.5551*	*-0.0269*	*-20.6605****
90	*62.25*	*62.25*	*17h30’*	*17h20’*	*0.3879*	*-0.1823*	*-2.1274****

90	*62.25*	*62.25*	*18h30'*	*18h20'*	*0.2126*	*-0.3452*	*-0.6159****

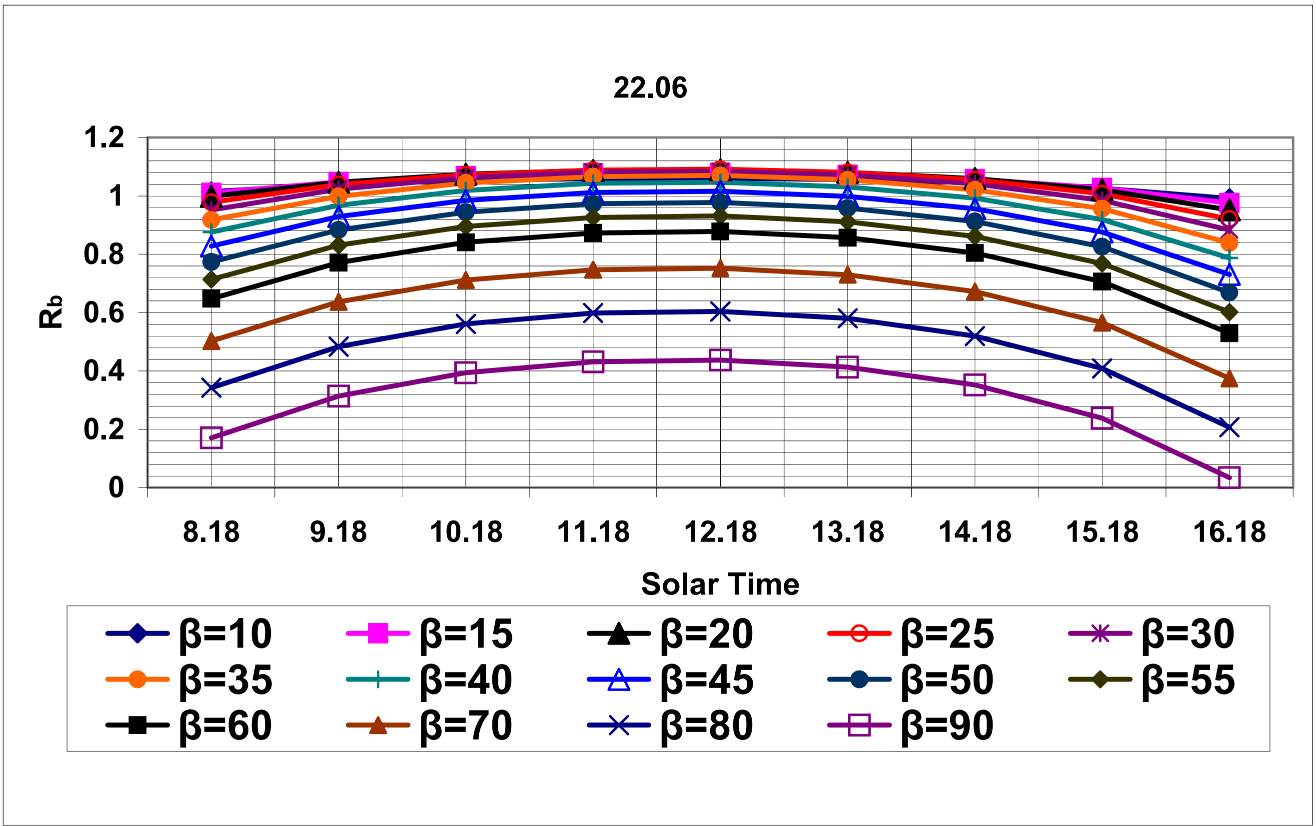

Figure IV.2: *The diagram of* R_b, *for* ***ST***, *at various* β. *This is for 22.06.*

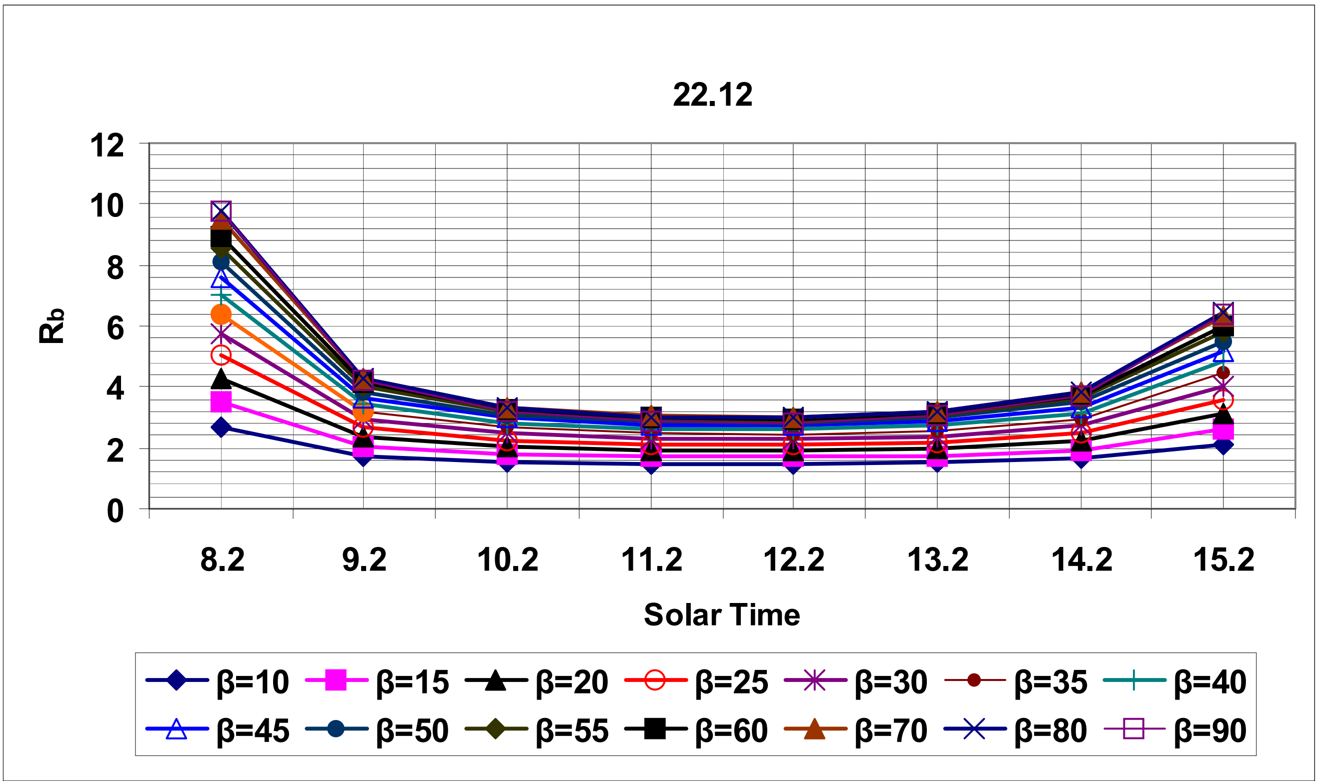

Figure IV.3: *The diagram of* R_b, *for* ***ST***, *at various* β. *This is for 22.12.*

Cluj-Napoca

Latitude: 46.47^0
Longitude: 23.34^0
Altitude: 410 m
Calculations for: a. the 22nd June: WT is from $6^{30}$to 22^{30} for summer time or equivalent 5^{30} to 21^{30} for winter time which is the proper time to be used for WT
b. the 22 nd December: WT is from 6^{30} to 18^{30}.

For 22.06 ⇒ n=173 and for 22.12 ⇒ n=356.

B	E	L_{st}	L_{loc}	WT	WT	ST	ω	δ
For 22.06	(minutes)			Summer Time	Winter Time			
90.99	-1.70	30	23.34	6h30’	5h30’	5h2’	-104.50	23.45
90.99	-1.70	30	23.34	7h30’	6h30’	6h2’	-89.50	23.45
90.99	-1.70	30	23.34	8h30’	7h30’	7h2’	-74.50	23.45
90.99	-1.70	30	23.34	9h30’	8h30’	8h2’	-59.50	23.45
90.99	-1.70	30	23.34	10h30’	9h30’	9h2’	-44.50	23.45
90.99	-1.70	30	23.34	11h30’	10h30’	10h2’	-29.50	23.45
90.99	-1.70	30	23.34	12h30’	11h30’	11h2’	-14.50	23.45
90.99	-1.70	30	23.34	13h30’	12h30’	12h2’	0.50	23.45
90.99	-1.70	30	23.34	14h30’	13h30’	13h2’	15.50	23.45
90.99	-1.70	30	23.34	15h30’	14h30’	14h2’	30.50	23.45
90.99	-1.70	30	23.34	16h30’	15h30’	15h2’	45.50	23.45
90.99	-1.70	30	23.34	17h30’	16h30’	16h2’	60.50	23.45
90.99	-1.70	30	23.34	18h30’	17h30’	17h2’	75.50	23.45
90.99	-1.70	30	23.34	19h30’	18h30’	18h2’	90.50	23.45
90.99	-1.70	30	23.34	20h30’	19h30’	19h2’	105.50	23.45
90.99	-1.70	30	23.34	21h30’	20h30’	20h2’	120.50	23.45
90.99	-1.70	30	23.34	22h30’	21h30’	21h2’	135.50	23.45
For 22.12								
271.98	0.62	30	23.34		6h30’	6h4’	-89.00	-23.45
271.98	0.62	30	23.34		7h30’	7h4’	-74.00	-23.45
271.98	0.62	30	23.34		8h30’	8h4’	-59.00	-23.45
271.98	0.62	30	23.34		9h30’	9h4’	-44.00	-23.45
271.98	0.62	30	23.34		10h30’	10h4’	-29.00	-23.45
271.98	0.62	30	23.34		11h30’	11h4’	-14.00	-23.45
271.98	0.62	30	23.34		12h30’	12h4’	1.00	-23.45
271.98	0.62	30	23.34		13h30’	13h4’	16.00	-23.45
271.98	0.62	30	23.34		14h30’	14h4’	31.00	-23.45
271.98	0.62	30	23.34		15h30’	15h4’	46.00	-23.45
271.98	0.62	30	23.34		16h30’	16h4’	61.00	-23.45
271.98	0.62	30	23.34		17h30’	17h4’	76.00	-23.45
271.98	0.62	30	23.34		18h30’	18h4’	91.00	-23.45

φ	β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06								
46.47	10	117.19	108.73	6h30’	5h2’	0.0522	0.1305	0.3999
46.47	10	117.19	108.73	7h30’	6h2’	0.2433	0.2943	0.8269
46.47	10	117.19	108.73	8h30’	7h2’	0.4340	0.4576	0.9484
46.47	10	117.19	108.73	9h30’	8h2’	0.6112	0.6094	1.0030
46.47	10	117.19	108.73	10h30’	9h2’	0.7629	0.7393	1.0319
46.47	10	117.19	108.73	11h30’	10h2’	0.8787	0.8386	1.0479
46.47	10	117.19	108.73	12h30’	11h2’	0.9508	0.9003	1.0561
46.47	10	117.19	108.73	13h30’	12h2’	0.9743	0.9204	1.0585
46.47	10	117.19	108.73	14h30’	13h2’	0.9475	0.8975	1.0557
46.47	10	117.19	108.73	15h30’	14h2’	0.8723	0.8331	1.0471
46.47	10	117.19	108.73	16h30’	15h2’	0.7538	0.7316	1.0304
46.47	10	117.19	108.73	17h30’	16h2’	0.6001	0.5999	1.0004
46.47	10	117.19	108.73	18h30’	17h2’	0.4216	0.4470	0.9432
46.47	10	117.19	108.73	19h30’	18h2’	0.2305	0.2833	0.8137
6.47	10	117.19	108.73	20h30’	19h2’	0.0398	0.1199	0.3317
46.47	*10*	*117.19*	*108.73*	*21h30’*	*20h2’*	*-0.1376*	*-0.0320*	*4.2977***
46.47	*10*	*117.19*	*108.73*	*22h30’*	*21h2’*	*-0.2894*	*-0.1621*	*1.7854***
For 22.12								
46.47	*10*	*62.90*	*62.90*	*6h30’*	*6h4’*	*-0.2229*	*-0.2767*	*0.8053***
46.47	*10*	*62.90*	*62.90*	*7h30’*	*7h4’*	*-0.0324*	*-0.1136*	*0.2855***
46.47	10	62.90	62.90	8h30’	8h4’	0.1441	0.0376	3.8312
46.47	10	62.90	62.90	9h30’	9h4’	0.2947	0.1667	1.7686
46.47	10	62.90	62.90	10h30’	10h4’	0.4092	0.2647	1.5458
46.47	10	62.90	62.90	11h30’	11h4’	0.4798	0.3252	1.4755
46.47	10	62.90	62.90	12h30’	12h4’	0.5016	0.3438	1.4588
46.47	10	62.90	62.90	13h30’	13h4’	0.4731	0.3194	1.4810
46.47	10	62.90	62.90	14h30’	14h4’	0.3964	0.2537	1.5623
46.47	10	62.90	62.90	15h30’	15h4’	0.2765	0.1511	1.8306
46.47	10	62.90	62.90	16h30’	16h4’	0.1218	0.0185	6.5779
46.47	*10*	*62.90*	*62.90*	*17h30’*	*17h4’*	*-0.0573*	*-0.1349*	*0.4248***
46.47	*10*	*62.90*	*62.90*	*18h30’*	*18h4’*	*-0.2486*	*-0.2988*	*0.8321***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
15	117.19	105.43	6h30’	5h2’	0.0123	0.1305	0.0941
15	117.19	105.43	7h30’	6h2’	0.2150	0.2943	0.7306
15	117.19	105.43	8h30’	7h2’	0.4172	0.4576	0.9117
15	117.19	105.43	9h30’	8h2’	0.6051	0.6094	0.9930
15	117.19	105.43	10h30’	9h2’	0.7660	0.7393	1.0361
15	117.19	105.43	11h30’	10h2’	0.8889	0.8386	1.0600
15	117.19	105.43	12h30’	11h2’	0.9653	0.9003	1.0722
15	117.19	105.43	13h30’	12h2’	0.9902	0.9204	1.0758
15	117.19	105.43	14h30’	13h2’	0.9618	0.8975	1.0717
15	117.19	105.43	15h30’	14h2’	0.8820	0.8331	1.0588
15	117.19	105.43	16h30’	15h2’	0.7564	0.7316	1.0339
15	117.19	105.43	17h30’	16h2’	0.5933	0.5999	0.9891
15	117.19	105.43	18h30’	17h2’	0.4040	0.4470	0.9039
15	117.19	105.43	19h30’	18h2’	0.2014	0.2833	0.7108
15	*117.19*	*105.43*	*20h30’*	*19h2’*	*-0.0009*	*0.1199*	*-0.0075**
15	*117.19*	*105.43*	*21h30’*	*20h2’*	*-0.1890*	*-0.0320*	*5.9037***
15	*117.19*	*105.43*	*22h30’*	*21h2’*	*-0.3500*	*-0.1621*	*2.1593***
For 22.12							
15	*62.90*	*62.90*	*6h30’*	*6h4’*	*-0.1933*	*-0.2767*	*0.6984***
15	*62.90*	*62.90*	*7h30’*	*7h4’*	*0.0087*	*-0.1136*	*-0.0763****
15	62.90	62.90	8h30’	8h4’	0.1959	0.0376	5.2084
15	62.90	62.90	9h30’	9h4’	0.3557	0.1667	2.1341
15	62.90	62.90	10h30’	10h4’	0.4771	0.2647	1.8022
15	62.90	62.90	11h30’	11h4’	0.5519	0.3252	1.6973
15	62.90	62.90	12h30’	12h4’	0.5750	0.3438	1.6724
15	62.90	62.90	13h30’	13h4’	0.5448	0.3194	1.7055
15	62.90	62.90	14h30’	14h4’	0.4634	0.2537	1.8267
15	62.90	62.90	15h30’	15h4’	0.3364	0.1511	2.2266
15	62.90	62.90	16h30’	16h4’	0.1723	0.0185	9.3024
15	*62.90*	*62.90*	*17h30’*	*17h4’*	*-0.0177*	*-0.1349*	*0.1312***
15	*62.90*	*62.90*	*18h30’*	*18h4’*	*-0.2206*	*-0.2988*	*0.7383***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
20	*117.19*	*102.51*	*6h30’*	*5h2’*	*-0.0277*	*0.1305*	*-0.2123**
20	117.19	102.51	7h30’	6h2’	0.1850	0.2943	0.6287
20	117.19	102.51	8h30’	7h2’	0.3972	0.4576	0.8681

