ANEXO 1

Institut für Wärme- und Brennstofftechnik
TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG

MASTER THESIS

"Simulation of the power and heat demand of a building in Soller and the solution with solar-thermal collector and photovoltaic generator"

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TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG
INSTITUT FÜR WÄRME- UND BRENNSTOFFTECHNIK
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Assignment of the
Master thesis
for Mr. Andres Gil Cladera
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Topic:

Simulation of the power and heat demand of a building in Soller and the solution with solar-thermal collector and photovoltaic generator

In this thesis, a regenerative generator system with solar-thermal and photovoltaic technology should be developed to meet the power, heat, cooling and warm water demand of a building in Soller. Heat and cooling demand of this building should be covered primarily by the photovoltaic generator by driving a suitable air-conditioning to maintain the required temperature. Heat for warm water should be primarily supplied by a suitable solar-thermal collector with heat storage. The electrical grid is considered as backup power source for case of too high power demand. The goal of the thesis is the development of a suitable photovoltaic and solar-thermal system for the building of Soller throughout a reference year by simulation. The thesis should contain the following steps,

- verification of the power, heat, cooling and warm water demand of the building in Soller throughout the reference year
- literature research to establish an overview of potential suitable system components and concepts
- design of the required system including photovoltaic generator and solar-thermal collector
- simulation based on the verified energy demand
- parameter study and evaluation

The work must be carried out individually. The details of the thesis are to be discussed with the supervisors. The guidelines for the preparation of studies or graduation projects at the "Institut für Wärme- und Brennstofftechnik" should be followed. The thesis should be finished within 4 months. The acknowledgement of this thesis in *Universidad de Zaragoza* will be regulated by the responsible tutors and faculty of this university according to its currently valid examination regulation.
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Braunschweig, 21. 5. 2010

Prof. Dr.-techn. R. Leithner

Starting date: _____ :

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Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Bachelor-Arbeit selbstständig angefertigt, keine anderen als die angegebenen Hilfsmittel benutzt habe.

Braunschweig, den 12. November 2010

Andres Gil Cladera

*** Abstract ***

In this Thesis, a simulation of the energy demand of a building in Soller is made according to the characteristics of the building and the climatic variables in this locality.

Two different regenerative generator systems are developed to meet the power, heat, cooling and hot sanitary water demand of the building. The first installation covers the heat and cooling demand by means of a photovoltaic generator in combination with a reversible heat pump. The hot sanitary water demand is covered in this case through a thermal collectors installation. The second developed installation uses a thermal collectors installation to cover the heat and hot sanitary water demand. Cooling is also supply by the same thermal collectors installation in combination with an adsorption machine.

The electrical grid is considered as backup power source for both installations for case of too high power demand.

The performance of both installations is simulated and compared one another.

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Basics Units List

Magnitude	Units in I.S.	
	name	symbol
length	Meter	m
time	Second	s
force	Newton	N
energy	Jule	J
temperature	Celsius/Kelvin grade	°C - K
mass	Kilogram	kg
power	Watt	W

Symbol list of Variables

Symbol	Description	Units
A	Surface	[m^2]
a_1	First order loss coefficient of thermal collector	[$W.m^{-2}.K^{-1}$]
a_2	Second order loss coefficient of thermal collector	[$W.m^{-2}.K^{-1}$]
B'	Characteristic length	[m]
B	Cost	[€]
B_0	Investment cost	[€]
b	Cost per year	[€/year]
C_{batt}	Capacity of the Batteries	[Amperes.h]
C_{Solar}	Solar Constant	[$W.m^{-2}$]
c_P	Specific heat, constant pressure	[$J.kg^{-1}.K^{-1}$]
c_V	Specific heat, constant volume	[$J.kg^{-1}.K^{-1}$]
DD	Direction of the wind respect North direction	[º]
DOD	Deep of Discharge	[%]
D_{lv}	mass diffusivity of liquid and vapor	(m^2/s)
d	Diameter	[m]
E	Electrical energy	[J]
FF	Form Factor of photovoltaic panels	Dimensionless
F_{shadow}	Fraction of the window without shadows	Dimensionless
F_M	Fraction of the hollow taken up by the frame	Dimensionless
F_{solar}	Fraction of solar radiation able to go trough the window	Dimensionless

Symbol	Description	Units
g	Transmittance of windows glasses	Dimensionless
G	Solar irradiance	[$W.m^{-2}$]
H	high	[m]
h	Convection Heat transfer coefficient	[$W.m^{-2}.K^{-1}$]
h_{pg}	Evaporation enthalpy	[$J.kg^{-1}$]
I_{el}	Intensity of electricity	[Amperes]
i	Consumer price index	[%]
j	Bank interest	[%]
B_0	Solar constant	[$W.m^{-2}$]
k	Looses coefficient	[dimensionless]
K_{simult}	Simultaneity coefficient	[dimensionless]
K_{system}	gain	[dimensionless]
L	length	[m]
M	Maintenance costs	[€]
m	Mass	[kg]
$\dot{m}$	Mass flow	[$kg.s^{-1}$]
N_{day}	Number of days	[days]
$N_{s,cells}$	Number of cells in series connection	
N_{Panel}	Number of panels in a photovoltaic installation	
N_{Person}	Number of persons	
P	Electric power	Watt [$J.s^{-1}$]
p	Pressure	Pascal [$N.m^{-2}$]
$\dot{Q}$	Heat flow rate	Watt [$J.s^{-1}$]
Q	Heat amount	[J]
R_{th}	Thermal resistance	[$m^2.K.W^{-1}$]
RH	Relative Humidity	[%]
s	Laplace's variable	
T	Temperature	[ºC]
t	time	
U	Overall heat transfer coefficient	[$W.m^{-2}.K^{-1}$]
V_{el}	Voltage	[Volts]
V_{MPP}	Voltage at maximum power of the panel	[Volts]
v	Velocity	[$m.s^{-1}$]
v_{wind}	Speed of the wind over a surface	[$m.s^{-1}$]
w	Specific humidity	[$kg.kg^{-1}$]

Symbol	Description	Units
X	Moisture content	[dimensionless]
x	thickness	[m]
z	altitude	[m]

Greek Symbols List

Symbol	Description	Units
α	steam transfer diffusivity	$[m^2.s^{-1}]$
α_0	absorptance	Dimensionless
ρ	density	$[kg.m^{-3}]$
δ	Inclination of the surface	[°]
φ	Solar altitude	[°]
ϵ	Emissivity	Dimensionless
ϕ	Azimuth	[°]
θ	Orientation of the surface	[°]
η	Efficiency	Dimensionless
η_0	Optical factor	Dimensionless
λ	Thermal conductivity	$[W.m^{-1}.K^{-1}]$
μ	Dynamic viscosity	Poise $[kg.m^{-1}.s^{-1}]$
ν	Cinematic viscosity	m/r $[m^2.s^{-1}]$
σ	Stefan-Boltzmann constant	$[W.m^{-2}.K^{-4}]$
υ	Temperature	[°C]
τ	Constant of time	[s]

Climatic Variables List

Symbol	Description	Units
Az_M	Solar Azimuth	[°]
DD_M	Direction of wind	[°]
FF_M	Speed of wind	[m/s]
G_Bh_M	Direct solar radiation	$[W/m^2]$
G_Dh_M	Diffuse solar radiation	$[W/m^2]$
G_Gh_M	Global solar radiation	$[W/m^2]$
Ta_M	Air temperature	[°C]
hs_M	Solar altitude	[°]

Symbol	Description	Units
p_M	Atmospheric pressure	[mbar]
RH_M	Relative Humidity	[%]
dm_M	Day of the month	
dy_M	day of the year	
h_M	Hour of the day	
hy_M	Hour of the year	
m_M	Month of the year	
y	year	

Subscripts

0	Conditions inside the building		MPP	Maximal power point
1	Referent to case 1		m	Median value
2	Referent to case 2		N	North
acc	Water accumulator		OC	Open circuit
ads	Adsorption machine installation		obst	obstacle
amb	External ambient		op	operating
b	Building		P	produced
batt	Battery		panel	Photovoltaic panel
Bh	Beams over horizontal surface		photo	Photovoltaic installation
cell	Photovoltaic cell		rad	radiative
circuit	Hydraulic circuit in thermal collector		S	Solar / South
collector	Thermal collector		sat	saturation
cond	condenser		SC	Short circuit
convert	DC/AC converter		sens	sensible
Gh	Global over horizontal surface		surf	surface
Dh	Diffuse over horizontal surface		T	theoretical
E	East		tank	Expansion tank
eq	Equivalent		transfer	Heat transfer
H	Heating / cooling		vapor	vaporizer
HSW	Hot sanitary water		W	West
i	Nodes of building envelop		w	Water
lat	latent		w,net	Water from public net
M	Maintenance			

Abbreviation List

F	Fraction
caib	Cabildo insular balear
COP	Coefficient of performance
CPI	Consumer price index
HSW	Hot sanitary water
IDA	Calidad del aire interior (Quality of internal air)
INE	Instituto nacional de estadística
Mityc	Ministry of Industry, Tourism and Commerce
MPP	Maximal power point
NOCT	Nominal operating cell temperature
PPD	Predictable percentage of dissatisfied
REE	Red eléctrica española
STC	Standard test conditions

1. INTRODUCTION

1.1. Motivation

In opposition to the growing problems that are being caused by the traditional forms of energy production, renewable energies have undergone a great development during the last years including solar technologies.

Nowadays, solar technologies are able to supply energy in remote places where no other kinds of energy are available.
It is also possible today connecting installations to the electric grid in order to get profit from the reduction of the electrical bill, certainty in energy supply and for using environment friendly technologies.

1.2. Objectives

1.2.1. General Objectives

The main objective of the project is to calculate the necessities of power, heat and warm water of a building.
In the present study the equations which govern the transfer of heat will be implemented to make a simulation of the energy balance in a building.

1.2.2. Specific Objectives

The building in which the simulation will be made is located in Soller (Mallorca) where a regenerative generator system with solar-thermal and photovoltaic technology should be developed to provide with the power, heat, cooling and warm water demand of the building.
The climatic dates from a reference year and the design conditions established by the Spanish current legislation will be used to solve the equations.

Likewise, the installation covering the energy demand will be sized and calculated.
In a first part of this study, warm water will be provided by a thermo-solar collector. Heat and cool for heating and air conditioning will be provided by a reversible heat pump. Electricity to feed the heat pump will be provided by a photovoltaic generator.
In the second part, the study of viability of an absorption machine to provide heating and air conditioning will be made in order to compare with the heat pump installation from the first part and to chose the best technology for this case. The solar collectors will provide hot water to feed the absorption machine as well as hot sanitary water.

1.3. Description of the project

1.3.1. Fundamentals

The basis of conduction heat exchange are the equations of heat transfer from Fourier

$$\dot{Q} = -\lambda \cdot A \cdot \frac{\partial T}{\partial x} \qquad (1.1)$$

and the variation of internal energy

$$\dot{Q} = \rho \cdot c_p \cdot A \cdot \frac{\partial T}{\partial t} \cdot dx \qquad (1.2)$$

Some simplifying assumptions are going to be accepted

- Heat and moisture flow are one-dimensional
- Thermal properties of the building materials are homogeneous
- The properties of the air-stream flowing over the surface of the building structures are homogeneous.
- The surface temperature differences between the partition walls, ceiling, and floors are small; therefore, the radiative exchange between these surfaces can be ignored.

The finite difference method will be used to solve the energy balance in the building. The complete description of it will be made in **chapter 3**.

1.4. Solar Resources

1.4.1. The Sun

The *Sun* is a giant sphere of very high temperature gases with a 1.39 x 10^9 m diameter and placed about 1.5 x 10^{11} m from the Earth.
The Earth receives on its external atmosphere about 1.73 x 10^{14} kW power from the Sun.
The irradiance, G_{surf} , is the radiative energy that arrives per square meter on a surface perpendicular to the beams. It is in W.m^{-2} measured.
It is also defined the Solar Constant, C_{Solar} , as the irradiation that arrives at the external surface of the atmosphere. Its value is given by the NASA as 1353 W.m^{-2} ($\pm$ 1.6%).

Nevertheless, the temporal distribution of the irradiance which arrives at the surface of the

Earth is lower and very irregular according to the instantaneous composition of the atmosphere. This fact is observed in **figure 1.1**

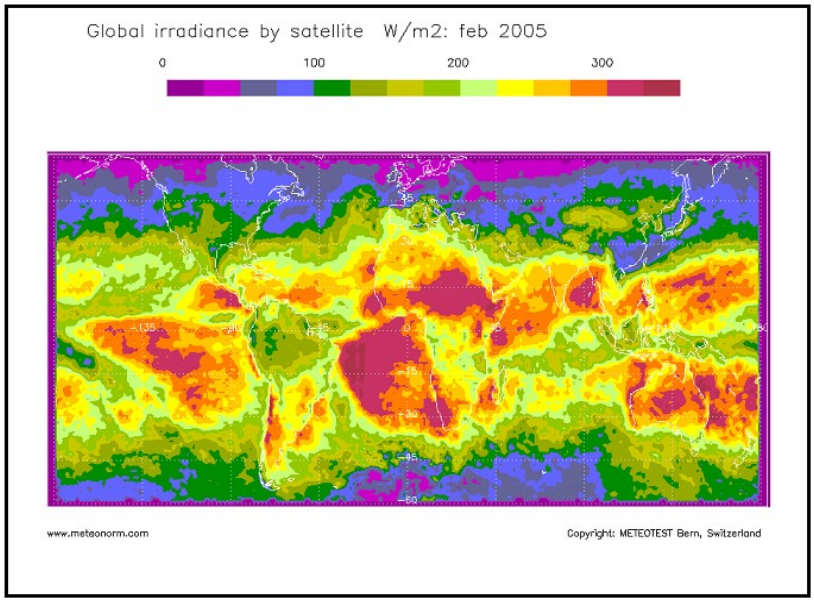

Figure 1.1 *– Solar irradiance on the Earth surface*

1.4.2. Composition of Solar Irradiance

As result of the interaction between the solar radiation with the atmosphere, the energy which arrive at a surface has several components:
Direct irradiance, G_{Bh} ($W.m^{-2}$), whose direction has not been modified by the atmosphere;
Diffuse irradiance, G_{Dh} ($W.m^{-2}$), which came from all over the vault of heaven because of multiples reflections on the atmosphere; and the radiation which has been previously reflected on the floor.

The reflectance on the floor depends on the *Albeldo*, that is a property of the surface of the floor. Some examples are shown in **table 1.1**.

Surface	Albeldo
Snow	0.95
Water (big incidence angles)	0.07
Grass	0.26
Gravel	0.13

Table 1.1 *– Albeldo of different surfaces (source:* ***[12]****)*

The composition of these radiations is called *Global irradiance*, G_{Gh} ($W.m^{-2}$). The proportion between one type or other depends on the meteorological conditions as shown in **table 1.2**

Climatic conditions	Irradiance ($W.m^{-2}$)	Diffuse component (%)
Clear sky	700 – 1000	10 – 20
Partially cloudy	200 – 500	20 – 90
Totally cloudy	50 – 150	90 – 100

Table 1.2 – Diffuse irradiance on several conditions (source [10])

The diffuse irradiance is not isotropic. Also in very cloudy days, the diffuse irradiance is clearly anisotropic. In this project, the value of diffuse irradiance on the horizontal surface, given by METEONORM, (**see Appendix A**), will be considered constant in all directions for each instant. This assumption is acceptable because mostly days of the year in the place where the project is located are very sunny, and global irradiance involve a low percentage of the diffuse component .
Detailed information about the calculation of diffuse irradiance on inclined planes is given in **[16]**.