20	117.19	102.51	9h30’	8h2’	0.5945	0.6094	0.9755
20	117.19	102.51	10h30’	9h2’	0.7633	0.7393	1.0324
20	117.19	102.51	11h30’	10h2’	0.8922	0.8386	1.0640
20	117.19	102.51	12h30’	11h2’	0.9725	0.9003	1.0801
20	117.19	102.51	13h30’	12h2’	0.9986	0.9204	1.0849
20	117.19	102.51	14h30’	13h2’	0.9688	0.8975	1.0794

continued

20	117.19	102.51	15h30’	14h2’	0.8851	0.8331	1.0624
20	117.19	102.51	16h30’	15h2’	0.7532	0.7316	1.0296
20	117.19	102.51	17h30’	16h2’	0.5821	0.5999	0.9703
20	117.19	102.51	18h30’	17h2’	0.3834	0.4470	0.8578
20	117.19	102.51	19h30’	18h2’	0.1707	0.2833	0.6026
20	117.19	102.51	20h30’	19h2’	-0.0416	0.1199	-0.3467*
20	117.19	102.51	21h30’	20h2’	-0.2389	-0.0320	7.4649**
20	117.19	102.51	22h30’	21h2’	-0.4080	-0.1621	2.5167**
For 22.12							
20	62.90	62.90	6h30’	6h4’	-0.1622	-0.2767	0.5862**
20	62.90	62.90	7h30’	7h4’	0.0497	-0.1136	-0.4376***
20	62.90	62.90	8h30’	8h4’	0.2462	0.0376	6.5461
20	62.90	62.90	9h30’	9h4’	0.4139	0.1667	2.4834
20	62.90	62.90	10h30’	10h4’	0.5413	0.2647	2.0448
20	62.90	62.90	11h30’	11h4’	0.6198	0.3252	1.9062
20	62.90	62.90	12h30’	12h4’	0.6441	0.3438	1.8733
20	62.90	62.90	13h30’	13h4’	0.6124	0.3194	1.9171
20	62.90	62.90	14h30’	14h4’	0.5270	0.2537	2.0772
20	62.90	62.90	15h30’	15h4’	0.3936	0.1511	2.6056
20	62.90	62.90	16h30’	16h4’	0.2214	0.0185	11.9561
20	62.90	62.90	17h30’	17h4’	0.0220	-0.1349	-0.1634***
20	62.90	62.90	18h30’	18h4’	-0.1909	-0.2988	0.6389**

β	ω_s	ω'_s	WT	ST	$\cos\theta$	$\cos\theta_z$	R_b
For 22.06							
25	117.19	99.86	6h30’	5h2’	-0.0675	0.1305	-0.5172*
25	117.19	99.86	7h30’	6h2’	0.1536	0.2943	0.5221
25	117.19	99.86	8h30’	7h2’	0.3742	0.4576	0.8178
25	117.19	99.86	9h30’	8h2’	0.5793	0.6094	0.9506
25	117.19	99.86	10h30’	9h2’	0.7548	0.7393	1.0209
25	117.19	99.86	11h30’	10h2’	0.8888	0.8386	1.0599
25	117.19	99.86	12h30’	11h2’	0.9722	0.9003	1.0799
25	117.19	99.86	13h30’	12h2’	0.9994	0.9204	1.0858
25	117.19	99.86	14h30’	13h2’	0.9684	0.8975	1.0790
25	117.19	99.86	15h30’	14h2’	0.8814	0.8331	1.0580
25	117.19	99.86	16h30’	15h2’	0.7443	0.7316	1.0174
25	117.19	99.86	17h30’	16h2’	0.5664	0.5999	0.9442
25	117.19	99.86	18h30’	17h2’	0.3599	0.4470	0.8051
25	117.19	99.86	19h30’	18h2’	0.1387	0.2833	0.4898

25	117.19	99.86	20h30’	19h2’	-0.0819	0.1199	-0.6832*
25	117.19	99.86	21h30’	20h2’	-0.2871	-0.0320	8.9693**
25	117.19	99.86	22h30’	21h2’	-0.4628	-0.1621	2.8550**
For 22.12							
25	62.90	62.90	6h30’	6h4’	-0.1299	-0.2767	0.4695**
25	62.90	62.90	7h30’	7h4’	0.0904	-0.1136	-0.7955***

continued

25	62.90	62.90	8h30’	8h4’	0.2947	0.0376	7.8340
25	62.90	62.90	9h30’	9h4’	0.4690	0.1667	2.8139
25	62.90	62.90	10h30’	10h4’	0.6014	0.2647	2.2718
25	62.90	62.90	11h30’	11h4’	0.6830	0.3252	2.1007
25	62.90	62.90	12h30’	12h4’	0.7082	0.3438	2.0599
25	62.90	62.90	13h30’	13h4’	0.6753	0.3194	2.1141
25	62.90	62.90	14h30’	14h4’	0.5865	0.2537	2.3119
25	62.90	62.90	15h30’	15h4’	0.4479	0.1511	2.9649
25	62.90	62.90	16h30’	16h4’	0.2689	0.0185	14.5190
25	62.90	62.90	17h30’	17h4’	0.0616	-0.1349	-0.4567***
25	62.90	62.90	18h30’	18h4’	-0.1597	-0.2988	0.5346**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
30	117.19	97.41	6h30’	5h2’	-0.1068	0.1305	-0.8181*
30	117.19	97.41	7h30’	6h2’	0.1211	0.2943	0.4115
30	117.19	97.41	8h30’	7h2’	0.3484	0.4576	0.7614
30	117.19	97.41	9h30’	8h2’	0.5597	0.6094	0.9184
30	117.19	97.41	10h30’	9h2’	0.7405	0.7393	1.0016
30	117.19	97.41	11h30’	10h2’	0.8786	0.8386	1.0478
30	117.19	97.41	12h30’	11h2’	0.9646	0.9003	1.0714
30	117.19	97.41	13h30’	12h2’	0.9926	0.9204	1.0784
30	117.19	97.41	14h30’	13h2’	0.9606	0.8975	1.0704
30	117.19	97.41	15h30’	14h2’	0.8710	0.8331	1.0455
30	117.19	97.41	16h30’	15h2’	0.7297	0.7316	0.9974
30	117.19	97.41	17h30’	16h2’	0.5464	0.5999	0.9109
30	117.19	97.41	18h30’	17h2’	0.3336	0.4470	0.7463
30	117.19	97.41	19h30’	18h2’	0.1057	0.2833	0.3733
30	117.19	97.41	20h30’	19h2’	-0.1216	0.1199	-1.0145*
30	117.19	97.41	21h30’	20h2’	-0.3331	-0.0320	10.4055**
30	117.19	97.41	22h30’	21h2’	-0.5141	-0.1621	3.1716**
For 22.12							
30	62.90	62.90	6h30’	6h4’	-0.0967	-0.2767	0.3493**
30	62.90	62.90	7h30’	7h4’	0.1304	-0.1136	-1.1474***
30	62.90	62.90	8h30’	8h4’	0.3409	0.0376	9.0623
30	62.90	62.90	9h30’	9h4’	0.5205	0.1667	3.1229
30	62.90	62.90	10h30’	10h4’	0.6570	0.2647	2.4816
30	62.90	62.90	11h30’	11h4’	0.7411	0.3252	2.2791

30	62.90	62.90	12h30’	12h4’	0.7670	0.3438	2.2309
30	62.90	62.90	13h30’	13h4’	0.7331	0.3194	2.2950
30	62.90	62.90	14h30’	14h4’	0.6416	0.2537	2.5290
30	62.90	62.90	15h30’	15h4’	0.4988	0.1511	3.3016
30	62.90	62.90	16h30’	16h4’	0.3143	0.0185	16.9714
30	62.90	62.90	17h30’	17h4’	0.1007	-0.1349	-0.7466***
30	62.90	62.90	18h30’	18h4’	-0.1274	-0.2988	0.4263**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
35	117.19	95.09	6h30’	5h2’	-0.1453	0.1305	-1.1128*
35	117.19	95.09	7h30’	6h2’	0.0876	0.2943	0.2977
35	117.19	95.09	8h30’	7h2’	0.3199	0.4576	0.6991
35	117.19	95.09	9h30’	8h2’	0.5358	0.6094	0.8793
35	117.19	95.09	10h30’	9h2’	0.7206	0.7393	0.9747
35	117.19	95.09	11h30’	10h2’	0.8618	0.8386	1.0277
35	117.19	95.09	12h30’	11h2’	0.9496	0.9003	1.0548
35	117.19	95.09	13h30’	12h2’	0.9782	0.9204	1.0628
35	117.19	95.09	14h30’	13h2’	0.9456	0.8975	1.0536
35	117.19	95.09	15h30’	14h2’	0.8539	0.8331	1.0251
35	117.19	95.09	16h30’	15h2’	0.7096	0.7316	0.9699
35	117.19	95.09	17h30’	16h2’	0.5223	0.5999	0.8706
35	117.19	95.09	18h30’	17h2’	0.3048	0.4470	0.6819
35	117.19	95.09	19h30’	18h2’	0.0719	0.2833	0.2539
35	117.19	95.09	20h30’	19h2’	-0.1604	0.1199	-1.3381*
35	117.19	95.09	21h30’	20h2’	-0.3765	-0.0320	11.7626**
35	117.19	95.09	22h30’	21h2’	-0.5615	-0.1621	3.4640**
For 22.12							
35	62.90	62.90	6h30’	6h4’	-0.0627	-0.2767	0.2264**
35	62.90	62.90	7h30’	7h4’	0.1694	-0.1136	-1.4906***
35	62.90	62.90	8h30’	8h4’	0.3845	0.0376	10.2217
35	62.90	62.90	9h30’	9h4’	0.5680	0.1667	3.4083
35	62.90	62.90	10h30’	10h4’	0.7075	0.2647	2.6726
35	62.90	62.90	11h30’	11h4’	0.7934	0.3252	2.4402
35	62.90	62.90	12h30’	12h4’	0.8200	0.3438	2.3850
35	62.90	62.90	13h30’	13h4’	0.7853	0.3194	2.4584
35	62.90	62.90	14h30’	14h4’	0.6918	0.2537	2.7269
35	62.90	62.90	15h30’	15h4’	0.5458	0.1511	3.6132
35	62.90	62.90	16h30’	16h4’	0.3573	0.0185	19.2949
35	62.90	62.90	17h30’	17h4’	0.1391	-0.1349	-1.0307***
35	62.90	62.90	18h30’	18h4’	-0.0940	-0.2988	0.3147**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
40	117.19	92.86	6h30’	5h2’	-0.1826	0.1305	-1.3991*

40	117.19	92.86	7h30’	6h2’	0.0535	0.2943	0.1817
40	117.19	92.86	8h30’	7h2’	0.2890	0.4576	0.6316
40	117.19	92.86	9h30’	8h2’	0.5079	0.6094	0.8334
40	117.19	92.86	10h30’	9h2’	0.6953	0.7393	0.9404
40	117.19	92.86	11h30’	10h2’	0.8384	0.8386	0.9998
40	117.19	92.86	12h30’	11h2’	0.9274	0.9003	1.0301
40	117.19	92.86	13h30’	12h2’	0.9564	0.9204	1.0391

continued

40	117.19	92.86	14h30’	13h2’	0.9233	0.8975	1.0288
40	117.19	92.86	15h30’	14h2’	0.8304	0.8331	0.9968
40	117.19	92.86	16h30’	15h2’	0.6840	0.7316	0.9351
40	117.19	92.86	17h30’	16h2’	0.4941	0.5999	0.8238
40	117.19	92.86	18h30’	17h2’	0.2736	0.4470	0.6122
40	117.19	92.86	19h30’	18h2’	0.0376	0.2833	0.1326
40	*117.19*	*92.86*	*20h30’*	*19h2’*	*-0.1980*	*0.1199*	*-1.6516**
40	*117.19*	*92.86*	*21h30’*	*20h2’*	*-0.4171*	*-0.0320*	*13.0302***
40	*117.19*	*92.86*	*22h30’*	*21h2’*	*-0.6047*	*-0.1621*	*3.7302***
For 22.12							
40	*62.90*	*62.90*	*6h30’*	*6h4’*	*-0.0282*	*-0.2767*	*0.1018***
40	*62.90*	*62.90*	*7h30’*	*7h4’*	*0.2071*	*-0.1136*	*-1.8224****
40	62.90	62.90	8h30’	8h4’	0.4251	0.0376	11.3034
40	62.90	62.90	9h30’	9h4’	0.6112	0.1667	3.6677
40	62.90	62.90	10h30’	10h4’	0.7527	0.2647	2.8432
40	62.90	62.90	11h30’	11h4’	0.8398	0.3252	2.5828
40	62.90	62.90	12h30’	12h4’	0.8667	0.3438	2.5209
40	62.90	62.90	13h30’	13h4’	0.8316	0.3194	2.6032
40	62.90	62.90	14h30’	14h4’	0.7368	0.2537	2.9040
40	62.90	62.90	15h30’	15h4’	0.5888	0.1511	3.8973
40	62.90	62.90	16h30’	16h4’	0.3976	0.0185	21.4716
40	*62.90*	*62.90*	*17h30’*	*17h4’*	*0.1763*	*-0.1349*	*-1.3071****
40	*62.90*	*62.90*	*18h30’*	*18h4’*	*-0.0600*	*-0.2988*	*0.2007***

β	ω_s	ω'_s	WT	ST	$\cos\theta$	$\cos\theta_z$	R_b
For 22.06							
45	*117.19*	*90.68*	*6h30’*	*5h2’*	*-0.2186*	*0.1305*	*-1.6747**
45	117.19	90.68	7h30’	6h2’	0.0189	0.2943	0.0643
45	117.19	90.68	8h30’	7h2’	0.2559	0.4576	0.5592
45	117.19	90.68	9h30’	8h2’	0.4761	0.6094	0.7813
45	117.19	90.68	10h30’	9h2’	0.6646	0.7393	0.8990
45	117.19	90.68	11h30’	10h2’	0.8086	0.8386	0.9643
45	117.19	90.68	12h30’	11h2’	0.8982	0.9003	0.9976
45	117.19	90.68	13h30’	12h2’	0.9274	0.9204	1.0075
45	117.19	90.68	14h30’	13h2’	0.8941	0.8975	0.9962
45	117.19	90.68	15h30’	14h2’	0.8006	0.8331	0.9610
45	117.19	90.68	16h30’	15h2’	0.6533	0.7316	0.8931
45	117.19	90.68	17h30’	16h2’	0.4623	0.5999	0.7706