1.4.3. Position of the sun.

The position of the sun for an observer placed on the surface of the Earth is defined by two angles:

1) Azimuth, ϕ (º): Is the angle between the horizontal projection of the line that links the observer with the Sun, and the South direction.
   The Azimuth is 0° if the projection of solar radiation on an horizontal plane follows the axis North-South. Azimuth angles are negatives from the South direction to the East. Azimuth angles are positives from South direction to the West.
2) Solar altitude, φ (º): Is the angle between an horizontal surface and the line that links the observer with the Sun.

On the other hand, for mostly of problems involving solar technologies, the surfaces where the solar radiation arrives are defined also with two angles

δ (º): inclination of the main plane of the surface respect the horizontal.

θ (º): angle between the horizontal projection of the normal vector of the surface, and the axis North-South.

The relation between these angles is shown in **figure 1.2**

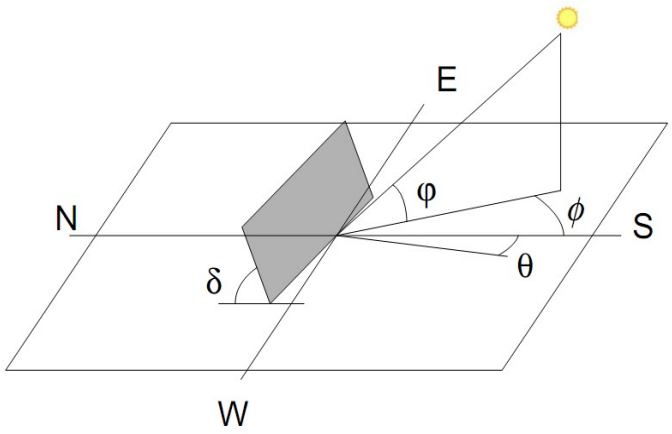

Figure 1.2 *– Position of the sun.*

1.4.4. Calculation of shadows

The looses of solar radiation suffered by a surface due to projected shadows from surrounding obstacles are variables during a day and depend on the latitude, the date and the time. They must be considered in order to get the maximum profit from a solar installation.

The basis relation between the length of the shadow, L_{shadow} , the height of the obstacle, H_{obst} , and the solar altitude is

$$tg(h_s) = \frac{H_{obst}}{L_{shadow}} \qquad \textbf{(1.3)}$$

Solar installations expose great surfaces to the sun by means of thermal or photovoltaic collectors depending the used technology to catch the energy from the sun.

In the present study it is generally used the name “collector” for any surface catching the solar radiation to get profit of it; it is used the name “photovoltaic panel” if the solar radiation is directly transformed into electrical power; and “thermal collector” if the solar radiation is transformed into heat power.

The purpose of this discussion is avoiding that any shadow is projected over a panel or collector. Therefore, the minimum distance in which the collectors must be placed, according the **figure 1.3**, will be

$$L_{min} = L_{collector} \cdot \left[\frac{sen(\delta)}{tg(\varphi)} + \cos(\delta) \right] \qquad \textbf{(1.4)}$$

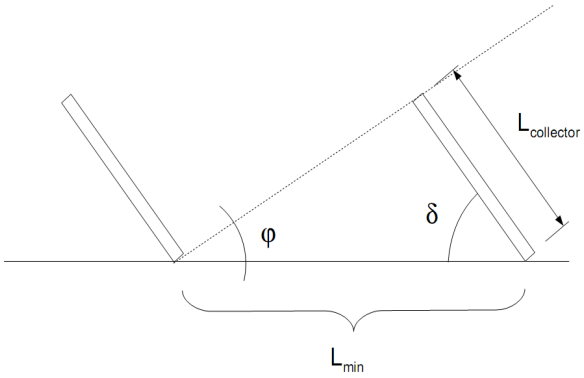

Figure 1.3 – *Minimum distance between collectors*

1.4.5. Inclination of collectors

The radiation that arrives at a surface is given by the equation **(1.5)** – see also **chapter 3** – for each orientation an inclination of the surface and each position of the sun.

$$G_{surf} = G_{Bh} \cdot [\cos(\varphi) \cdot sen(\delta) \cdot \cos(\phi - \theta) + sen(\varphi) \cdot \cos(\delta)] + G_{Dh} \quad [W/m^2] \qquad \textbf{(1.5)}$$

Solar installations have usually mechanical systems to orient the collectors into the sun called *solar trackers*. Its function is to ensure that the surface of collectors remains perpendicular to solar beams.

There are two main groups, according to the degrees of freedom:

Dual axis tracker

They have two degrees of freedom. Therefore, the surface remains always perpendicular to the sun. They are divided into

Tilt Dual Axis Tracker: The axes of rotation are typically aligned either along a true North meridian or an east west line of latitude.

Azimuth – Altitude Dual Axis Tracker : Its primary axis is vertical to the ground. The secondary axis is then typically normal to the primary axis.

Single axis tracker

There is one degree of freedom. They are divided into

Horizontal single axis tracker: The axis of rotation is horizontal with respect to the ground.

Vertical Single Axis Trackers : The axis of rotation is vertical with respect to the ground. These trackers rotate from East to West over the course of the day.

Tilted Single Axis Trackers : They are so considered all trackers with axes of rotation between horizontal and vertical. A particular implementation of this type of tracker is the Polar Aligned Single Axis Trackers, in which the tilt angle is equal to the latitude of the installation.

Fixed installation

The collectors of these installation have not any degree of freedom.
The collectors should be oriented to the South, if the installation is placed on North hemisphere; and to the North, if the installation is placed in South hemisphere, in order get the greatest profit of solar irradiance.
The optimal angle of collectors δ(º) depends on the use of the installation during a year

If it is desired an optimal efficiency for all the year, the tilt of the panels should be equal to the latitude of the place.
This tilt will be 15º bigger if it is needed a best use in winter, and 15º smaller for a best use in summer.

The relation between the tilt of the panels and the energy which arrive at them is shown in **figure 1.3**

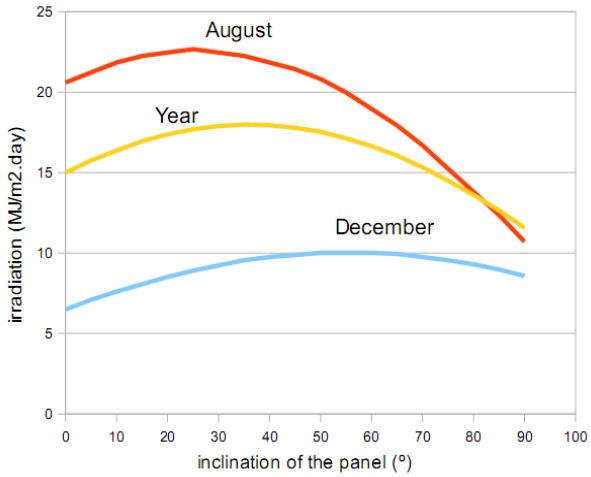

Figure 1.3 *– Received energy in Baleares according to the tilt of the panels*

2. DESCRIPTION OF THE HOUSE

2.1. Location

The building is located in Soller, in Mallorca (Spain).
The coordinates of this place are 39º 47' Latitude North and 2º 4" Longitude East **[1]**.
Exact location of this locality is shown in **figure 2.1**.