45	117.19	90.68	18h30’	17h2’	0.2404	0.4470	0.5379
45	117.19	90.68	19h30’	18h2’	0.0029	0.2833	0.0103
45	117.19	90.68	20h30’	19h2’	-0.2341	0.1199	-1.9524*
45	117.19	90.68	21h30’	20h2’	-0.4545	-0.0320	14.1989**
45	117.19	90.68	22h30’	21h2’	-0.6432	-0.1621	3.9679**
For 22.12							
45	62.90	62.90	6h30’	6h4’	0.0065	-0.2767	-0.0236***

continued

45	62.90	62.90	7h30’	7h4’	0.2432	-0.1136	-2.1404***
45	62.90	62.90	8h30’	8h4’	0.4626	0.0376	12.2992
45	62.90	62.90	9h30’	9h4’	0.6498	0.1667	3.8992
45	62.90	62.90	10h30’	10h4’	0.7921	0.2647	2.9921
45	62.90	62.90	11h30’	11h4’	0.8798	0.3252	2.7057
45	62.90	62.90	12h30’	12h4’	0.9069	0.3438	2.6376
45	62.90	62.90	13h30’	13h4’	0.8715	0.3194	2.7281
45	62.90	62.90	14h30’	14h4’	0.7761	0.2537	3.0591
45	62.90	62.90	15h30’	15h4’	0.6272	0.1511	4.1518
45	62.90	62.90	16h30’	16h4’	0.4349	0.0185	23.4851
45	62.90	62.90	17h30’	17h4’	0.2123	-0.1349	-1.5735***
45	62.90	62.90	18h30’	18h4’	-0.0255	-0.2988	0.0852**

β	ω_s	ω'_s	WT	ST	$\cos\theta$	$\cos\theta_z$	R_b
For 22.06							
50	117.19	88.51	6h30’	5h2’	-0.2529	0.1305	-1.9376*
50	117.19	88.51	7h30’	6h2’	-0.0158	0.2943	-0.0536*
50	117.19	88.51	8h30’	7h2’	0.2208	0.4576	0.4826
50	117.19	88.51	9h30’	8h2’	0.4407	0.6094	0.7232
50	117.19	88.51	10h30’	9h2’	0.6289	0.7393	0.8507
50	117.19	88.51	11h30’	10h2’	0.7727	0.8386	0.9214
50	117.19	88.51	12h30’	11h2’	0.8621	0.9003	0.9576
50	117.19	88.51	13h30’	12h2’	0.8912	0.9204	0.9683
50	117.19	88.51	14h30’	13h2’	0.8580	0.8975	0.9560
50	117.19	88.51	15h30’	14h2’	0.7647	0.8331	0.9179
50	117.19	88.51	16h30’	15h2’	0.6176	0.7316	0.8443
50	117.19	88.51	17h30’	16h2’	0.4269	0.5999	0.7116
50	117.19	88.51	18h30’	17h2’	0.2054	0.4470	0.4595
50	117.19	88.51	19h30’	18h2’	-0.0317	0.2833	-0.1120*
50	117.19	88.51	20h30’	19h2’	-0.2684	0.1199	-2.2385*
50	117.19	88.51	21h30’	20h2’	-0.4884	-0.0320	15.2595**
50	117.19	88.51	22h30’	21h2’	-0.6769	-0.1621	4.1755**
For 22.12							
50	62.90	62.90	6h30’	6h4’	0.0412	-0.2767	-0.1488***
50	62.90	62.90	7h30’	7h4’	0.2775	-0.1136	-2.4421***
50	62.90	62.90	8h30’	8h4’	0.4965	0.0376	13.2014
50	62.90	62.90	9h30’	9h4’	0.6835	0.1667	4.1010
50	62.90	62.90	10h30’	10h4’	0.8255	0.2647	3.1184

50	62.90	62.90	11h30’	11h4’	0.9131	0.3252	2.8081
50	62.90	62.90	12h30’	12h4’	0.9401	0.3438	2.7343
50	62.90	62.90	13h30’	13h4’	0.9048	0.3194	2.8324
50	62.90	62.90	14h30’	14h4’	0.8096	0.2537	3.1909
50	62.90	62.90	15h30’	15h4’	0.6609	0.1511	4.3748
50	62.90	62.90	16h30’	16h4’	0.4689	0.0185	25.3200
50	*62.90*	*62.90*	*17h30’*	*17h4’*	*0.2466*	*-0.1349*	*-1.8279******
50	*62.90*	*62.90*	*18h30’*	*18h4’*	*0.0092*	*-0.2988*	*-0.0309******

β	**ω_s**	**ω'_s**	**WT**	**ST**	**$\cos\theta$**	**$\cos\theta_z$**	**R_b**
For 22.06							
55	*117.19*	*86.32*	*6h30’*	*5h2’*	*-0.2853*	*0.1305*	*-2.1857**
55	*117.19*	*86.32*	*7h30’*	6h2’	*-0.0503*	*0.2943*	*-0.1710**
55	117.19	86.32	8h30’	7h2’	0.1841	0.4576	0.4023
55	117.19	86.32	9h30’	8h2’	0.4020	0.6094	0.6596
55	117.19	86.32	10h30’	9h2’	0.5885	0.7393	0.7959
55	117.19	86.32	11h30’	10h2’	0.7309	0.8386	0.8716
55	117.19	86.32	12h30’	11h2’	0.8195	0.9003	0.9102
55	117.19	86.32	13h30’	12h2’	0.8483	0.9204	0.9217
55	117.19	86.32	14h30’	13h2’	0.8154	0.8975	0.9086
55	117.19	86.32	15h30’	14h2’	0.7230	0.8331	0.8678
55	117.19	86.32	16h30’	15h2’	0.5773	0.7316	0.7891
55	117.19	86.32	17h30’	16h2’	0.3883	0.5999	0.6472
55	117.19	86.32	18h30’	17h2’	0.1688	0.4470	0.3777
55	*117.19*	*86.32*	*19h30’*	18h2’	*-0.0662*	*0.2833*	*-0.2336**
55	*117.19*	*86.32*	*20h30’*	*19h2’*	*-0.3006*	*0.1199*	*-2.5075**
55	*117.19*	*86.32*	*21h30’*	*20h2’*	*-0.5187*	*-0.0320*	*16.2041***
55	*117.19*	*86.32*	*22h30’*	*21h2’*	*-0.7054*	*-0.1621*	*4.3514***
For 22.12							
55	*62.90*	*62.90*	*6h30’*	*6h4’*	*0.0755*	*-0.2767*	*-0.2729******
55	*62.90*	*62.90*	*7h30’*	*7h4’*	*0.3096*	*-0.1136*	*-2.7253******
55	62.90	62.90	8h30’	8h4’	0.5267	0.0376	14.0033
55	62.90	62.90	9h30’	9h4’	0.7119	0.1667	4.2717
55	62.90	62.90	10h30’	10h4’	0.8527	0.2647	3.2209
55	62.90	62.90	11h30’	11h4’	0.9394	0.3252	2.8891
55	62.90	62.90	12h30’	12h4’	0.9662	0.3438	2.8102
55	62.90	62.90	13h30’	13h4’	0.9312	0.3194	2.9150
55	62.90	62.90	14h30’	14h4’	0.8368	0.2537	3.2985
55	62.90	62.90	15h30’	15h4’	0.6895	0.1511	4.5644
55	62.90	62.90	16h30’	16h4’	0.4993	0.0185	26.9625
55	*62.90*	*62.90*	*17h30’*	*17h4’*	*0.2791*	*-0.1349*	*-2.0685******
55	*62.90*	*62.90*	*18h30’*	*18h4’*	*0.0439*	*-0.2988*	*-0.1468******

β	**ω_s**	**ω'_s**	**WT**	**ST**	**$\cos\theta$**	**$\cos\theta_z$**	**R_b**
For 22.06							
60	*117.19*	*84.06*	*6h30’*	*5h2’*	*-0.3156*	*0.1305*	*-2.4172**

60	117.19	84.06	7h30’	6h2’	-0.0845	0.2943	-0.2872*
60	117.19	84.06	8h30’	7h2’	0.1459	0.4576	0.3189
60	117.19	84.06	9h30’	8h2’	0.3601	0.6094	0.5910
60	117.19	84.06	10h30’	9h2’	0.5435	0.7393	0.7351
60	117.19	84.06	11h30’	10h2’	0.6835	0.8386	0.8151
60	117.19	84.06	12h30’	11h2’	0.7707	0.9003	0.8560
60	117.19	84.06	13h30’	12h2’	0.7990	0.9204	0.8681
60	117.19	84.06	14h30’	13h2’	0.7666	0.8975	0.8542
60	117.19	84.06	15h30’	14h2’	0.6757	0.8331	0.8111
60	117.19	84.06	16h30’	15h2’	0.5325	0.7316	0.7279
60	117.19	84.06	17h30’	16h2’	0.3467	0.5999	0.5779
60	117.19	84.06	18h30’	17h2’	0.1309	0.4470	0.2929
60	117.19	84.06	19h30’	18h2’	-0.1001	0.2833	-0.3533*
60	117.19	84.06	20h30’	19h2’	-0.3306	0.1199	-2.7574*
60	117.19	84.06	21h30’	20h2’	-0.5449	-0.0320	17.0256**
60	117.19	84.06	22h30’	21h2’	-0.7285	-0.1621	4.4941**
For 22.12							
60	62.90	62.90	6h30’	6h4’	0.1093	-0.2767	-0.3949***
60	62.90	62.90	7h30’	7h4’	0.3395	-0.1136	-2.9877***
60	62.90	62.90	8h30’	8h4’	0.5529	0.0376	14.6987
60	62.90	62.90	9h30’	9h4’	0.7349	0.1667	4.4099
60	62.90	62.90	10h30’	10h4’	0.8733	0.2647	3.2990
60	62.90	62.90	11h30’	11h4’	0.9586	0.3252	2.9481
60	62.90	62.90	12h30’	12h4’	0.9849	0.3438	2.8647
60	62.90	62.90	13h30’	13h4’	0.9505	0.3194	2.9756
60	62.90	62.90	14h30’	14h4’	0.8578	0.2537	3.3810
60	62.90	62.90	15h30’	15h4’	0.7129	0.1511	4.7194
60	62.90	62.90	16h30’	16h4’	0.5259	0.0185	28.3999
60	62.90	62.90	17h30’	17h4’	0.3094	-0.1349	-2.2933***
60	62.90	62.90	18h30’	18h4’	0.0782	-0.2988	-0.2616***

continued

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
70	117.19	79.17	6h30’	5h2’	-0.3686	0.1305	-2.8235*
70	117.19	79.17	7h30’	6h2’	-0.1507	0.2943	-0.5121*
70	117.19	79.17	8h30’	7h2’	0.0666	0.4576	0.1456
70	117.19	79.17	9h30’	8h2’	0.2686	0.6094	0.4408
70	117.19	79.17	10h30’	9h2’	0.4416	0.7393	0.5972
70	117.19	79.17	11h30’	10h2’	0.5736	0.8386	0.6840
70	117.19	79.17	12h30’	11h2’	0.6558	0.9003	0.7284
70	117.19	79.17	13h30’	12h2’	0.6825	0.9204	0.7415
70	117.19	79.17	14h30’	13h2’	0.6520	0.8975	0.7265
70	117.19	79.17	15h30’	14h2’	0.5663	0.8331	0.6797
70	117.19	79.17	16h30’	15h2’	0.4312	0.7316	0.5894
70	117.19	79.17	17h30’	16h2’	0.2559	0.5999	0.4267

70	117.19	79.17	18h30’	17h2’	0.0525	0.4470	0.1174
70	*117.19*	*79.17*	*19h30’*	18h2’	*-0.1654*	*0.2833*	*-0.5839**
70	*117.19*	*79.17*	*20h30’*	*19h2’*	*-0.3828*	*0.1199*	*-3.1927**
70	*117.19*	*79.17*	*21h30’*	*20h2’*	*-0.5849*	*-0.0320*	*18.2749***
70	*117.19*	*79.17*	*22h30’*	*21h2’*	*-0.7581*	*-0.1621*	*4.6764***
For 22.12							
70	*62.90*	*62.90*	*6h30’*	*6h4’*	*0.1741*	*-0.2767*	*-0.6290****

continued

70	*62.90*	*62.90*	*7h30’*	*7h4’*	*0.3911*	*-0.1136*	*-3.4426****
70	62.90	62.90	8h30’	8h4’	0.5924	0.0376	15.7499
70	62.90	62.90	9h30’	9h4’	0.7641	0.1667	4.5850
70	62.90	62.90	10h30’	10h4’	0.8946	0.2647	3.3794
70	62.90	62.90	11h30’	11h4’	0.9750	0.3252	2.9987
70	62.90	62.90	12h30’	12h4’	0.9999	0.3438	2.9082
70	62.90	62.90	13h30’	13h4’	0.9674	0.3194	3.0285
70	62.90	62.90	14h30’	14h4’	0.8800	0.2537	3.4684
70	62.90	62.90	15h30’	15h4’	0.7434	0.1511	4.9208
70	62.90	62.90	16h30’	16h4’	0.5670	0.0185	30.6177
70	*62.90*	*62.90*	*17h30’*	*17h4’*	*0.3628*	*-0.1349*	*-2.6890****
70	*62.90*	*62.90*	*18h30’*	*18h4’*	*0.1447*	*-0.2988*	*-0.4843****

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
80	*117.19*	*73.35*	*6h30’*	*5h2’*	*-0.4105*	*0.1305*	*-3.1441**
80	*117.19*	*73.35*	*7h30’*	6h2’	*-0.2123*	*0.2943*	*-0.7215**
80	*117.19*	*73.35*	*8h30’*	7h2’	*-0.0147*	*0.4576*	*-0.0321**
80	117.19	73.35	9h30’	8h2’	0.1690	0.6094	0.2773
80	117.19	73.35	10h30’	9h2’	0.3262	0.7393	0.4412
80	117.19	73.35	11h30’	10h2’	0.4463	0.8386	0.5322
80	117.19	73.35	12h30’	11h2’	0.5210	0.9003	0.5787
80	117.19	73.35	13h30’	12h2’	0.5453	0.9204	0.5925
80	117.19	73.35	14h30’	13h2’	0.5176	0.8975	0.5767
80	117.19	73.35	15h30’	14h2’	0.4396	0.8331	0.5277
80	117.19	73.35	16h30’	15h2’	0.3168	0.7316	0.4330
80	117.19	73.35	17h30’	16h2’	0.1574	0.5999	0.2624
80	*117.19*	*73.35*	*18h30’*	17h2’	*-0.0276*	*0.4470*	*-0.0617**
80	*117.19*	*73.35*	*19h30’*	18h2’	*-0.2257*	*0.2833*	*-0.7967**
80	*117.19*	*73.35*	*20h30’*	*19h2’*	*-0.4234*	*0.1199*	*-3.5311**
80	*117.19*	*73.35*	*21h30’*	*20h2’*	*-0.6072*	*-0.0320*	*18.9694***
80	*117.19*	*73.35*	*22h30’*	*21h2’*	*-0.7646*	*-0.1621*	*4.7166***
For 22.12							
80	*62.90*	*62.90*	*6h30’*	*6h4’*	*0.2336*	*-0.2767*	*-0.8440****
80	*62.90*	*62.90*	*7h30’*	*7h4’*	*0.4309*	*-0.1136*	*-3.7930****
80	62.90	62.90	8h30’	8h4’	0.6139	0.0376	16.3229

80	62.90	62.90	9h30’	9h4’	0.7701	0.1667	4.6208
80	62.90	62.90	10h30’	10h4’	0.8888	0.2647	3.3573
80	62.90	62.90	11h30’	11h4’	0.9619	0.3252	2.9582
80	62.90	62.90	12h30’	12h4’	0.9845	0.3438	2.8633
80	62.90	62.90	13h30’	13h4’	0.9550	0.3194	2.9895
80	62.90	62.90	14h30’	14h4’	0.8754	0.2537	3.4506
80	62.90	62.90	15h30’	15h4’	0.7512	0.1511	4.9728

continued

80	62.90	62.90	16h30’	16h4’	0.5908	0.0185	31.9062
80	62.90	62.90	17h30’	17h4’	0.4052	-0.1349	-3.0031***
80	62.90	62.90	18h30’	18h4’	0.2069	-0.2988	-0.6924***