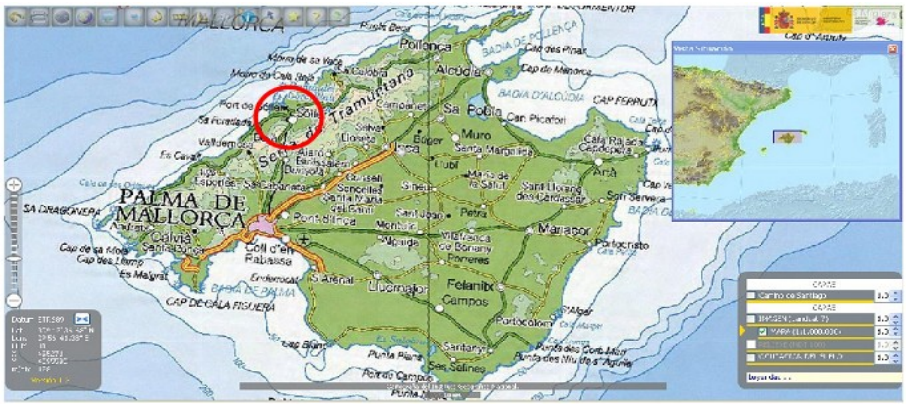

*Figure 2.1 – Location of the building (source: **National Geographic Institute [1]**)*

2.2. Climatic Data

The climatic data in this place have been calculated with the software **METEONORM [2]** from the measurements of 2005, every hour, by interpolating from the real data from the nearest meteorological stations **[3]**. A summary of results is described in the **Appendix A**.
The assumption of 2005 as a reference year is accepted and the measurements are considered representative enough for this locality.

The main obtained data are shown in **table 2.1**.

Symbol	Description	Units
G_{Gh}	Global solar radiation measured in horizontal surface	[W.m^{-2}]
G_{Bh}	Direct solar radiation measured in horizontal surface	[W.m^{-2}]
G_{Dh}	Diffuse solar radiation measured in horizontal surface	[W.m^{-2}]
ϕ	Azimuth	[º]
φ	Solar Altitude	[º]
v_{wind}	Speed of the wind	[m.s^{-1}]
DD	Direction of the wind respect North direction	[º]
T_{amb}	Temperature of the air	[ºC]
RH_{amb}	Relative Humidity of air	[%]

***Table 2.1** – Obtained parameters with software METEONORM*

Figure 2.2 shows the different climatic zones in which the land is divided.

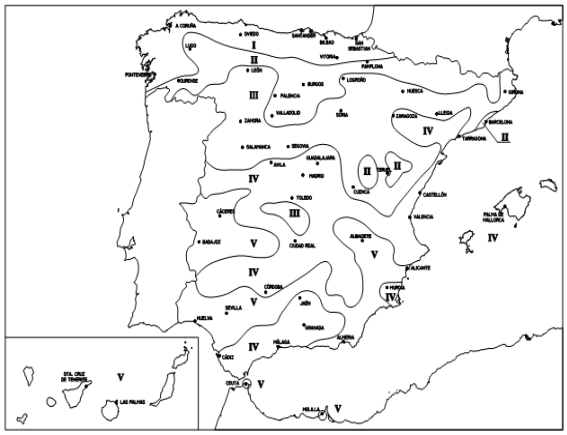

Figure 2.2** – Climatic zones in Spain according to **[4]

According to **[4]**, there is 12 climatic zones in function of climatic severity of winter (A, B, C, D y E), and summer (1, 2, 3, 4). Impossible combinations for Spanish climatology are excluded.

Knowing to which climatic zone belong the installation is required to set some design parameters in next sections.

The location where this project is placed corresponds with the climatic zone B-IV.

2.3. Geometric Description

A plane of the building is shown in the **figure 2.3**

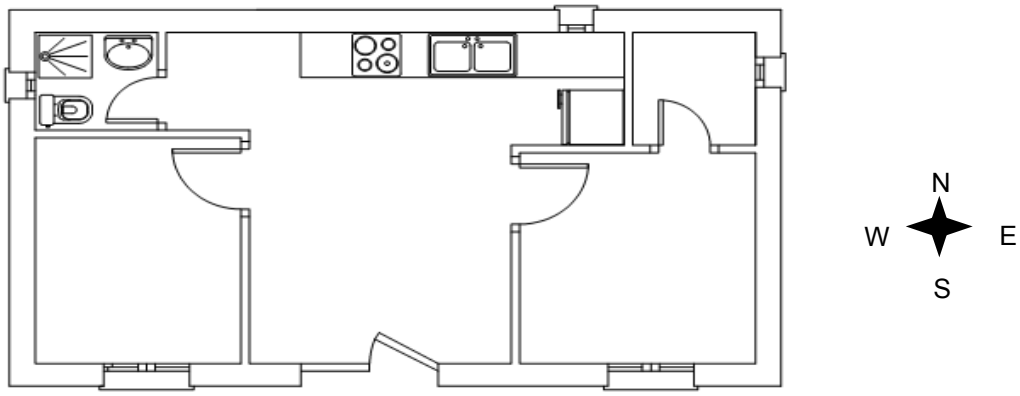

Figure 2.3 *– Plane of the building*

The orientation of the principal axis of the house is East – West. This fact will permit a best use of solar radiation in winter and a lower insolation in Summer, reducing the cooling loads. See also **Appendix B** for more details about the size and the distribution of the house.

2.4. Building envelope

The building envelope is formed by the external walls, the floor and the roof. Each one is formed by a multilayer composition of different materials.
The materials of these elements are characterized by the thermal conductivity, λ [$W.m^{-1}.K^{-1}$], the density ρ [$kg.m^{-3}$], the specific heat at constant pressure, c_p [$J.kg^{-1}.K^{-1}$], the thickness, x [m] and the steam transfer diffusivity, α [$m^2.s^{-1}$] .

The characteristic parameter of a multilayer wall composition is the thermal resistance of the surface, R_{th} [m^2 .$K.W^{-1}$]

$$R_{th}=\frac{x_i}{\lambda_i} \quad [m^2.K.W^{-1}] \qquad \textit{(2.1)}$$

where

x_i = thickness of each layer
λ_i = thermal conductivity of each material

It is also defined the heat transfer coefficient, U [$W.m^{-2}.K^{-1}$], as

$$U=\frac{1}{R_{th}} \quad [W.m^{-2}.K^{-1}] \qquad \textit{(2.2)}$$

2.4.1. External walls

The composition of external walls is given in **table 2.2**. They all are in contact with air. The properties of the materials are extracted from reference **[6]**.
The composition of external walls is always the same, excepted in the bad room, where there is also ceramic plaques and the thickness of the mortar is bigger.

Material	λ [$W.K^{-1}.m^{-1}$]	x [m]	c_P [$J.kg^{-1}.K^{-1}$]	ρ [$kg.m^{-3}$]	[$m^2.s^{-1}$]	R_l [$m^2.K.W^{-1}$]
Plaster	0,57	0.015	920	800	6	0,03
Hollow Block	0.435	0.10	840	1200	10	0,48
Concrete Block	0,47	0.25	1000	1800	6	0,53
Mortar	0,55	0.015	1000	1125	10	0,03
Mortar bathroom	0,55	0,02	1000	1125	10	0,04
Ceramic Plaques	1,3	0,01	840	2300	10^{30}	0,01

***Table 2.2** – Composition of external walls*

In **table 2.3** are detailed the geometric parameters of walls, which will allow to determine the solar gain in the building. The hollows can be windows or doors.
The criterion for the sign of the orientation is the following:

- 0° for South orientation
- positive angles for East orientation
- negatives angles for West orientation.

Wall	Orientation (º)	Surface (m^2)	Hollows (m^2)	Net surface (m^2)
South	0	18,92	5,4	13,52
East	+90	12,17	0,19	11,98
North	±180	23,22	0,19	23,03
North bathroom	±180	4,83	0	4,83
West	-90	12,17	0	12,17
West bathroom	-90	3,35	0,11	3,24

***Table 2.3.** Geometric parameters of external walls*

2.4.2. Roof

The composition and orientation of the roof is given in **tables 2.4** and **2.5** respectively.