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
90	117.19	65.73	6h30’	5h2’	-0.4399	0.1305	-3.3693*
90	117.19	65.73	7h30’	6h2’	-0.2675	0.2943	-0.9090*
90	117.19	65.73	8h30’	7h2’	-0.0956	0.4576	-0.2089*
90	117.19	65.73	9h30’	8h2’	0.0642	0.6094	0.1053
90	117.19	65.73	10h30’	9h2’	0.2010	0.7393	0.2718
90	117.19	65.73	11h30’	10h2’	0.3054	0.8386	0.3642
90	117.19	65.73	12h30’	11h2’	0.3704	0.9003	0.4114
90	117.19	65.73	13h30’	12h2’	0.3916	0.9204	0.4254
90	117.19	65.73	14h30’	13h2’	0.3674	0.8975	0.4094
90	117.19	65.73	15h30’	14h2’	0.2996	0.8331	0.3597
90	117.19	65.73	16h30’	15h2’	0.1928	0.7316	0.2635
90	117.19	65.73	17h30’	16h2’	0.0541	0.5999	0.0903
90	117.19	65.73	18h30’	17h2’	-0.1068	0.4470	-0.2389*
90	117.19	65.73	19h30’	18h2’	-0.2791	0.2833	-0.9854*
90	117.19	65.73	20h30’	19h2’	-0.4511	0.1199	-3.7623*
90	117.19	65.73	21h30’	20h2’	-0.6110	-0.0320	19.0882**
90	117.19	65.73	22h30’	21h2’	-0.7479	-0.1621	4.6137**
For 22.12							
90	62.90	62.90	6h30’	6h4’	0.2860	-0.2767	-1.0334***
90	62.90	62.90	7h30’	7h4’	0.4577	-0.1136	-4.0282***
90	62.90	62.90	8h30’	8h4’	0.6169	0.0376	16.4005
90	62.90	62.90	9h30’	9h4’	0.7527	0.1667	4.5165
90	62.90	62.90	10h30’	10h4’	0.8559	0.2647	3.2332
90	62.90	62.90	11h30’	11h4’	0.9195	0.3252	2.8280
90	62.90	62.90	12h30’	12h4’	0.9392	0.3438	2.7316
90	62.90	62.90	13h30’	13h4’	0.9135	0.3194	2.8597
90	62.90	62.90	14h30’	14h4’	0.8443	0.2537	3.3280
90	62.90	62.90	15h30’	15h4’	0.7363	0.1511	4.8739
90	62.90	62.90	16h30’	16h4’	0.5968	0.0185	32.2262
90	62.90	62.90	17h30’	17h4’	0.4353	-0.1349	-3.2261***
90	62.90	62.90	18h30’	18h4’	0.2628	-0.2988	-0.8794***

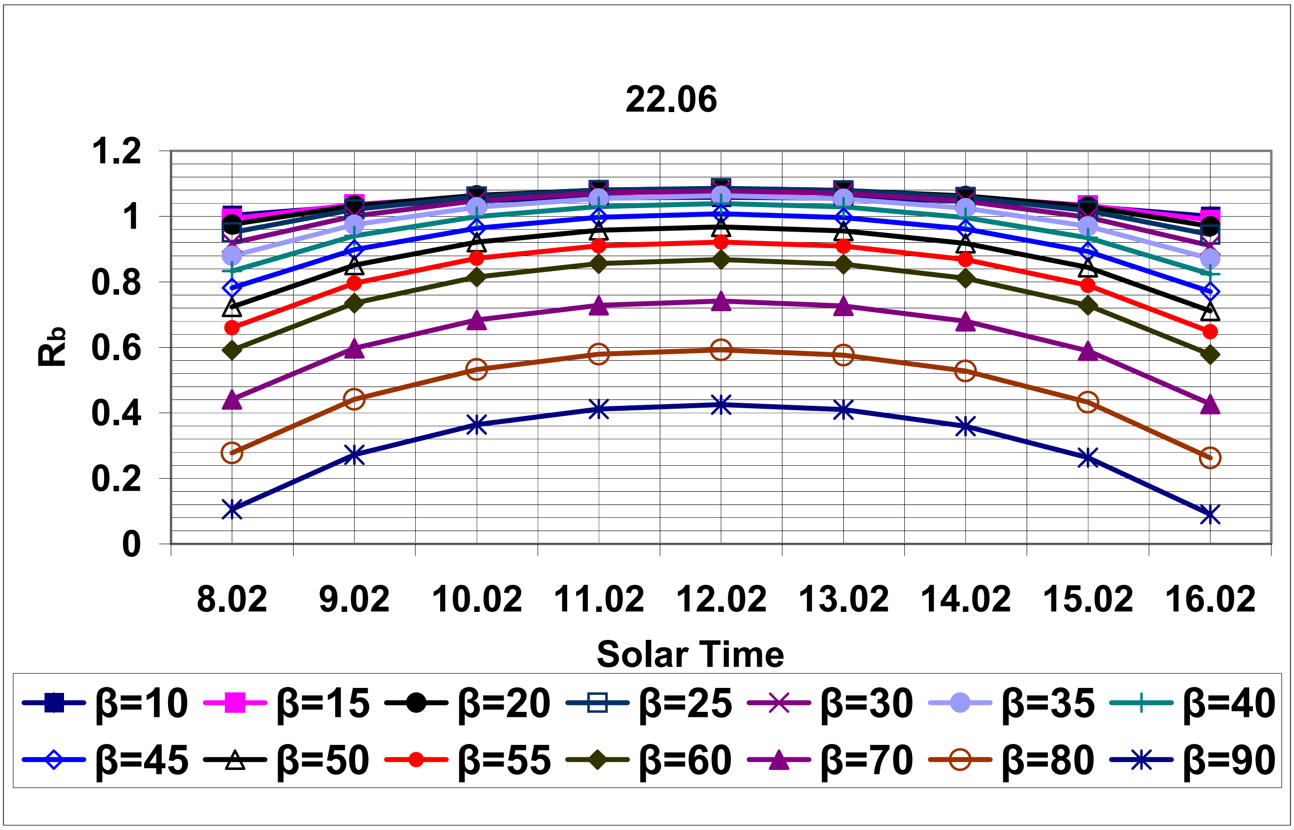

Figure IV.4: The diagram of $\mathbf{R_b}$, for **ST**, at various **β**. This is for 22.06.

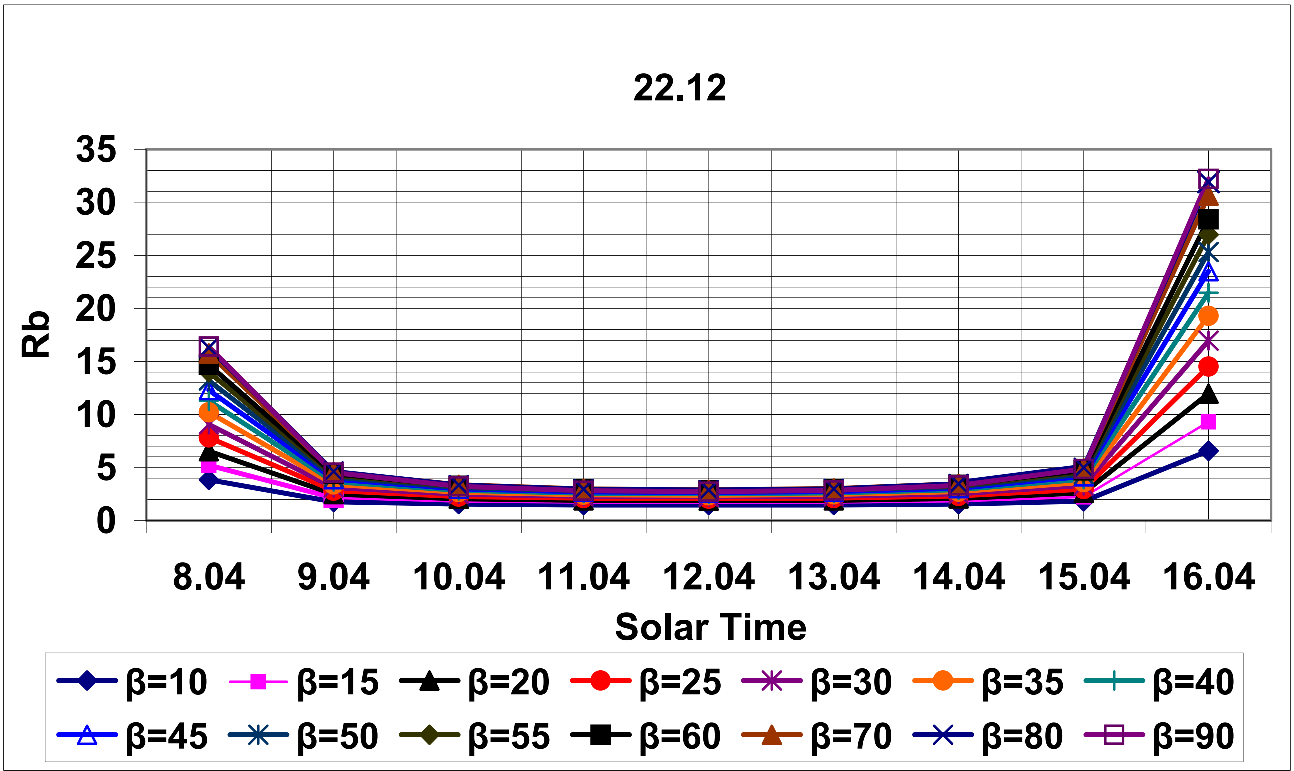

Figure IV.5: *The diagram of **R_b**, for **ST**, at various **β**. This is for 22.12.*

Bucuresti

Latitude: 44.45^0
Longitude: 26.09^0
Altitude: 88m
Calculations for: a. the 22nd June: WT is from 6^{30} to 22^{30} for summer time or equivalent 5^{30} to 21^{30} for winter time which is the proper time to be used for WT
b. the 22 nd December: WT is from 6^{30} to 18^{30}.

For 22.06 ⇒ n=173 and for 22.12 ⇒ n=356.

B	E	L_{st}	L_{loc}	WT	WT	ST	ω	δ
For 22.06	(minutes)			Summer Time	Winter Time			
90.99	-1.70	30	26.09	6 h 30'	5 h 30'	5 h 13'	-101.75	23.45
90.99	-1.70	30	26.09	7 h 30'	6 h 30'	6 h 13'	-86.75	23.45
90.99	-1.70	30	26.09	8 h 30'	7 h 30'	7 h 13'	-71.75	23.45
90.99	-1.70	30	26.09	9 h 30'	8 h 30'	8 h 13'	-56.75	23.45
90.99	-1.70	30	26.09	10 h 30'	9 h 30'	9 h 13'	-41.75	23.45
90.99	-1.70	30	26.09	11 h 30'	10 h 30'	10 h 13'	-26.75	23.45
90.99	-1.70	30	26.09	12 h 30'	11 h 30'	11 h 13'	-11.75	23.45
90.99	-1.70	30	26.09	13 h 30'	12 h 30'	12 h 13'	3.25	23.45
90.99	-1.70	30	26.09	14 h 30'	13 h 30'	13v13'	18.25	23.45
90.99	-1.70	30	26.09	15 h 30'	14 h 30'	14 h 13'	33.25	23.45
90.99	-1.70	30	26.09	16 h 30'	15 h 30'	15 h 13'	48.25	23.45
90.99	-1.70	30	26.09	17 h 30'	16 h 30'	16 h 13'	63.25	23.45
90.99	-1.70	30	26.09	18 h 30'	17 h 30'	17 h 13'	78.25	23.45

90.99	-1.70	30	26.09	19 h 30’	18 h 30’	18 h 13’	93.25	23.45
90.99	-1.70	30	26.09	20 h 30’	19 h 30’	19 h 13’	108.25	23.45
90.99	*-1.70*	*30*	*26.09*	*21 h 30’*	*20 h 30’*	*20 h 13’*	*123.25*	*23.45*
90.99	*-1.70*	*30*	*26.09*	*22 h 30’*	*21 h 30’*	*21h13’*	*138.25*	*23.45*
For 22.12								
271.98	*0,62*	*30*	*26.09*		*6h30’*	*6h15’*	*-86.75*	*-23.45*
271.98	*0,62*	*30*	*26.09*		*7h30’*	*7h15’*	*-71.75*	*-23.45*
271.98	0,62	30	26.09		8h30’	8h15’	-56.75	-23.45
271.98	0,62	30	26.09		9h30’	9h15’	-41.75	-23.45
271.98	0,62	30	26.09		10h30’	10h15’	-26.75	-23.45
271.98	0,62	30	26.09		11h30’	11h15’	-11.75	-23.45
271.98	0,62	30	26.09		12h30’	12h15’	3.25	-23.45
271.98	0,62	30	26.09		13h30’	13h15’	18.25	-23.45
271.98	0,62	30	26.09		14h30’	14h15’	33.25	-23.45
271.98	0,62	30	26.09		15h30’	15h15’	48.25	-23.45
271.98	0,62	30	26.09		16h30’	16h15’	63.25	-23.45
271.98	*0,62*	*30*	*26.09*		*17h30’*	*17h15’*	*78.25*	*-23.45*
271.98	*0,62*	*30*	*26.09*		*18h30’*	*18h15’*	*93.25*	*-23.45*

φ	**β**	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06								
44.45	10	115.2059	107.34	6 h 30’	5h13’	0.1055	0.1456	0.7245
44.45	10	115.2059	107.34	7 h 30’	6h13’	0.2588	0.3161	0.8186
44.45	10	115.2059	107.34	8 h 30’	7h13’	0.4097	0.4840	0.8465
44.45	10	115.2059	107.34	9 h 30’	8h13’	0.5481	0.6380	0.8592
44.45	10	115.2059	107.34	10 h 30’	9h13’	0.6645	0.7674	0.8659
44.45	10	115.2059	107.34	11 h 30’	10h13’	0.7509	0.8636	0.8696
44.45	10	115.2059	107.34	12 h 30’	11h13’	0.8016	0.9199	0.8714
44.45	10	115.2059	107.34	13 h 30’	12h13’	0.8130	0.9326	0.8717
44.45	10	115.2059	107.34	14 h 30’	13h13’	0.7843	0.9007	0.8708
44.45	10	115.2059	107.34	15 h 30’	14h13’	0.7176	0.8265	0.8682
44.45	10	115.2059	107.34	16 h 30’	15h13’	0.6173	0.7149	0.8634
44.45	10	115.2059	107.34	17 h 30’	16h13’	0.4903	0.5737	0.8547
44.45	10	115.2059	107.34	18 h 30’	17h13’	0.3453	0.4123	0.8374
44.45	10	115.2059	107.34	19 h 30’	18h13’	0.1920	0.2418	0.7940
44.45	10	115.2059	107.34	20 h 30’	19h13’	0.0410	0.0738	0.5550
44.45	10	115.2059	107.34	21 h 30’	20h13’	-0.0975	-0.0802	1.2155**
44.45	10	115.2059	107.34	22 h 30’	21h13’	-0.2141	-0.2099	1.0200**
For 22.12								
44,45	10	64,8854	64,89	6h30’	6h15’	-0,1911	-0,2408	0,7935**
44,45	10	64,8854	64,89	7h30’	7h15’	-0,0401	-0,0728	0,5504**
44,45	10	64,8854	64,89	8h30’	8h15’	0,0983	0,0811	1.2121
44,45	10	64,8854	64,89	9h30’	9h15’	0,2147	0,2106	1.0196