Material	λ [W.K^{-1}.m^{-1}]	x [m]	c_P [J.kg^{-1}.ºC^{-1}]	ρ [kg.m^{-3}]	α [m^2.s^{-1}]	R_i [m^2.K.W^{-1}]
Plaster	0,57	0.015	920	800	6	0,04
Hollow Block	0.435	0.10	840	1200	10	0,11
Isolation	0.03	0.04	1590	25	20	1,74
Reinforced concrete	1,15	0,06	1050	1900	60	0.05
Tile	1	0,02	800	2000	30	0,02
Wood Beams	0,16	0,2	1600	660	50	1,25

Table 2.4. *Composition of the roof*

	Orientation (º)	Surface (m^2)	Hollow (m^2)	Net surface (m^2)	Inclination respect horizontal (º)
Roof	0	35,32	0	35,32	12.41
Beams	0	6,14	0	6,14	12,41

Table 2.5. *Orientation of the roof*

2.4.3. Floor

The composition of the floor is given in **table 2.6**

Material	λ [W.K^{-1}.m^{-1}]	x [m]	c_P [J.kg^{-1}.ºC^{-1}]	ρ [kg.m^{-3}]	α [m^2.s^{-1}]	R_i [m^2.K.W^{-1}]
Floor tile	2,3	0,02	1000	2500	30	0,01
Morter	0,55	0,04	1000	1125	10	0,07
Isolation	0.03	0.04	1590	25	20	1,74
Reinforced Concrete	1,15	0,15	1050	1900	60	0,13
Gravel	2	0,15	1050	1450	50	0,08

Table 2.6. *Composition of the floor*

According to the appendix E of **[4]**, the value of the U_{floor} (heat transfer coefficient of the floor), is given in **table 2.7**, after defining the next parameters

		D = 0.5 m					D = 1.0 m					D ≥ 1.5 m				
	R_s	R_s (m² K/W)					R_s (m² K/W)					R_s (m² K/W)				
B'	0,00	0,50	1,00	1,50	2,00	2,50	0,50	1,00	1,50	2,00	2,50	0,50	1,00	1,50	2,00	2,50
1	2,35	1,57	1,30	1,16	1,07	1,01	1,39	1,01	0,80	0,66	0,57	-	-	-	-	-
5	0,85	0,69	0,64	0,61	0,59	0,58	0,65	0,58	0,54	0,51	0,49	0,64	0,55	0,50	0,47	0,44
6	0,74	0,61	0,57	0,54	0,53	0,52	0,58	0,52	0,48	0,46	0,44	0,57	0,50	0,45	0,43	0,41
7	0,66	0,55	0,51	0,49	0,48	0,47	0,53	0,47	0,44	0,42	0,41	0,51	0,45	0,42	0,39	0,37
8	0,60	0,50	0,47	0,45	0,44	0,43	0,48	0,43	0,41	0,39	0,38	0,47	0,42	0,38	0,36	0,35
9	0,55	0,46	0,43	0,42	0,41	0,40	0,44	0,40	0,38	0,36	0,35	0,43	0,39	0,36	0,34	0,33
10	0,51	0,43	0,40	0,39	0,38	0,37	0,41	0,37	0,35	0,34	0,33	0,40	0,36	0,34	0,32	0,31
12	0,44	0,38	0,36	0,34	0,34	0,33	0,36	0,33	0,31	0,30	0,29	0,36	0,32	0,30	0,28	0,27
14	0,39	0,34	0,32	0,31	0,30	0,30	0,32	0,30	0,28	0,27	0,27	0,32	0,29	0,27	0,26	0,25
16	0,35	0,31	0,29	0,28	0,27	0,27	0,29	0,27	0,26	0,25	0,24	0,29	0,26	0,25	0,24	0,23
18	0,32	0,28	0,27	0,26	0,25	0,25	0,27	0,25	0,24	0,23	0,22	0,27	0,24	0,23	0,22	0,21
≥20	0,30	0,26	0,25	0,24	0,23	0,23	0,25	0,23	0,22	0,21	0,21	0,25	0,22	0,21	0,20	0,20

***Table 2.7** – Heat transfer coefficient, U_{floor} [W.m^{-2}.K^{-1}]*

isolation thermal resistance, $R_{th,floor}$ = 1.74 [m^2.K.W^{-1}]
width of perimetrical isolation band, D > 1.5 m (The floor is isolated in all the surface)

Characteristic length, $$B' = \frac{Surface}{\frac{1}{2}Perimeter} = 3.21 \text{ m}$$

2.5. Hollows on building envelope

2.5.1. Glazed surfaces

The chosen glasses for windows are double glasses, 4-6-4. According to **[13]**, the properties of these glasses are

U_{glass} = Heat transfer coefficient of the glass

The frames are made in Aluminium without thermal bridges with a heat transfer coefficient, U_{frame} equal 4 (W/m^2.K), according to UNE-EN ISO 10077-1 **[14]**. The colour of them are blue medium.

For the chosen windows the thermal transfer coefficient of hollows, U_{window} ,is given in reference **[4]** as

$$U_{window} = (1 - F_{frame}) \cdot U_{glass} + U_{frame} \cdot F_{frame} \quad [\text{W.m}^{-2}.\text{K}^{-1}] \qquad (2.4)$$

where

F_{frame} = percentage of surface covered by the frame (including the box for the blind)
U_{glass} = heat transfer coefficient of the glass [W.m^{-2}.K^{-1}]
U_{frame} = heat transfer coefficient of the frame [W.m^{-2}.K^{-1}]

2.5.2. Main Door

The main door are made in wood, with the next properties:

x_{wood} = thickness of the door = 5 [cm]
λ_{wood} = thermal conductivity of wood = 0.2 [$W.m^{-1}.K^{-1}$]
$x_{frame,door}$ = thickness of the frame of the door = 10 [cm]
$\lambda_{frame,door}$ = thermal conductivity of frame of the door = 0.2 [$W.m^{-1}.K^{-1}$]

$$U_{wood} = \frac{\lambda_{wood}}{x_{wood}} \qquad (2.5)$$

$$U_{frame,door} = \frac{\lambda_{frame,door}}{x_{frame,door}} \qquad (2.6)$$

The heat transfer coefficient of the door, U_{door} is given as

$$U_{door} = (1 - F_{frame,door}) \cdot U_{frame,door} + U_{wood,door} \cdot F_{frame,door} \qquad (2.7)$$

In **[4]** are set the maximum values of the heat transfer coefficient according to the surface occupied by the hollows in relation with the walls. This values and geometric properties are given in **table 2.8**.

Element	Orientation	Surface (m^2)	(%)	U_{lim}	U_{glass}	F_{frame}	U_{window}
Window 1	South	1,1	28.54	5.6	3.3	0,37	3,56
Window 2		1,1					
Main door		3,2			5	-	5
Window 3	East	0,19	1,58	5,7	3.3	0,5	3,65
Window 4	North	0,19	5,62				
Window 5	West	0,11	0,89			0,6	3,72

Table 2.8. *Heat transfer coefficient and geometric parameters of windows and door*

The windows and door will be supposed without thermal inertia. That means that they will not keep energy on themes selves and the temperature changes will be as fast as the changes is outside temperature. The thermal inertia of theses elements is very small compared with the thermal inertia of walls. Therefore it can be ignored.

2.6. Internal Walls

Knowing the composition of internal walls is needed in order to calculated the capacity of walls to keep energy.
In this case is not considered the plaques on bath room because its effect to this calculation

is negligible.
It is assumed that there will be no heat transfer through the internal walls from one room to other. This assumption is reasonable and will allow to simplify the calculations since the internal temperature in rooms will be controlled and kept around the design temperature.

The composition of the internal walls is given in **table 2.9**.