44,45	10	64,8854	64,89	10h30’	10h15’	0,3011	0,3067	0.9818
44,45	10	64,8854	64,89	11h30’	11h15’	0,3518	0,3631	0.9689
44,45	10	64,8854	64,89	12h30’	12h15’	0,3632	0,3757	0.9666
44,45	10	64,8854	64,89	13h30’	13h15’	0,3345	0,3439	0.9728
44,45	10	64,8854	64,89	14h30’	14h15’	0,2678	0,2696	0.9932
44,45	10	64,8854	64,89	15h30’	15h15’	0,1675	0,1581	1.0596
44,45	10	64,8854	64,89	16h30’	16h15’	0,0405	0,0168	2.4101
44,45	10	64,8854	64,89	17h30’	17h15’	-0,1046	-0,1446	0,7233**
44,45	10	64,8854	64,89	18h30’	18h15’	-0,2578	-0,3150	0,8184**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
15	115.2059	104.21	6 h 30’	5h13’	0.0694	0.1456	0.4765
15	115.2059	104.21	7 h 30’	6h13’	0.2312	0.3161	0.7315
15	115.2059	104.21	8 h 30’	7h13’	0.3906	0.4840	0.8070
15	115.2059	104.21	9 h 30’	8h13’	0.5367	0.6380	0.8414
15	115.2059	104.21	10 h 30’	9h13’	0.6596	0.7674	0.8596
15	115.2059	104.21	11 h 30’	10h13’	0.7509	0.8636	0.8695
15	115.2059	104.21	12 h 30’	11h13’	0.8044	0.9199	0.8744
15	115.2059	104.21	13 h 30’	12h13’	0.8164	0.9326	0.8754
15	115.2059	104.21	14 h 30’	13h13’	0.7862	0.9007	0.8728
15	115.2059	104.21	15 h 30’	14h13’	0.7157	0.8265	0.8660
15	115.2059	104.21	16 h 30’	15h13’	0.6098	0.7149	0.8530
15	115.2059	104.21	17 h 30’	16h13’	0.4757	0.5737	0.8293
15	115.2059	104.21	18 h 30’	17h13’	0.3225	0.4123	0.7823
15	115.2059	104.21	19 h 30’	18h13’	0.1607	0.2418	0.6646
15	115.2059	104.21	20 h 30’	19h13’	0.0013	0.0738	0.0171
15	115.2059	104.21	21 h 30’	20h13’	-0.1450	-0.0802	1.8072**
15	115.2059	104.21	22 h 30’	21h13’	-0.2680	-0.2099	1.2772**
For 22.12							
15	64.8854	64.89	6h30’	6h15’	-0.1597	-0.2408	0.6634**
15	64.8854	64.89	7h30’	7h15’	-0.0003	-0.0728	0.0045**
15	64.8854	64.89	8h30’	8h15’	0.1458	0.0811	1.7980

15	64.8854	64.89	9h30'	9h15'	0.2687	0.2106	1.2761
15	64.8854	64.89	10h30'	10h15'	0.3600	0.3067	1.1736
15	64.8854	64.89	11h30'	11h15'	0.4135	0.3631	1.1388
15	64.8854	64.89	12h30'	12h15'	0.4255	0.3757	1.1324
15	64.8854	64.89	13h30'	13h15'	0.3952	0.3439	1.1494
15	64.8854	64.89	14h30'	14h15'	0.3248	0.2696	1.2045
15	64.8854	64.89	15h30'	15h15'	0.2189	0.1581	1.3846
15	64.8854	64.89	16h30'	16h15'	0.0848	0.0168	5.0447
15	64.8854	64.89	17h30'	17h15'	-0.0684	-0.1446	0.4731**
15	64.8854	64.89	18h30'	18h15'	-0.2302	-0.3150	0.7308**

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
20	115.2059	101.41	6 h 30'	5h13'	0.0327	0.1456	0.2248
20	115.2059	101.41	7 h 30'	6h13'	0.2019	0.3161	0.6388
20	115.2059	101.41	8 h 30'	7h13'	0.3686	0.4840	0.7614
20	115.2059	101.41	9 h 30'	8h13'	0.5213	0.6380	0.8171
20	115.2059	101.41	10 h 30'	9h13'	0.6498	0.7674	0.8467
20	115.2059	101.41	11 h 30'	10h13'	0.7452	0.8636	0.8629
20	115.2059	101.41	12 h 30'	11h13'	0.8011	0.9199	0.8708
20	115.2059	101.41	13 h 30'	12h13'	0.8137	0.9326	0.8725
20	115.2059	101.41	14 h 30'	13h13'	0.7820	0.9007	0.8682

continued

20	115.2059	101.41	15 h 30'	14h13'	0.7084	0.8265	0.8571
20	115.2059	101.41	16 h 30'	15h13'	0.5977	0.7149	0.8360
20	115.2059	101.41	17 h 30'	16h13'	0.4575	0.5737	0.7975
20	115.2059	101.41	18 h 30'	17h13'	0.2974	0.4123	0.7213
20	115.2059	101.41	19 h 30'	18h13'	0.1282	0.2418	0.5303
20	115.2059	101.41	20 h 30'	19h13'	-0.0385	0.0738	-0.5209*
20	115.2059	101.41	21 h 30'	20h13'	-0.1913	-0.0802	2.3851**
20	115.2059	101.41	22 h 30'	21h13'	-0.3200	-0.2099	1.5247**
For 22.12							
20	64.8854	64.89	6h30'	6h15'	-0.1272	-0.2408	0.5283**
20	64.8854	64.89	7h30'	7h15'	0.0394	-0.0728	-0.5415***
20	64.8854	64.89	8h30'	8h15'	0.1922	0.0811	2.3701
20	64.8854	64.89	9h30'	9h15'	0.3207	0.2106	1.5229
20	64.8854	64.89	10h30'	10h15'	0.4161	0.3067	1.3566
20	64.8854	64.89	11h30'	11h15'	0.4720	0.3631	1.3000
20	64.8854	64.89	12h30'	12h15'	0.4846	0.3757	1.2897
20	64.8854	64.89	13h30'	13h15'	0.4529	0.3439	1.3172
20	64.8854	64.89	14h30'	14h15'	0.3793	0.2696	1.4067
20	64.8854	64.89	15h30'	15h15'	0.2686	0.1581	1.6991
20	64.8854	64.89	16h30'	16h15'	0.1284	0.0168	7.6410
20	64.8854	64.89	17h30'	17h15'	-0.0317	-0.1446	0.2194**
20	64.8854	64.89	18h30'	18h15'	-0.2009	-0.3150	0.6376**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
25	115.2059	98.85	6 h 30’	5h13’	-0.0042	0,1456	-0,0286*
25	115.2059	98.85	7 h 30’	6h13’	0.1711	0,3161	0,5412
25	115.2059	98.85	8 h 30’	7h13’	0.3437	0,4840	0,7101
25	115.2059	98.85	9 h 30’	8h13’	0.5019	0,6380	0,7867
25	115.2059	98.85	10 h 30’	9h13’	0.6350	0,7674	0,8274
25	115.2059	98.85	11 h 30’	10h13’	0.7338	0,8636	0,8497
25	115.2059	98.85	12 h 30’	11h13’	0.7917	0,9199	0,8606
25	115.2059	98.85	13 h 30’	12h13’	0.8047	0,9326	0,8629
25	115.2059	98.85	14 h 30’	13h13’	0.7720	0,9007	0,8571
25	115.2059	98.85	15 h 30’	14h13’	0.6957	0,8265	0,8417
25	115.2059	98.85	16 h 30’	15h13’	0.5810	0,7149	0,8127
25	115.2059	98.85	17 h 30’	16h13’	0.4358	0,5737	0,7597
25	115.2059	98.85	18 h 30’	17h13’	0.2700	0,4123	0,6548
25	115.2059	98.85	19 h 30’	18h13’	0.0948	0,2418	0,3918
25	115.2059	98.85	20 h 30’	19h13’	-0.0779	0,0738	-1,0549*
25	115.2059	98.85	21 h 30’	20h13’	-0.2362	-0,0802	2,9449**
25	115.2059	98.85	22 h 30’	21h13’	-0.3695	-0,2099	1,7606**
For 22.12							
25	64.8854	64.89	6h30’	6h15’	-0.0937	-0,2408	0,3891**
25	64.8854	64.89	7h30’	7h15’	0.0789	-0,0728	-1,0833***

continued

25	64.8854	64.89	8h30’	8h15’	0.2371	0,0811	2.9243
25	64.8854	64.89	9h30’	9h15’	0.3702	0,2106	1.7582
25	64.8854	64.89	10h30’	10h15’	0.4690	0,3067	1.5292
25	64.8854	64.89	11h30’	11h15’	0.5269	0,3631	1.4514
25	64.8854	64.89	12h30’	12h15’	0.5400	0,3757	1.4371
25	64.8854	64.89	13h30’	13h15’	0.5072	0,3439	1.4750
25	64.8854	64.89	14h30’	14h15’	0.4309	0,2696	1.5982
25	64.8854	64.89	15h30’	15h15’	0.3163	0,1581	2.0007
25	64.8854	64.89	16h30’	16h15’	0.1711	0,0168	10.1791
25	64.8854	64.89	17h30’	17h15’	0.0052	-0,1446	-0,0360***
25	64.8854	64.89	18h30’	18h15’	-0.1700	-0,3150	0,5396**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
30	115.2059	96.46	6 h 30’	5h13’	-0.0410	0.1456	-0.2817*
30	115.2059	96.46	7 h 30’	6h13’	0.1389	0.3161	0.4396
30	115.2059	96.46	8 h 30’	7h13’	0.3162	0.4840	0.6533
30	115.2059	96.46	9 h 30’	8h13’	0.4787	0.6380	0.7503
30	115.2059	96.46	10 h 30’	9h13’	0.6153	0.7674	0.8018
30	115.2059	96.46	11 h 30’	10h13’	0.7168	0.8636	0.8301
30	115.2059	96.46	12 h 30’	11h13’	0.7763	0.9199	0.8439
30	115.2059	96.46	13 h 30’	12h13’	0.7897	0.9326	0.8467
30	115.2059	96.46	14 h 30’	13h13’	0.7560	0.9007	0.8394

30	115.2059	96.46	15 h 30'	14h13'	0.6777	0.8265	0.8199
30	115.2059	96.46	16 h 30'	15h13'	0.5599	0.7149	0.7832
30	115.2059	96.46	17 h 30'	16h13'	0.4108	0.5737	0.7161
30	115.2059	96.46	18 h 30'	17h13'	0.2405	04123	0.5833
30	115.2059	96.46	19 h 30'	18h13'	0.0606	0.2418	0.2505
30	115.2059	96.46	20 h 30'	19h13'	-0.1167	0.0738	-1.5810*
30	115.2059	96.46	21 h 30'	20h13'	-0.2793	-0.0802	3.4823**
30	115.2059	96.46	22 h 30'	21h13'	-0.4162	-0.2099	1.9831**
For 22.12							
30	64.8854	64.89	6h30'	6h15'	-0.0595	-0.2408	0.2470**
30	64.8854	64.89	7h30'	7h15'	0.1178	-0.0728	-1,6169***
30	64.8854	64.89	8h30'	8h15'	0.2803	0.0811	3.4562
30	64.8854	64.89	9h30'	9h15'	0.4169	0.2106	1.9801
30	64.8854	64.89	10h30'	10h15'	0.5184	0.3067	1.6902
30	64.8854	64.89	11h30'	11h15'	0.5779	0.3631	1.5917
30	64.8854	64.89	12h30'	12h15'	0.5913	0.3757	1.5736
30	64.8854	64.89	13h30'	13h15'	0.5576	0.3439	1.6216
30	64.8854	64.89	14h30'	14h15'	0.4793	0.2696	1.775
30	64.8854	64.89	15h30'	15h15'	0.3615	0.1581	2.2871
30	64.8854	64.89	16h30'	16h15'	0.2124	0.0168	12.6399
30	64.8854	64.89	17h30'	17h15'	0.0421	-0.1446	-0.2912***
30	64.8854	64,89	18h30'	18h15'	-0.1378	-0.3150	0.4375**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
35	115.2059	94.18	6 h 30'	5h13'	-0.0776	0.1456	-0.5328*
35	115.2059	94.18	7 h 30'	6h13'	0.1058	0.3161	0.3346
35	115.2059	94.18	8 h 30'	7h13'	0.2863	0.4840	0.5915
35	115.2059	94.18	9 h 30'	8h13'	0.4518	0.6380	0.7082
35	115.2059	94.18	10 h 30'	9h13'	0.5910	0.7674	0.7701
35	115.2059	94.18	11 h 30'	10h13'	0.6944	0.8636	0.8041
35	115.2059	94.18	12 h 30'	11h13'	0.7550	0.9199	0.8207
35	115.2059	94.18	13 h 30'	12h13'	0.7686	0.9326	0.8242
35	115.2059	94.18	14 h 30'	13h13'	0.7343	0.9007	0.8153
35	115.2059	94.18	15 h 30'	14h13'	0.6545	0.8265	0.7919
35	115.2059	94.18	16 h 30'	15h13'	0.5346	0.7149	0.7477
35	115.2059	94.18	17 h 30'	16h13'	0.3827	0.5737	0.6671
35	115.2059	94.18	18 h 30'	17h13'	0.2092	0.4123	0.5074
35	115.2059	94.18	19 h 30'	18h13'	0.0259	0.2418	0.1072
35	115.2059	94.18	20 h 30'	19h13'	-0.1547	0.0738	-2.0950*
35	115.2059	94.18	21 h 30'	20h13'	-0.3203	-0.0802	3.9932**
35	115.2059	94.18	22 h 30'	21h13'	-0.4597	-0.2099	2.1906**
For 22.12							
35	64.8854	64.89	6h30'	6h15'	-0.0248	-0.2408	0.1030**
35	64.8854	64.89	7h30'	7h15'	0.1558	-0.0728	-2.1381***
35	64.8854	64.89	8h30'	8h15'	0.3213	0.0811	3.9618

35	64.8854	64.89	9h30’	9h15’	0.4605	0.2106	2.1869
35	64.8854	64.89	10h30’	10h15’	0.5639	0.3067	1.8383
35	64.8854	64.89	11h30’	11h15’	0.6244	0.3631	1.7199
35	64.8854	64.89	12h30’	12h15’	0.6380	0.3757	1.6982
35	64.8854	64.89	13h30’	13h15’	0.6038	0.3439	1.7559
35	64.8854	64.89	14h30’	14h15’	0.5240	0.2696	1.9434
35	64.8854	64.89	15h30’	15h15’	0.4040	0.1581	2.5560
35	64.8854	64.89	16h30’	16h15’	0.2522	0.0168	15.0045
35	64.8854	64.89	17h30’	17h15’	0.0787	-0.1446	-0.5441***
35	64.8854	64.89	18h30’	18h15’	-0.1046	-0.3150	0.3321**