Material	λ [$W.K^{-1}.m^{-1}$]	x [m]	c_P [$J.kg^{-1}.°C^{-1}$]	ρ [$kg.m^{-3}$]	α [$m^2.s^{-1}$]	R_i [$m^2.K.W^{-1}$]
Plaster	0,57	0.015	920	800	6	0,04
Hollow Block	0.435	0.10	840	1200	10	0,11
Plaster	0,57	0.015	920	800	6	0,04

***Table 2.9** – Composition of internal walls*

3. LOAD CALCULATION

3.1. Design Conditions

3.1.1. Heating and Air Conditioning

The design conditions for Air Conditioning and Heating are established according to the valuation of thermal comfort. Thermal comfort can be defined like a subjective perception of conformity with existing thermal ambiance.
There is six parameters which influence on the thermal comfort.

Environmental parameters
- Air Temperature inside the room, T_0
- Relative Humidity inside the room, RH_0
- Medium Radiative Temperature inside the room, $T_{m,rad,0}$
- Medium speed of air inside the room, $v_{m,0}$

Personal parameters
- Metabolism
- Thermal Resistance of Clothes

The design conditions for air conditioning installations are regulated by the **[5]** (RITE – Regulations of Thermal Installations of Buildings, according its initials in Spanish), on the basis of Fanger's method about heat exchange between human body and the environment. Fanger's method is detailed explained in the norm UNE-EN ISO 7730 **[7]**, and the inform CR 1742-1998 **[8]**, about quality of air. In absence of more details, the values given in **[11]** are going to be accepted.

Four parameters should be studied to satisfy this regulations:
- Exigence of environmental thermal quality
- Exigence of internal air quality
- Exigence of hygiene

- Exigence of acoustic environmental quality

The design values of these parameters are shown in **table 3.1**

Parameters	Winter	Summer
Operative Temperature	21 – 23	23 – 25
Speed of air	< 0.15 m/s	< 0.25 m/s
Relative Humidity	40 – 50	45 – 60
Thermal resistance of clothes	1 clo	0.5 clo
Metabolic activity	1.2 Met	1.2 Met

Table 3.1 *– Parameters of thermal comfort inside the room*

The velocity of air inside the room, for a PPD = 15%, is set in reference **[5]** as

$$v_0 = \frac{T_0}{100} - 0.07 \quad [\text{m/s}] \qquad (3.1)$$

where

T_0 = Dry temperature of the air inside the room
PPD = Predictable percentage of dissatisfied.

The operative Temperature is also in **[5]** defined as

$$T_{operative} = \frac{T_0 + T_{m,rad}}{2} \quad [°C] \qquad (3.2)$$

where

$T_{m,rad}$ = Medium radiative temperature of building envelope.

In relation with the quality of air there is four categories according to the use of the building. For each category there is a minimum external flow of ventilation.
For this project the quality IDA 2 will be set.

All the space in the building are considered habitable space with low internal heat dissipation, according to the classification made in **[4]**, where the amount of heat dissipated from illuminating or equipment will be low.
In absence of more detailed dates, the hygrometric rate will be 3, according to the norm UNE-EN ISO 13788: 2002 **[9]**.
The values of ventilation flow are shown in the **table 3.2**.

Category	Use of the building	Ventilation flow (dm^3/s per person)
IDA 1 (excellent quality air)	Hospitals, clinics, laboratories, nurseries	20
IDA 2 (good quality air)	Offices, residences, libraries, museums, schools	12.5
IDA 3 (medium quality air)	Magazines, cinemas, theaters, hotel rooms, bars, cafeterias, computer rooms...	8
IDA 4 (bad quality air)	-	5

Table 3.2 - *Quality of air and external flow of ventilation* ***[5]***

3.1.2. Electrical Appliances.

In absence of more details, the installation of **table 3.3** is assumed to be placed in the building.

Units	Description	Power per unit (W)	Subtotal (W)	Time of use (hours/day)	Energy (Wh/day)
2	Fluorescent kitchen	36	72	4	288
7	Compact fluorescent lamp	11	77	4	308
1	Wash machine	1000	1000	1	1000
1	Refrigerator	200	200	6	1200
1	Electric cooker	1500	1500	1	1500
1	TV	75	75	2	150
1	Computer	100	100	2	200
1	Iron	1500	1500	0.5	750
1	Hair dryer	800	800	0.5	400
1	Toaster	800	800	0.5	400
		TOTAL	**6124 (W)**		**6196 (Wh/day)**

Table 3.3 - *Installed Power and times of use*

It is imposed a 0.3 coefficient of simultaneity, K_{simult} , as design condition for the current study, according to the planned use of the building. The highest instantaneous power demanded by the building by accepting $P_{installed} \approx$ 6200 (W) is given as:

$$P_{max,appliances} = P_{installed} * K_{simult} = 6200 * 0.3 = 1860 \text{ W}$$

The energy consumed by the appliances, in I.S. Units and by accepting $6196 \approx 6200$ (Wh) , is:

$E_{appliances}$ = 6200.3600 (J) = 22.32 10^6 (J)

3.1.3. Hot sanitary water

Table 3.4 is an extract from reference **[4]**. It shows the needed flow of hot sanitary water, $\dot{V}_{HSW}$ [liters/day.person], according to the use of the building.

Use of the building	Flow [liters of HSW/day] (60°C)	
Single family house	30	Per person
Multi family building	22	Per person
Hospitals and clinics	55	Per bed
Hotels (four star)	70	Per bed
Hotels (three star)	55	Per bed
Hostel/Hotel (two star)	40	Per bed
Camping	40	Per place
Pension/Hotel (one star)	35	Per bed
Residence (old people, students...)	55	Per bed
Schools	3	Per student
Factories	15	Per person
Gymnasium	20 to 25	Per person
Laundry	3 to 5	Per kilogram of clothes
Restaurants	5 to 10	Per meal
Cafeterias	1	Per lunch

***Table 3.4** – Consumption of Hot sanitary water (HSW) according the use of the building*

According to **[4]**, the temperature of storage will be 60 °C

If the installation is designed with a different storage temperature, T_{acc} , the required flow $\dot{V}_{HSW(T_{acc})}$ must to be modified every month like follows, according the equation given in **[4]**.

$$\dot{V}_{HSW(T_{acc}\,°C)} = \dot{V}_{HSW(60°C)} \cdot \frac{60 - T_{w,net}}{T_{acc} - T_{w,net}} \quad \text{[liters/day.person]} \quad \textit{(3.3)}$$

where

$\dot{V}_{HSW(T_{acc})}$ = Flow of HSW at temperature T

$\dot{V}_{HSW(60)}$ = Flow of HSW at temperature 60 °C (given in **table 3.4**)

$T_{w,net}$ = Median temperature of water in public net every month (°C)

3.2. Calculation of Solar Radiation Loads

3.2.1. Solar radiation on any orientation

In the locality of Soller, the value of solar radiation can be very important in order to calculate the load of heating and air conditioning. A difference is make between the radiation which arrives at opaque surfaces – walls, roof and doors – and the radiation which arrives at windows (transparent hollows)

From the dates of solar radiation of the software METEONORM, the values of solar radiation on an horizontal surface are known, as well as the position of sun, which is given by the Azimuth, ϕ , and the solar altitude, φ (see also **chapter 1 – Position of the Sun**)

The criterion for Azimuth angle is the following

0° for South orientation
positive angles for East orientation
negatives angles for West orientation.