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
40	115.2059	91.98	6 h 30’	5h13’	-0.1135	0.1456	-0.7797*
40	115.2059	91.98	7 h 30’	6h13’	0.0718	0.3161	0.2270
40	115.2059	91.98	8 h 30’	7h13’	0.2542	0.4840	0.5253
40	115.2059	91.98	9 h 30’	8h13’	0.4215	0.6380	0.6607
40	115.2059	91.98	10 h 30’	9h13’	0.5622	0.7674	0.7326
40	115.2059	91.98	11 h 30’	10h13’	0.6667	0.8636	0.7720
40	115.2059	91.98	12 h 30’	11h13’	0.7279	0.9199	0.7913
40	115.2059	91.98	13 h 30’	12h13’	0.7417	0.9326	0.7953
40	115.2059	91.98	14 h 30’	13h13’	0.7071	0.9007	0.7850
40	115.2059	91.98	15 h 30’	14h13’	0.6264	0.8265	0.7579
40	115.2059	91.98	16 h 30’	15h13’	0.5052	0.7149	0.7066
40	115.2059	91.98	17 h 30’	16h13’	0.3517	0.5737	0.6130
40	115.2059	91.98	18 h 30’	17h13’	0.1763	0.4123	0.4276
40	115.2059	91.98	19 h 30’	18h13’	-0.0089	0.2418	-0.0369*
40	115.2059	91.98	20 h 30’	19h13’	-0.1915	0.0738	-2.5931*
40	115.2059	91.98	21 h 30’	20h13’	-0.3589	-0.0802	4.4738**
40	115.2059	91.98	22 h 30’	21h13’	-0.4998	-0.2099	2.3814**
For 22.12							
40	64.8854	64.89	6h30’	6h15’	0.0101	-0.2408	-0.0418***
40	64.8854	64.89	7h30’	7h15’	0.1926	-0.0728	-2.6432***
40	64.8854	64.89	8h30’	8h15’	0.3598	0.0811	4.4373
40	64.8854	64.89	9h30’	9h15’	0.5005	0.2106	2.3771
40	64.8854	64.89	10h30’	10h15’	0.6050	0.3067	1.9725
40	64.8854	64.89	11h30’	11h15’	0.6662	0.3631	1.8350
40	64.8854	64.89	12h30’	12h15’	0.6800	0.3757	1.8098
40	64.8854	64.89	13h30’	13h15’	0.6454	0.3439	1.8768
40	64.8854	64.89	14h30’	14h15’	0.5647	0.2696	2.0944
40	64.8854	64.89	15h30’	15h15’	0.4435	0.1581	2.8056
40	64.8854	64.89	16h30’	16h15’	0.2900	0.0168	17.2551
40	64.8854	64.89	17h30’	17h15’	0.1146	-0.1446	-0.7929***
40	64.8854	64.89	18h30’	18h15’	-0.0706	-0.3150	0.2242**

continued

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
45	115,2059	89,81	6 h 30’	5h13’	-0.1486	0.1456	-1.0208*
45	115,2059	89,81	7 h 30’	6h13’	0.0372	0.3161	0.1177
45	115,2059	89,81	8 h 30’	7h13’	0.2202	0.4840	0.4550
45	115,2059	89,81	9 h 30’	8h13’	0.3880	0.6380	0.6082
45	115,2059	89,81	10 h 30’	9h13’	0.5291	0.7674	0.6895
45	115,2059	89,81	11 h 30’	10h13’	0.6339	0.8636	0.7341
45	115,2059	89,81	12 h 30’	11h13’	0.6953	0.9199	0.7559
45	115,2059	89,81	13 h 30’	12h13’	0.7091	0.9326	0.7604
45	115,2059	89,81	14 h 30’	13h13’	0.6744	0.9007	0.7487
45	115,2059	89,81	15 h 30’	14h13’	0.5935	0.8265	0.7181
45	115,2059	89,81	16 h 30’	15h13’	0.4719	0.7149	0.6601
45	115,2059	89,81	17 h 30’	16h13’	0.3180	0.5737	0.5543
45	115,2059	89,81	18 h 30’	17h13’	0.1421	0.4123	0.3446
45	115,2059	89,81	19 h 30’	18h13’	-0.0437	0.2418	-0.1808*
45	115,2059	89,81	20 h 30’	19h13’	-0.2268	0.0738	-3.0715*
45	115,2059	89,81	21 h 30’	20h13’	-0.3947	-0.0802	4.9204*
45	115,2059	89,81	22 h 30’	21h13’	-0.5360	-0.2099	2.5541**
For 22.12							
45	64.8854	64.89	6h30’	6h15’	0.0448	-0.2408	-0.1863***
45	64.8854	64.89	7h30’	7h15’	0.2279	-0.0728	-3.1281***

continued

45	64.8854	64.89	8h30’	8h15’	0.3957	0.0811	4.8791
45	64.8854	64.89	9h30’	9h15’	0.5368	0.2106	2.5492
45	64.8854	64.89	10h30’	10h15’	0.6416	0.3067	2.0917
45	64.8854	64.89	11h30’	11h15’	0.7030	0.3631	1.9362
45	64.8854	64.89	12h30’	12h15’	0.7168	0.3757	1.9077
45	64.8854	64.89	13h30’	13h15’	0.6820	0.3439	1.9835
45	64.8854	64.89	14h30’	14h15’	0.6011	0.2696	2.2295
45	64.8854	64.89	15h30’	15h15’	0.4796	0.1581	3.0338
45	64.8854	64.89	16h30’	16h15’	0.3256	0.0168	19.3745
45	64.8854	64.89	17h30’	17h15’	0.1497	-0.1446	-1.0357***
45	64.8854	64.89	18h30’	18h15’	-0.0361	-0.3150	0.1145**

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
50	115.2059	87.63	6 h 30’	5h13’	-0.1826	0.1456	-1.2541*
50	115.2059	87.63	7 h 30’	6h13’	0.0024	0.3161	0.0076
50	115.2059	87.63	8 h 30’	7h13’	0.1846	0.4840	0.3813
50	115.2059	87.63	9 h 30’	8h13’	0.3516	0.6380	0.5511
50	115.2059	87.63	10 h 30’	9h13’	0.4920	0.7674	0.6411
50	115.2059	87.63	11 h 30’	10h13’	0.5963	0.8636	0.6905
50	115.2059	87.63	12 h 30’	11h13’	0.6575	0.9199	07147
50	115.2059	87.63	13 h 30’	12h13’	0.6712	0.9326	0.7197
50	115.2059	87.63	14 h 30’	13h13’	0.6366	0.9007	0.7068

50	115.2059	87.63	15 h 30’	14h13’	0.5561	0.8265	0.6728
50	115.2059	87.63	16 h 30’	15h13’	0.4351	0.7149	0.6086
50	115.2059	87.63	17 h 30’	16h13’	0.2818	0.5737	0.4913
50	115.2059	87.63	18 h 30’	17h13’	0.1068	0.4123	0.2590
50	115.2059	87.63	19 h 30’	18h13’	-0.0782	0.2418	-0.3232*
50	115.2059	87.63	20 h 30’	19h13’	-0.2604	0.0738	-3.5265*
50	115.2059	87.63	21 h 30’	20h13’	-0.4275	-0.0802	5.3295**
50	115.2059	87.63	22 h 30’	21h13’	-0.5682	-0.2099	2.7073**
For 22.12							
50	64.8854	64.89	6h30’	6h15’	0.0793	-0.2408	-0.3293***
50	64.8854	64.89	7h30’	7h15’	0.2615	-0.0728	-3.5893***
50	64.8854	64.89	8h30’	8h15’	0.4285	0.0811	5.2838
50	64.8854	64.89	9h30’	9h15’	0.5689	0.2106	2.7020
50	64.8854	64.89	10h30’	10h15’	0.6732	0.3067	2.1949
50	64.8854	64.89	11h30’	11h15’	0.7344	0.3631	2.0227
50	64.8854	64.89	12h30’	12h15’	0.7481	0.3757	1.9911
50	64.8854	64.89	13h30’	13h15’	0.7135	0.3439	2.0751
50	64.8854	64.89	14h30’	14h15’	0.6330	0.2696	2.3477
50	64.8854	64.89	15h30’	15h15’	0.5120	0.1581	3.2389
50	64.8854	64.89	16h30’	16h15’	0.3587	0.0168	21.3466
50	64.8854	64.89	17h30’	17h15’	0.1837	-0.1446	-1.2706***
50	64.8854	64.89	18h30’	18h15’	-0.0013	-0.3150	0.0040**

β	**ω_s**	**ω'_s**	**WT**	**ST**	**cosθ**	**$\cos\theta_z$**	**R_b**
For 22.06							
55	115.2059	85.41	6 h 30’	5h13’	-0.2151	0.1456	-1.4778*
55	115.2059	85.41	7 h 30’	6h13’	-0.0324	0.3161	-0.1027*
55	115.2059	85.41	8 h 30’	7h13’	0.1475	0.4840	0.3047
55	115.2059	85.41	9 h 30’	8h13’	0.3124	0.6380	0.4898
55	115.2059	85.41	10 h 30’	9h13’	0.4512	0.7674	0.5879
55	115.2059	85.41	11 h 30’	10h13’	0.5542	0.8636	0.6418
55	115.2059	85.41	12 h 30’	11h13’	0.6146	0.9199	0.6681
55	115.2059	85.41	13 h 30’	12h13’	0.6282	0.9326	0.6736
55	115.2059	85.41	14 h 30’	13h13’	0.5940	0.9007	0.6595
55	115.2059	85.41	15 h 30’	14h13’	0.5145	0.8265	0.6225
55	115.2059	85.41	16 h 30’	15h13’	0.3949	0.7149	0.5524
55	115.2059	85.41	17 h 30’	16h13’	0.2436	0.5737	0.4246
55	115.2059	85.41	18 h 30’	17h13’	00707	0.4123	0.1714
55	115.2059	85.41	19 h 30’	18h13’	-0.1120	0.2418	-0.4632*
55	115.2059	85.41	20 h 30’	19h13’	-0.2920	0.0738	-3.9547*
55	115.2059	85.41	21 h 30’	20h13’	-0.4571	-0.0802	5.6981**
55	115.2059	85.41	22 h 30’	21h13’	-0.5960	-0.2099	2.8400**
For 22.12							
55	64.8854	64.89	6h30’	6h15’	0.1131	-0.2408	-0.4698***
55	64.8854	64.89	7h30’	7h15’	0.2931	-0.0728	-4.0231***
55	64.8854	64.89	8h30’	8h15’	0.4580	0.0811	5.6483

55	64.8854	64.89	9h30’	9h15’	0.5968	0.2106	2.8342
55	64.8854	64.89	10h30’	10h15’	0.6998	0.3067	2.2815
55	64.8854	64.89	11h30’	11h15’	0.7602	0.3631	2.0938
55	64.8854	64.89	12h30’	12h15’	0.7737	0.3757	2.0593
55	64.8854	64.89	13h30’	13h15’	0.7396	0.3439	2.1509
55	64.8854	64.89	14h30’	14h15’	0.6600	0.2696	2.4481
55	64.8854	64.89	15h30’	15h15’	0.5405	0.1581	3.4195
55	64.8854	64.89	16h30’	16h15’	0.3891	0.0168	23.1564
55	64.8854	64.89	17h30’	17h15’	0.2162	-0.1446	-1.4958***
55	64.8854	64.89	18h30’	18h15’	0.0336	-0.3150	-0.1065***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
60	115.2059	83.12	6 h 30’	5h13’	-0.2461	0.1456	-1.6903*
60	115.2059	83.12	7 h 30’	6h13’	-0.0670	0.3161	-0.2121*
60	115.2059	83.12	8 h 30’	7h13’	0.1093	0.4840	0.2258
60	115.2059	83.12	9 h 30’	8h13’	0.2709	0.6380	0.4247
60	115.2059	83.12	10 h 30’	9h13’	0.4069	0.7674	0.5302
60	115.2059	83.12	11 h 30’	10h13’	0.5079	0.8636	0.5881
60	115.2059	83.12	12 h 30’	11h13’	0.5670	0.9199	0.6164
60	115.2059	83.12	13 h 30’	12h13’	0.5803	0.9326	0.6223
60	115.2059	83.12	14 h 30’	13h13’	0.5469	0.9007	0.6071

continued

60	115.2059	83.12	15 h 30’	14h13’	0.4689	0.8265	0.5674
60	115.2059	83.12	16 h 30’	15h13’	0.3518	0.7149	0.4920
60	115.2059	83.12	17 h 30’	16h13’	0.2034	0.5737	0.3546
60	115.2059	83.12	18 h 30’	17h13’	0.0340	0.4123	0.0825
60	115.2059	83.12	19 h 30’	18h13’	-0.1450	0.2418	-0.5997*
60	115.2059	83.12	20 h 30’	19h13’	-0.3214	0.0738	-4.3529*
60	115.2059	83.12	21 h 30’	20h13’	-0.4832	-0.0802	6.0234**
60	115.2059	83.12	22 h 30’	21h13’	-0.6193	-0.2099	2.9511**
For 22.12							
60	64.8854	64.89	6h30’	6h15’	0.1461	-0.2408	-0.6068***
60	64.8854	64.89	7h30’	7h15’	0.3225	-0.0728	-4.4264***
60	64.8854	64.89	8h30’	8h15’	0.4841	0.0811	5.9699
60	64.8854	64.89	9h30’	9h15’	0.6201	0.2106	2.9448
60	64.8854	64.89	10h30’	10h15’	0.7210	0.3067	2.3507
60	64.8854	64.89	11h30’	11h15’	0.7802	0.3631	2.1489
60	64.8854	64.89	12h30’	12h15’	0.7935	0.3757	2.1119
60	64.8854	64.89	13h30’	13h15’	0.7600	0.3439	2.2103
60	64.8854	64.89	14h30’	14h15’	0.6821	0.2696	2.5298
60	64.8854	64.89	15h30’	15h15’	0.5649	0.1581	3.5740
60	64.8854	64.89	16h30’	16h15’	0.4166	0.0168	24.7901
60	64.8854	64.89	17h30’	17h15’	0.2472	-0.1446	-1.7097***
60	64.8854	64.89	18h30’	18h15’	0.0681	-0.3150	-0.2163***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
70	115.2059	78.09	6 h 30’	5h13’	-0.3021	0.1456	-2.0753*
70	115.2059	78.09	7 h 30’	6h13’	-0.1344	0.3161	-0.4254*
70	115.2059	78.09	8 h 30’	7h13’	0.0307	0.4840	0.0634
70	115.2059	78.09	9 h 30’	8h13’	0.1821	0.6380	0.2854
70	115.2059	78.09	10 h 30’	9h13’	0.3094	0.7674	0.4032
70	115.2059	78.09	11 h 30’	10h13’	0.4040	0.8636	0.4678
70	115.2059	78.09	12 h 30’	11h13’	0.4594	0.9199	0.4994
70	115.2059	78.09	13 h 30’	12h13’	0.4719	0.9326	0.5060
70	115.2059	78.09	14 h 30’	13h13’	0.4405	0.9007	0.4891
70	115.2059	78.09	15 h 30’	14h13’	0.3675	0.8265	0.4447
70	115.2059	78.09	16 h 30’	15h13’	0.2578	0.7149	0.3606
70	115.2059	78.09	17 h 30’	16h13’	0.1189	0.5737	0.2072
70	115.2059	78.09	18 h 30’	17h13’	-0.0398	0.4123	-0.0966*
70	115.2059	78.09	19 h 30’	18h13’	-0.2075	0.2418	-0.8579*
70	115.2059	78.09	20 h 30’	19h13’	-0.3727	0.0738	-5.0471*
70	115.2059	78.09	21 h 30’	20h13’	-0.5242	-0.0802	6.5345**
70	115.2059	78.09	22 h 30’	21h13’	-0.6517	-0.2099	3.1053**
For 22.12							
70	64.8854	64.89	6h30’	6h15’	0.2085	-0.2408	-0.8659***
70	64.8854	64.89	7h30’	7h15’	0.3737	-0.0728	-5.1292***
70	64.8854	64.89	8h30’	8h15’	0.5250	0.0811	6.4747
70	64.8854	64.89	9h30’	9h15’	0.6524	0.2106	3.0983
70	64.8854	64.89	10h30’	10h15’	0.7469	0.3067	2.4352
70	64.8854	64.89	11h30’	11h15’	0.8024	0.3631	2.2099
70	64.8854	64.89	12h30’	12h15’	0.8148	0.3757	2.1686
70	64.8854	64.89	13h30’	13h15’	0.7835	0.3439	2.2785
70	64.8854	64.89	14h30’	14h15’	0.7105	0.2696	2.6350
70	64.8854	64.89	15h30’	15h15’	0.6008	0.1581	3.8005
70	64.8854	64.89	16h30’	16h15’	0.4618	0.0168	27.4812
70	64.8854	64.89	17h30’	17h15’	0.3031	-0.1446	-2.0969***
70	64.8854	64.89	18h30’	18h15’	0.1355	-0.3150	-0.4300***

continued

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
80	115.2059	72.00	6 h 30’	5h13’	-0.3490	0.1456	-2.3973*
80	115.2059	72.00	7 h 30’	6h13’	-0.1978	0.3161	-0.6257*
80	115.2059	72.00	8 h 30’	7h13’	-0.0488	0.4840	-0.1008*
80	115.2059	72.00	9 h 30’	8h13’	0.0877	0.6380	0.1375
80	115.2059	72.00	10 h 30’	9h13’	0.2026	0.7674	0.2639
80	115.2059	72.00	11 h 30’	10h13’	0.2879	0.8636	0.3333
80	115.2059	72.00	12 h 30’	11h13’	0.3378	0.9199	0.3672
80	115.2059	72.00	13 h 30’	12h13’	0.3491	0.9326	0.3743
80	115.2059	72.00	14 h 30’	13h13’	0.3208	0.9007	0.3562
80	115.2059	72.00	15 h 30’	14h13’	0.2549	0.8265	0.3085