With those parameters it is possible to calculate the radiation of sun on any orientation and inclination surface, by using the relation of Fariña (1990) **[22]**:

$$G_{surf} = G_{Bh} \cdot [\cos(\varphi) \cdot sen(\delta) \cdot \cos(\phi - \theta) + sen(\varphi) \cdot \cos(\delta)] + G_{Dh} \qquad \textit{(3.4)}$$

where

G_{Bh} = direct radiation on an horizontal surface (W/m^2)
G_{Dh} = diffuse radiation on an horizontal surface (W/m^2)
ϕ = Azimuth (º)
φ = solar altitude (°)
δ = inclination of the surface respect the horizontal (º)
θ = orientation of the surface (º)

In this project it is assumed that the diffuse radiation is constant in every direction. Detailed information about the calculation of diffuse irradiance on inclined planes is given in **[16]**.

3.2.2. Solar radiation on opaque surfaces

The value of solar radiation is taken in this section to calculate the temperature equivalent on the surface, T_{eq} **[24]** as following:

$$T_{eq} = T_{amb} + \frac{\alpha_0 \cdot G_{surf}}{h_{amb}} \qquad \textit{(3.5)}$$

where:

α_0 = absorptivity coefficient of the surface, given in **table 3.3**
h_{amb} = convection coefficient in external surface

To calculate h_{amb} the assumption of forced convection is accepted. According to **[12]**(chapter 3), it is given for a normal range of air velocities as

$$h_{amb} = 10.22 + 4.47 \cdot v_{wind} \quad [W/m^2.K] \qquad \textit{(3.6)}$$

where

v_{wind} = speed of wind over the surface (m/s)

The temperature equivalent on the surface, T_{eq} , is used on **section 3.3** to calculate the conduction heat.

3.2.3. Solar radiation trough transparent surfaces

The solar radiation which arrives at the surface of the window is given by **(3.4)**. But not all this radiation is able to go trough the window. It's needed to know the solar factor F_{solar} of the window, given like a % of radiation able to go inside the building through the window.

The modified solar factor is given in reference **[4]** as

$$F_{solar} = F_{shadow} \cdot [(1 - F_{frame}) \cdot g + F_{frame} \cdot 0.04 \cdot \alpha_0 \cdot U_{frame}] \quad [\%] \qquad \textit{(3.7)}$$

where

F_{frame} = percentage of surface covered by the frame (including the box for the blind)
U_{frame} = heat transfer coefficient of the frame
α_0 = absorptance of the surface, according the color of the material given in **table 3.5**
F_{shadow} = fraction of window surface receiving the solar radiation
g = transmittance of the glasses given in **[15]**

Colour	Claire	Medium	Dark
White	0,20	0,30	0,00
Yellow	0,30	0,50	0,70
Beige	0,35	0,55	0,75
Brown	0,50	0,75	0,92
Red	0,65	0,80	0,90
Green	0,40	0,70	0,88
Blue	0,50	0,80	0,85
Grease	0,40	0,65	--
Black	--	0,96	--

Table 3.5. *Absorptance coefficient of the frame according its colour*

The effect of curtains or drapes is not considered in a first approximation.

3.3. Heat convection transfer Loads

During the insolation time, the convection on external walls is already considered as indicated in **chapter 3.2.2**.
When solar radiation is equal zero, forced convection is considered on external walls, in which the parameter h_{amb} is given by the equation **(3.6)**

On internal walls, natural convection is considered with the coefficients of heat transfer given in the **table 3.6**, which has been extracted from **[4]**.

Position of the wall and direction of heat flow	h_0 [W/m².K]
Vertical enclosures – or pitch over horizontal $> 60°$ – and horizontal heat flow	7,69
Horizontal enclosures – or pitch over horizontal $\leq 60°$ – and ascending heat flow	10
Horizontal enclosures – or pitch over horizontal $\leq 60°$ – and descending heat flow	5,88

***Table 3.6** – Heat transfer coefficient for natural convection*

The equation for convection heat transfer is given for each surface of the building as

$$\dot{Q}_{surf} = A_{surf} \cdot h_{0,surf} \cdot (T_{surf} - T_0) \quad [W] \qquad \textit{(3.8)}$$

where

$h_{0,surface}$ = natural convection heat transfer coefficient, given in **table 3.6**
T_0 = air temperature inside the building (ºC)
T_{surf} = temperature on the internal surface of the building (ºC)
A_{surf} = area of considered surface [m²]

3.4. Air filtration and ventilation flow loads

3.4.1. Design parameters

In reference **[4]** are set the maximum values of permeability to the air for woodwork or metalwork, in the building envelope, with an overpressure of 100 Mpa, according to the climatic zone where the building is placed. The values are the followings:

a) Climatic zones A y B : 50 m³ / h.m² .

b) Climatic zones C, D and E : 27 m^3 /h.m^2 .

In the absence of more information, the maximum value for the climatic zone B is going to be used for the loads in this section.

On other hand, the **[4]**, sets the minimum values of ventilation flow, in l/s, as shown in **table 3.7**

		Per occupant	Per m^2	Per room
Type of local	Bedroom	5		
	Living room	3		
	Bath room			15
	Kitchen		2	

Table 3.7 – Minimum ventilation flow l/s

3.4.2. Sensible and latent heat

The loads of air filtration and ventilation have one component of sensible heat and one component of latent heat.
The component of sensible heat is due to the difference of temperatures between the exterior and the design temperature, and its value is given as

$$\dot{Q}_{amb,sens} = \rho_{amb} \cdot c_{p,amb} \cdot \dot{V}_{ventilation} \cdot (T_{design} - T_{amb}) \quad [W] \qquad (3.9)$$

The latent heat is due to the difference of humidity, and given as

$$\dot{Q}_{amb,lat} = 2442 \cdot \dot{m} \cdot (w_{amb} - w_0) \quad [W] \qquad (3.10)$$

where

2442 kJ/kg = enthalpy of vaporization of water at 25 °C (**[3]**) (design temperature in Summer)
w_{amb} = specific humidity of external air (kg water/kg dry air)
w_0 = air specific humidity inside the building (kg water/kg dry air)

$$w = 0.622 \cdot \frac{p_{steam}}{p - p_{steam}} \quad [\text{kg water/kg dry air}] \qquad (3.11)$$

where

p_{steam} = partial pressure of vapour (Pa)
p_{amb} = atmospheric pressure (Pa)

The next relation is needed to calculate p_{steam}

$$RH_{amb} = 100 \cdot \frac{p_{steam}}{p_{sat}} \quad [\%] \qquad (3.12)$$

where

p_{sat} = saturation pressure (Pa)

RH_{amb} = relative humidity of the ambiance, given in climatic data

according to appendix G of **[4]**, p_{sat} is given as

$$\text{if } T_{amb} > 0° \rightarrow \quad p_{sat} = 610.5 \cdot \exp\left(\frac{17.269 \cdot T_{amb}}{237.3 + T_{amb}}\right) \qquad \textit{(3.13)}$$

$$\text{if } T_{amb} < 0° \rightarrow \quad p_{sat} = 610.5 \cdot \exp\left(\frac{21.875 \cdot T_{amb}}{265.5 + T_{amb}}\right) \qquad \textit{(3.14)}$$

Note that equations **3.13** and **3.1**4 are just valid if temperatures are given in Kelvin [K], and not in Celsius degrees.

3.5. Human Heat, Lighting and Electrical Appliances Loads

The gains due to Human Heat, Lighting and Electrical Appliances are going to be ignored in this study because they are considered to have a very low influence compared with the other gains.

3.6. Energetic Balance – Finite Difference Method

This section is an extract of reference **[9]**.

To make the simulation of heat flows, the finite difference method is used.
Each surface composing external walls and roof is divided in small layers each one with the same length Δx. Each layer corresponds with a node. The subscript i makes reference to the number of the node. Interior nodes are located at the center of the layer and surface nodes are located on the surface, as shown in **figure 3.1**. An energy balance or a mass balance at each node at selected time intervals results in a system of algebraic equations that can be employed to determine the temperature and moisture for each node in terms of neighbouring nodal temperatures or moisture contents, nodal geometry, and the thermal and moisture properties of the building structure. The amounts of stored heat and moisture are expressed as an increase of internal energy and moisture content at the nodes.