80	115.2059	72.00	16 h 30’	15h13’	0.1560	0.7149	0.2182
80	115.2059	72.00	17 h 30’	16h13’	0.0307	0.5737	0.0535
80	115.2059	72.00	18 h 30’	17h13’	-0.1124	0.4123	-0.2727*
80	115.2059	72.00	19 h 30’	18h13’	-0.2636	0.2418	-1.0902*
80	115.2059	72.00	20 h 30’	19h13’	-0.4126	0.0738	-5.5882*
80	115.2059	72.00	21 h 30’	20h13’	-0.5493	-0.0802	6.8472**
80	115.2059	72.00	22 h 30’	21h13’	-0.6643	-0.2099	3.1653**
For 22.12							
80	64.8854	64.89	6h30’	6h15’	0.2646	-0.2408	-1.0987***
80	64.8854	64.89	7h30’	7h15’	0.4135	-0.0728	-5.6763***
80	64.8854	64.89	8h30’	8h15’	0.5500	0.0811	6.7831
80	64.8854	64.89	9h30’	9h15’	0.6649	0.2106	3.1577
80	64.8854	64.89	10h30’	10h15’	0.7502	0.3067	2.4458
80	64.8854	64.89	11h30’	11h15’	0.8002	0.3631	2.2039
80	64.8854	64.89	12h30’	12h15’	0.8114	0.3757	2.1595
80	64.8854	64.89	13h30’	13h15’	0.7831	0.3439	2.2775
80	64.8854	64.89	14h30’	14h15’	0.7173	0.2696	2.6603
80	64.8854	64.89	15h30’	15h15’	0.6183	0.1581	3.9117
80	64.8854	64.89	16h30’	16h15’	0.4930	0.0168	29.3381
80	64.8854	64.89	17h30’	17h15’	0.3499	-0.1446	-2.4205***
80	64.8854	64.89	18h30’	18h15’	0.1987	-0.3150	-0.6307***

β	ω_s	ω'_s	WT	ST	cosθ	$\cos\theta_z$	R_b
For 22.06							
90	115.2059	63.83	6 h 30’	5h13’	-0.3853	0.1456	-2.6464*
90	115.2059	63.83	7 h 30’	6h13’	-0.2551	0.3161	-0.8070*
90	115.2059	63.83	8 h 30’	7h13’	-0.1269	0.4840	-0.2621*
90	115.2059	63.83	9 h 30’	8h13’	-0.0093	0.6380	-0.0146*
90	115.2059	63.83	10 h 30’	9h13’	0.0895	0.7674	0.1167
90	115.2059	63.83	11 h 30’	10h13’	0.1630	0.8636	0.1887
90	115.2059	63.83	12 h 30’	11h13’	0.2060	0.9199	0.2239
90	115.2059	63.83	13 h 30’	12h13’	0.2157	0.9326	0.2313
90	115.2059	63.83	14 h 30’	13h13’	0.1913	0.9007	0.2124
90	115.2059	63.83	15 h 30’	14h13’	0.1346	0.8265	0.1629
90	115.2059	63.83	16 h 30’	15h13’	0.0495	0.7149	0.0692
90	115.2059	63.83	17 h 30’	16h13’	-0.0584	0.5737	-0.1018*
90	115.2059	63.83	18 h 30’	17h13’	-0.1816	0.4123	-0.4405*
90	115.2059	63.83	19 h 30’	18h13’	-0.3118	0.2418	-1.2893*
90	115.2059	63.83	20 h 30’	19h13’	-0.4401	0.0738	-5.9596*
90	115.2059	63.83	21 h 30’	20h13’	-0.5577	-0.0802	6.9521**
90	115.2059	63.83	22 h 30’	21h13’	-0.6567	-0.2099	3.1291**
For 22.12							
90	64.8854	64.89	6h30’	6h15’	0.3126	-0.2408	-1.2982***
90	64.8854	64.89	7h30’	7h15’	0.4408	-0.0728	-6.0510***

90	64.8854	64.89	8h30’	8h15’	0.5584	0.0811	6.8855
90	64.8854	64.89	9h30’	9h15’	0.6572	0.2106	3.1213
90	64.8854	64.89	10h30’	10h15’	0.7306	0.3067	2.3821
90	64.8854	64.89	11h30’	11h15’	0.7737	0.3631	2.1309
90	64.8854	64.89	12h30’	12h15’	0.7833	0.3757	2.0848
90	64.8854	64.89	13h30’	13h15’	0.7590	0.3439	2.2073
90	64.8854	64.89	14h30’	14h15’	0.7023	0.2696	2.6048
90	64.8854	64.89	15h30’	15h15’	0.6171	0.1581	3.9042
90	64.8854	64.89	16h30’	16h15’	0.5093	0.0168	30.3045
90	64.8854	64.89	17h30’	17h15’	0.3861	-0.1446	-2.6705***
90	64.8854	64.89	18h30’	18h15’	0.2559	-0.3150	-0.8122***

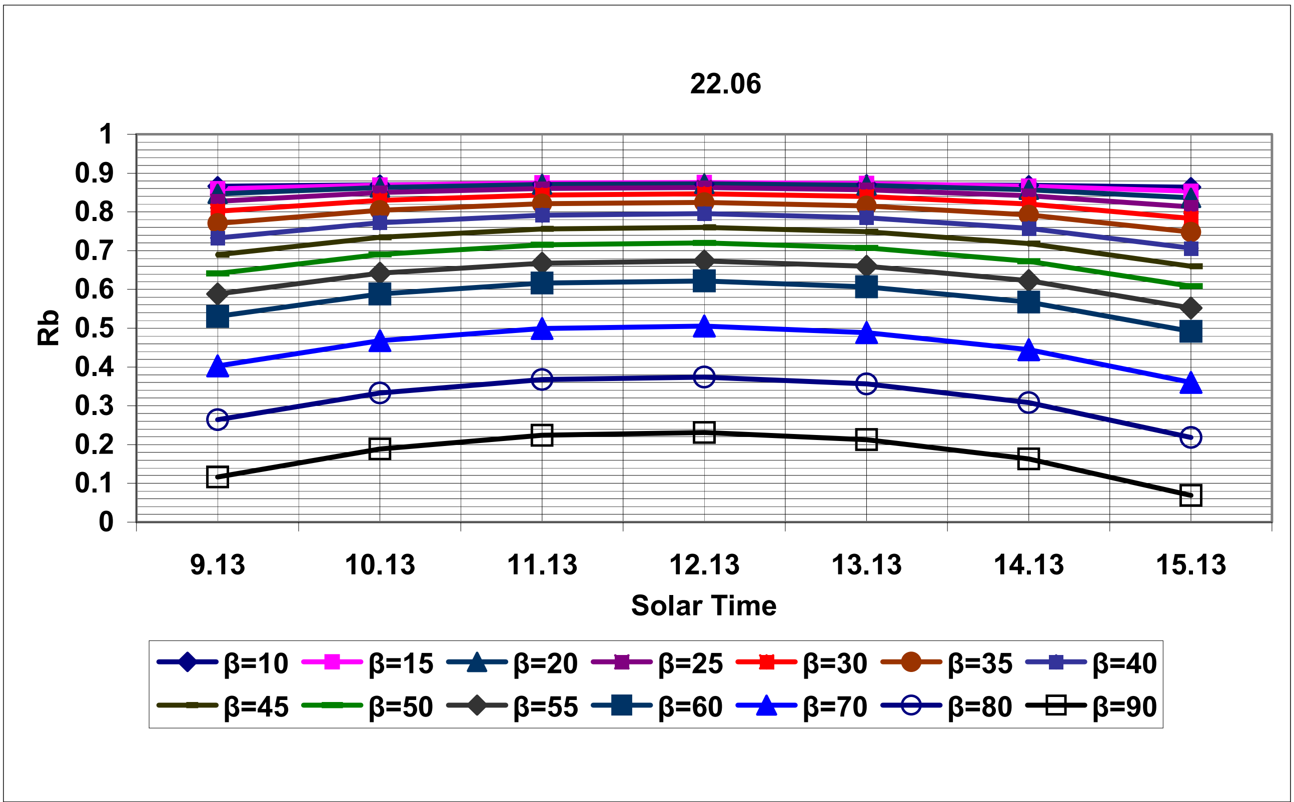

Figure IV.6: *The diagram of R_b, for* ***ST****, at various* β*. This is for 22.06.*

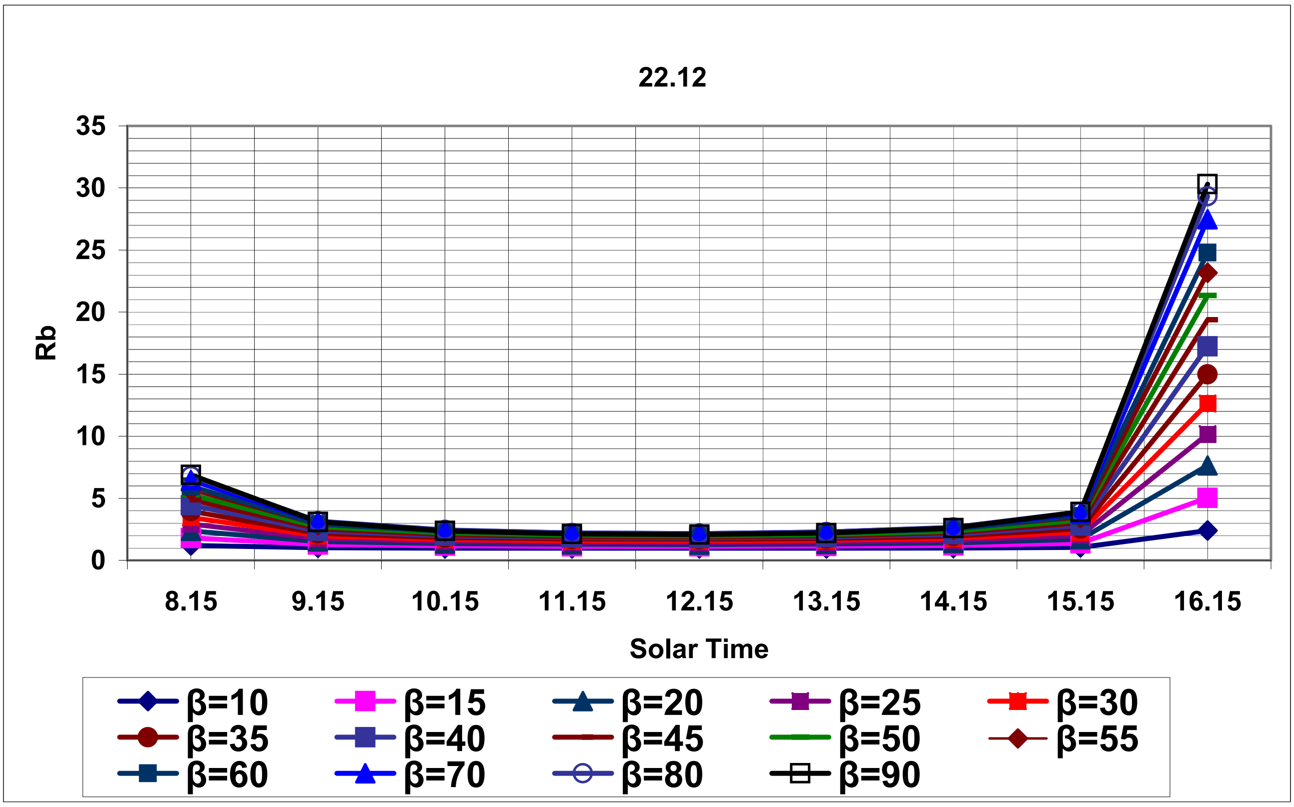

Figure IV.7: *The diagram of* R_b*, for* ***ST****, at various* β*. This is for 22.06.*

3. Determination of $\frac{\overline{H}_d}{\overline{H}}$ and $\overline{R}$ for various cities in Romania.

In this case three equations to determine $\frac{\overline{H}_d}{\overline{H}}$ are available:

(a) Liu and Jordan model:

$$\frac{\overline{H}_d}{\overline{H}} = 1.39 - 4.03 \times \overline{K}_t + 5.53 \times \overline{K}_t^2 - 3.11 \times \overline{K}_t^3$$

(b) Page model:

$$\frac{\overline{H}_d}{\overline{H}} = 1.00 - 1.13 \times \overline{K}_t$$

(c) Collares-Pereira model :

$$\frac{\overline{H}_d}{\overline{H}} = 0.775 + 0.00653 \times (\omega_s - 90) - [0.505 + 0.00455 \times (\omega_s - 90)] \times \cos(115 \times \overline{K}_t - 103)$$

and

$$\overline{R}_b = \frac{\cos(\varphi - \beta) \times \cos(\delta) \times \sin(\omega_s') + (\pi/180) \times \omega_s' \times \sin(\varphi - \beta) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta) \times \sin(\omega_s) + (\pi/180) \times \omega_s \times \sin(\varphi) \times \sin(\delta)}$$

$$\overline{R} = \left(1 - \frac{\overline{H}_d}{\overline{H}}\right)\overline{R}_b + \frac{\overline{H}_d}{\overline{H}}\left(\frac{1+\cos\beta}{2}\right) + r\left(\frac{1-\cos\beta}{2}\right)$$

Table IV.17

$\frac{\overline{H}_d}{\overline{H}}$ for **IASI**

Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
(a)	0.50	0.46	0.46	0.39	0.37	0.33	0.34	0.31	0.37	0.39	0.52	0.61
(b)	0.58	0.55	0.55	0.46	0.44	0.38	0.39	0.34	0.44	0.46	0.60	0.67
(c)	0.42	0.44	0.49	0.47	0.49	0.47	0.47	0.41	0.43	0.40	0.45	0.46

Table IV.18

$\overline{R}$ for **IASI**

Mean Monthly Day	**n**	**β**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	(a)	1.00	1.27	1.53	1.76	1.95	2.10	2.20	2.26	2.26	2.22
		(b)	1.00	1.23	1.44	1.63	1.78	1.90	1.99	2.03	2.03	1.99
		(c)	1.00	1.32	1.61	1.87	2.10	2.27	2.40	2.46	2.47	2.43
15 Feb	46	(a)	1.00	1.19	1.37	1.52	1.64	1.73	1.78	1.80	1.78	1.73
		(b)	1.00	1.16	1.31	1.43	1.53	1.61	1.65	1.66	1.64	1.59
		(c)	1.00	1.20	1.38	1.54	1.67	1.76	1.82	1.84	1.82	1.77
16 Mar	75	(a)	1.00	1.11	1.19	1.25	1.29	1.30	1.29	1.25	1.18	1.09
		(b)	1.00	1.09	1.16	1.21	1.23	1.24	1.22	1.18	1.11	1.03
		(c)	1.00	1.10	1.18	1.24	1.27	1.28	1.27	1.22	1.16	1.07
15 Apr	105	(a)	1.00	1.06	1.09	1.11	1.10	1.08	1.03	0.96	0.88	0.79
		(b)	1.00	1.05	1.08	1.09	1.08	1.05	1.01	0.95	0.87	0.78
		(c)	1.00	1.05	1.08	1.09	1.08	1.05	1.00	0.94	0.86	0.78
15 May	135	(a)	1.00	1.02	1.02	1.00	0.97	0.92	0.86	0.79	0.70	0.61
		(b)	1.00	1.01	1.01	1.00	0.97	0.92	0.86	0.79	0.71	0.62
		(c)	1.00	1.01	1.01	0.99	0.96	0.92	0.86	0.79	0.71	0.63
11 Jun	162	(a)	1.00	1.00	0.98	0.95	0.91	0.84	0.77	0.68	0.59	0.50
		(b)	1.00	1.00	0.98	0.95	0.91	0.85	0.77	0.69	0.60	0.51
		(c)	1.00	1.00	0.98	0.95	0.91	0.85	0.78	0.69	0.62	0.53

17 Jul	198	(a)	1.00	1.01	1.00	0.97	0.93	0.87	0.80	0.71	0.62	0.52
		(b)	1.00	1.01	1.00	0.97	0.93	0.87	0.80	0.72	0.63	0.53
		(c)	1.00	1.00	0.99	0.97	0.93	0.87	0.80	0.72	0.64	0.55
16 Aug	228	(a)	1.00	1.04	1.06	1.06	1.04	1.00	0.94	0.86	0.76	0.65
		(b)	1.00	1.04	1.06	1.06	1.03	0.99	0.93	0.85	0.76	0.65
		(c)	1.00	1.03	1.05	1.05	1.02	0.99	0.92	0.84	0.76	0.65
16 Sep	259	(a)	1.00	1.10	1.17	1.22	1.25	1.25	1.22	1.17	1.09	1.00
		(b)	1.00	1.09	1.15	1.19	1.21	1.21	1.18	1.13	1.06	0.96
		(c)	1.00	1.09	1.15	1.20	1.22	1.21	1.19	1.13	1.06	0.97
16 Oct	289	(a)	1.00	1.18	1.34	1.47	1.56	1.63	1.65	1.63	1.58	1.49
		(b)	1.00	1.16	1.30	1.41	1.49	1.54	1.56	1.54	1.48	1.40
		(c)	1.00	1.18	1.33	1.46	1.55	1.61	1.63	1.62	1.56	1.48
15 Nov	319	(a)	1.00	1.23	1.44	1.62	1.76	1.87	1.93	1.94	1.92	1.84
		(b)	1.00	1.19	1.36	1.51	1.62	1.70	1.74	1.75	1.72	1.65
		(c)	1.00	1.27	1.51	1.72	1.90	2.02	2.10	2.13	2.10	2.03
11 Dec	345	(a)	1.00	1.24	1.47	1.67	1.84	1.97	2.07	2.12	2.12	2.09
		(b)	1.00	1.20	1.39	1.56	1.70	1.81	1.89	1.92	1.93	1.89
		(c)	1.00	1.34	1.65	1.93	2.17	2.36	2.50	2.57	2.59	2.55

$\dfrac{\overline{H}_d}{\overline{H}}$ for **Bucuresti**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\dfrac{\overline{H}_d}{\overline{H}}$	0.47	0.46	0.45	0.39	0.37	0.32	0.31	0.31	0.35	0.38	0.50	0.59

Values are obtained by:

$$\frac{\overline{H}_d}{\overline{H}} = \mathbf{1.39} - \mathbf{4.03} \times \overline{\mathbf{K}}_t + \mathbf{5.53} \times \overline{\mathbf{K}}_t^2 - \mathbf{3.11} \times \overline{\mathbf{K}}_t^3 \quad \text{(by Liu and Jordan)}$$

Table IV.19

Table IV.20

$\overline{\mathbf{R}}$ for **Bucuresti**											
Mean Monthly Day	**β** / **n**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.25	1.48	1.69	1.86	1.99	2.08	2.12	2.12	2.07
15 Feb	46	1.00	1.17	1.33	1.46	1.56	1.64	1.68	1.69	1.67	1.61
16 Mar	75	1.00	1.10	1.17	1.23	1.26	1.26	1.24	1.20	1.13	1.04
15 Apr	105	1.00	1.05	1.08	1.09	1.08	1.05	1.00	0.93	0.85	0.75

15 May	135	1.00	1.01	1.01	0.99	0.95	0.90	0.84	0.76	0.68	0.59
11 Jun	162	1.00	1.00	0.98	0.94	0.89	0.83	0.75	0.66	0.56	0.47
17 Jul	198	1.00	1.00	0.99	0.96	0.91	0.85	0.77	0.69	0.59	0.49
16 Aug	228	1.00	1.04	1.05	1.05	1.02	0.97	0.91	0.82	0.72	0.62
16 Sep	259	1.00	1.09	1.16	1.20	1.22	1.21	1.18	1.13	1.05	0.95
16 Oct	289	1.00	1.17	1.31	1.42	1.50	1.55	1.57	1.55	1.49	1.40
15 Nov	319	1.00	1.21	1.41	1.57	1.70	1.79	1.84	1.84	1.81	1.73
11 Dec	345	1.00	1.22	1.42	1.60	1.75	1.86	1.94	1.98	1.98	1.94

$\frac{\overline{H}_d}{\overline{H}}$ for **Cluj-Napoca**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\frac{\overline{H}_d}{\overline{H}}$	0.44	0.38	0.36	.036	0.35	0.44	0.31	0.31	0.35	0.34	0.49	0.59

Table IV.21

Table IV.22

$\overline{R}$ for **Cluj-Napoca**											
Mean Monthly Day	**β** / **n**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.30	1.57	1.81	2.02	2.18	2.29	2.35	2.36	2.31
15 Feb	46	1.00	1.22	1.42	1.59	1.73	1.83	1.89	1.91	1.90	1.84
16 Mar	75	1.00	1.12	1.23	1.30	1.35	1.37	1.36	1.31	1.25	1.15
15 Apr	105	1.00	1.06	1.09	1.11	1.10	1.08	1.03	0.96	0.88	0.78
15 May	135	1.00	1.02	1.02	1.00	0.97	0.92	0.86	0.78	0.70	0.61
11 Jun	162	1.00	1.00	0.98	0.95	0.91	0.85	0.77	0.69	0.61	0.52

17 Jul	198	1.00	1.01	1.00	0.97	0.93	0.87	0.79	0.71	0.61	0.51
16 Aug	228	1.00	1.04	1.06	1.06	1.04	0.99	0.93	0.85	0.75	0.64
16 Sep	259	1.00	1.10	1.17	1.22	1.25	1.25	1.22	1.17	1.09	0.99
16 Oct	289	1.00	1.19	1.35	1.49	1.59	1.65	1.68	1.66	1.61	1.52
15 Nov	319	1.00	1.24	1.46	1.65	1.80	1.91	1.97	1.99	1.96	1.89
11 Dec	345	1.00	1.24	1.47	1.67	1.84	1.97	2.07	2.12	2.12	2.08

$\frac{\overline{H}_d}{\overline{H}}$ for **Constanta**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\frac{\overline{H}_d}{\overline{H}}$	0.49	0.44	0.39	0.34	0.31	0.30	0.28	0.28	0.32	0.36	0.45	0.55

Table IV.23

Table IV.24

$\overline{R}$ for **Constanta**											
Mean Monthly Day	**β** / **n**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.24	1.46	1.66	1.82	1.95	2.03	2.08	2.07	2.02
15 Feb	46	1.00	1.18	1.34	1.47	1.58	1.66	1.70	1.71	1.69	1.63
16 Mar	75	1.00	1.11	1.19	1.25	1.29	1.30	1.28	1.23	1.16	1.07
15 Apr	105	1.00	1.05	1.09	1.10	1.09	1.06	1.01	0.94	0.85	0.75
15 May	135	1.00	1.01	1.01	0.99	0.95	0.90	0.83	0.76	0.67	0.57
11 Jun	162	1.00	1.00	0.98	0.94	0.89	0.82	0.74	0.65	0.56	0.46

17 Jul	198	1.00	1.00	0.99	0.96	0.91	0.85	0.77	0.68	0.58	0.48
16 Aug	228	1.00	1.04	1.05	1.05	1.02	0.97	0.90	0.82	0.72	0.61
16 Sep	259	1.00	1.09	1.16	1.21	1.23	1.22	1.19	1.14	1.05	0.95
16 Oct	289	1.00	1.17	1.31	1.43	1.51	1.56	1.58	1.55	1.50	1.40
15 Nov	319	1.00	1.23	1.44	1.61	1.75	1.85	1.91	1.92	1.89	1.81
11 Dec	345	1.00	1.24	1.46	1.65	1.82	1.94	2.03	2.08	2.08	2.03

$\frac{\overline{H}_d}{\overline{H}}$ for **Craiova**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\frac{\overline{H}_d}{\overline{H}}$	0.42	0.42	0.38	0.34	0.31	0.37	0.29	0.34	0.36	0.36	0.42	0.46

Table IV.25

Table IV.26

$\overline{R}$ for **Craiova**											
Mean Monthly Day	**n** \ **β**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.27	1.52	1.75	1.93	2.07	2.17	2.22	2.22	2.17
15 Feb	46	1.00	1.18	1.35	1.49	1.60	1.68	1.73	1.74	1.72	1.66
16 Mar	75	1.00	1.11	1.20	1.26	1.30	1.31	1.29	1.25	1.17	1.08
15 Apr	105	1.00	1.05	1.09	1.10	1.09	1.06	1.01	0.94	0.85	0.75
15 May	135	1.00	1.01	1.01	0.99	0.95	0.90	0.83	0.76	0.67	0.57
11 Jun	162	1.00	1.00	0.98	0.94	0.89	0.83	0.75	0.66	0.57	0.48
17 Jul	198	1.00	1.00	0.99	0.96	0.91	0.85	0.77	0.68	0.58	0.48

16 Aug	228	1.00	1.03	1.05	1.04	1.01	0.96	0.90	0.82	0.72	0.61
16 Sep	259	1.00	1.09	1.15	1.20	1.21	1.21	1.17	1.12	1.04	0.94
16 Oct	289	1.00	1.17	1.31	1.43	1.51	1.56	1.58	1.55	1.50	1.40
15 Nov	319	1.00	1.24	1.46	1.65	1.80	1.91	1.97	1.98	1.95	1.87
11 Dec	345	1.00	1.29	1.55	1.78	1.98	2.14	2.25	2.30	2.31	2.26

$\frac{\overline{H}_d}{\overline{H}}$ for **Galati**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\frac{\overline{H}_d}{\overline{H}}$	0.49	0.46	0.46	0.39	0.38	0.34	0.31	0.31	0.34	0.36	0.50	0.61

Table IV.27

Table IV.28

$\overline{R}$ for **Galati**											
Mean Monthly Day	**β** / **n**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.26	1.49	1.70	1.88	2.01	2.11	2.15	2.15	2.11
15 Feb	46	1.00	1.18	1.34	1.48	1.59	1.67	1.71	1.72	1.70	1.65
16 Mar	75	1.00	1.10	1.18	1.23	1.26	1.27	1.25	1.21	1.14	1.05
15 Apr	105	1.00	1.05	1.08	1.09	1.09	1.06	1.01	0.94	0.86	0.76
15 May	135	1.00	1.01	1.01	0.99	0.96	0.91	0.85	0.77	0.69	0.60
11 Jun	162	1.00	1.00	0.98	0.95	0.90	0.83	0.76	0.67	0.58	0.48
17 Jul	198	1.00	1.00	0.99	0.96	0.92	0.86	0.78	0.69	0.60	0.50
16 Aug	228	1.00	1.04	1.05	1.05	1.03	0.98	0.91	0.83	0.74	0.63

16 Sep	259	1.00	1.09	1.17	1.21	1.24	1.23	1.20	1.15	1.07	0.97
16 Oct	289	1.00	1.18	1.33	1.45	1.54	1.60	1.62	1.60	1.54	1.45
15 Nov	319	1.00	1.22	1.42	1.59	1.73	1.83	1.88	1.89	1.86	1.78
11 Dec	345	1.00	1.22	1.42	1.60	1.75	1.87	1.95	1.99	1.99	1.95

$\frac{\overline{H}_d}{\overline{H}}$ for **Timisoara**												
Mean Monthly Day	17 Jan	15 Feb	16 Mar	15 Apr	15 May	11 Jun	17 Jul	16 Aug	16 Sep	16 Oct	15 Nov	11 Dec
n	17	46	75	105	135	162	198	228	259	289	319	345
$\frac{\overline{H}_d}{\overline{H}}$	0.55	0.46	0.39	0.38	0.34	0.36	0.32	0.32	0.35	0.39	0.51	0.55

Table IV.29

Table IV.30

$\overline{R}$ for **Timisoara**											
Mean Monthly Day	**β** / **n**	0^0	10^0	20^0	30^0	40^0	50^0	60^0	70^0	80^0	90^0
17 Jan	17	1.00	1.23	1.43	1.62	1.77	1.89	1.97	2.01	2.00	1.96
15 Feb	46	1.00	1.18	1.34	1.48	1.59	1.67	1.72	1.73	1.71	1.65
16 Mar	75	1.00	1.11	1.20	1.27	1.31	1.32	1.31	1.26	1.19	1.10
15 Apr	105	1.00	1.05	1.08	1.10	1.09	1.06	1.01	0.94	0.86	0.77
15 May	135	1.00	1.01	1.01	1.00	0.96	0.91	0.85	0.77	0.69	0.59
11 Jun	162	1.00	1.00	0.98	0.95	0.90	0.83	0.76	0.67	0.58	0.49
17 Jul	198	1.00	1.00	0.99	0.96	0.92	0.86	0.78	0.70	0.60	0.50

16 Aug	228	1.00	1.04	1.05	1.05	1.02	0.98	0.91	0.83	0.74	0.63
16 Sep	259	1.00	1.09	1.16	1.21	1.23	1.23	1.20	1.15	1.07	0.97
16 Oct	289	1.00	1.17	1.31	1.43	1.51	1.56	1.58	1.56	1.50	1.42
15 Nov	319	1.00	1.22	1.42	1.58	1.72	1.81	1.86	1.87	1.84	1.77
11 Dec	345	1.00	1.26	1.49	1.70	1.88	2.02	2.12	2.17	2.18	2.13

Appendix V
SI UNITS

Basics units (Name, Symbol, Quantity)

Meter,	m	Length
Kilogram,	kg	Mass
Second,	s	Time
Kelvin,	K	Temperature

tera	:T	10^{12}	milli	: m	10^{-3}
mega	:M	10^{6}	micro	: k	10^{-6}
giga	:G	10^{9}	nano	: k	10^{-9}
kilo	:k	10^{3}	pico	: p	10^{-12}

Physics Constants

Boltzmann constant : $k=1.38066\times10^{-23}$ J/K
Elementary charge : $q=1.60218\times10^{-19}$ C
Elementary mass : $m_0=0.91095\times10^{-30}$ kg
Planck constant : $h=6.62627\times10^{-34}$ J·s
Speed of light : $c=2.99792\times10^{8}$ m/s

Length, m

1 ft = 0.3048 m
1 in = 25.4 mm
1 mile = 1.609 km

Speed, m/sec

1 ft/min = 0.00508 m/s
1 mile/h = 0.4470 m/s
1 km/h = 0.27778 m/s

Volume m^3, but it is symbolized also as volume per mass, m^3/kg, or per sec, m^3/s

1 liter = 10^{-3} m^3
1 ft^3 = 28.32 liters
1 UK gal = 4.456 liters
1 US gal = 3.785 liters
1 ft^3/lb = 0.06253 m^3/kg

Force, N = kg·m / s

pascal Pa = N/m^2
1 lbf =4448 N
1 bar =105 Pa
1 psi =6.894 kPa
1 ton =2000 lb

Joule energy, Joule = N·m = W·s, or appears as energy produced per unit of mass, J/kg, J/kg·C

1 kWh = 3.6 MJ =860.4 kcal= 3412 Btu
1 Btu = 1.055 kJ = 2.93×10^{-4} kWh
1 kcal = 4.1868 kJ
1 Btu/lb= 2.326 kJ/kg
1 cal/cm^2= 0.04187 MJ/m^2

Power, watts = J/s, other expressions of practical sizing, W/m^2, W/m^2 ^{0}C

1 Btu/h = 0.2931 W
1 kcal/h= 1.163 W
1 hp = 0.7457 kW
1 Btu/h ft^2 F = 5.678 W/m^2 C
1 Btu/h ft F = 1.731 W/m C

Viscosity Pa·s = N·s/m^2 = kg/m·s

1 cP (centipoises) = 10^{-3} Pa·s
1 lbf·h/ft2 = 0.1724 MPa·s

Mass, kg, or density, or mass density per m^2, kg/m^3, kg/s, kg/s·m^2

1 kg = 2.204 lb
1 lb = 0.45359237 kg
1 lb/ft^3 = 16.02 kg/m^3
1 g/cm^3= 10^3 kg/m^3
1 lb/h = 0.0001256 kg/s

Practical units for energy

1 metric ton coal = 8200kWh
1 baril petrolium = 1700 kWh