Heat conduction can be approximated by using the finite difference form of the Fourier law, as

$$\dot{Q}_{i+1 \rightarrow i} = \frac{\lambda_i \cdot A_i (T^t_{i+1} - T^t_i)}{\Delta x} \quad [W] \qquad \textit{(3.15)}$$

where

λ_i = thermal conductivity of node i ($W.K^{-1}.m^{-1}$)

A_i = surface of layer i (m^2)

T_{i+1}^t = Temperature of node i+1, at time t (K)

T_i^t = Temperature of node i, at time t (K)

Δx = spacing between the nodal points (m)

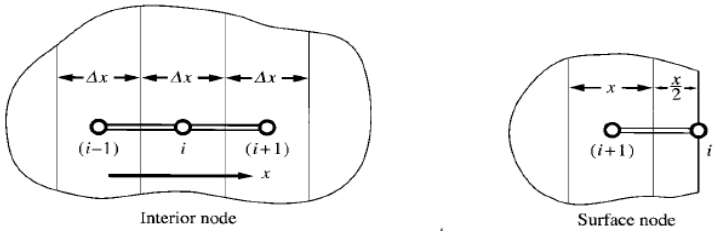

Figure 3.1 *– selection of nodes*

3.6.1. Simplifying Assumptions

When the finite difference method is used to calculate space cooling loads, simplifications are often required to reduce the number of computer calculations and to solve the problem more easily. The errors due to simplification should be within acceptable limits. For a typical room in the building, as shown in **figure. 3.1**, the following are the simplifying assumptions:

- Heat and moisture flow are one-dimensional.
- Thermal properties of the building materials are homogeneous.
- The properties of the air stream flowing over the surface of the building structures are homogeneous.
- The surface temperature differences between the partition walls, ceiling, and floors are small; therefore, the radiative exchange between these surfaces can be ignored.

3.6.2. Heat and Moisture Transfer at Interior Nodes

An interior node i is considered as shown in the left part of **figure. 3.1**. For a one-dimensional heat flow, if there is no internal energy generation and according to the principle of heat balance, the energy balance of node i is

$$\dot{Q}_{i-1\to i}+\dot{Q}_{i+1\to i}=\frac{\partial E_i}{\partial t}\approx\frac{\rho_b\cdot c_{p,b}\cdot A_i\cdot\Delta x\cdot(T_i^{t-\Delta t}-T_i^t)}{\Delta t} \qquad (3.16)$$

Substituting (3.15) into (3.16) and solving for $T_i^{t+\Delta t}$, we have

$$T_i^{t+\Delta t}=Fo_i\cdot(T_{i-1}^t+T_{i+1}^t)+(1-2\cdot Fo_i)\cdot T_i^t \qquad (3.17)$$

where

T_i^t = Temperature in node i at time t

T_{i+1}^t = Temperature in node i+1 at time t

T_{i-1}^t = Temperature in node i-1 at time t

$T_i^{t+\Delta t}$ = Temperature in node i at time t + Δt

Fo_i = Fourier number of layer i = $\frac{\lambda_b}{\rho_b \cdot c_{pb}} \frac{\Delta t}{(\Delta x)^2}$ ***(3.18)***

λ_b = conductivity heat transfer coefficient of the building material

ρ_b = density of the building material

$c_{p,b}$ = specific heat of the building material

Δx = thickness of the layer

Subscript *b* indicates the building material

The criterion to ensure the convergence of the method is

$Fo_i \leq 0.5$ for each layer

Similarly, for moisture transfer at the interior nodes,

$$X_i^{t+\Delta t} = Fo_{mass} \cdot (X_{i-1}^t + X_{i+1}^t) + (1 - 2 \cdot Fo_{mass}) \cdot X_i^t \qquad \textit{(3.19)}$$

and

$$Fo_{mass} = \frac{D_{lv} \cdot \Delta t}{(\Delta x)^2} \qquad \textit{(3.20)}$$

where

X= moisture content, dimensionless

D_{lv} = mass diffusivity of liquid and vapor (m^2/s)

3.6.3. Heat and Moisture Transfer at Surface Nodes

For one-dimensional heat flow, and by supposing that the radiative portion of energy of lights, occupants and appliances are zero, the energy balance at surface node i of the partition wall as shown in **figure 3.1** is

$$\frac{k_b \cdot A_i \cdot T_{i+1}^t - T_i^t}{\Delta x} + h_0 \cdot A_i \cdot (T_0^t - T_i^t) + \rho_{air} \cdot h_{mass,i} \cdot A_i \cdot X_i^t \cdot (w_0^t - w_i^t) \cdot h_{pg} = \rho_b \cdot c_{pb} \cdot A_i \cdot \frac{\Delta x}{2} \frac{T_i^{t+\Delta t} - T_i^t}{\Delta t}$$

(3.21)

where

h_0 = convective heat transfer coefficient inside the building ($W/m^2 K$)

$h_{mass,i}$ = convective mass transfer coefficient of surface (m/s)

w_i^t = humidity ration corresponding to surface i at time t

h_{fg} = latent heat of vaporization at surface temperature (J/kg)

solving for $T_i^{t+\Delta t}$, we have

$$T_i^{t+\Delta t}=2\cdot Fo\cdot\left\{T_{i+1}^{t}+Bi\cdot\left(T_0^t+\frac{\rho_{air}\cdot h_{mass,i}\cdot h_{fg}\cdot X_i^t\cdot(w_0^t-w_i^t)}{h_{ci}}\right)\right\}+\left[1-2\cdot Fo\cdot(1+Bi)\right]\cdot T_i^t \qquad \textbf{(3.22)}$$

where

Bi = number of Biot for external nodes

$$Bi=\frac{h_0\cdot\Delta x}{\lambda_b} \qquad \textbf{(3.23)}$$

The criterion to ensure the convergence of the method is

$$Fo\,(1+Bi)\ \leq\ 0.5$$

3.6.4. Space air temperature

If the infiltrated air is ignored, the heat balance on the space air or the plenum air can be described by the following relation:

Internal energy of supply air + convective heat transfer from building structures + Heat gains of the installation = variation of internal energy of space air

$$\dot{V}_{supply}\cdot\rho_{amb}\cdot c_{p,amb}\cdot T_{amb}^{t+\Delta t}+h_0\cdot A\cdot(T_{surf}^{t+\Delta t}-T_0^t)+\Sigma\dot{Q}=\rho_{amb}\cdot c_{p,amb}\cdot\dot{V}_{supply}\cdot T_0^{t+\Delta t} \qquad \textbf{(3.24)}$$

solving for $T_0^{t+\Delta t}$ gives

$$T_0^{t+\Delta t}=\frac{\rho_{amb}\cdot c_{p,amb}\cdot\dot{V}_{supply}\cdot T_{amb}^{t+\Delta t}+\sum h_0\cdot A_{surf}\cdot T_{surf}^{t+\Delta t}+\Sigma\dot{Q}}{\rho_{amb}\cdot c_{p,amb}\cdot\dot{V}_{supply}+\sum A_{surf}\cdot h_0} \qquad \textbf{(3.25)}$$

where

$\dot{Q}$ = *heating + air conditioning + solar radiation + ventilation flow* [W]

The calculation of $\dot{Q}_H$ is raised on the next section.

3.7. Control of temperature

This is the classical problem of Automatic Control, in which the control of the temperature of a room is desired face up the different disturbances, like the solar radiation, ventilation or the differences on external temperature.
To solve this problem in a first approximation, the Ziegler-Nichols empirical method is used, in order to know the value of the power which is necessary to introduce in the building.
The description of the method is made in the following chapter.

3.7.1. Ziegler-Nichols Method

A more detailed description of this method is made in reference **[18]**.
A model of the house is made with the software Matlab, according the description made in **chapter 2**, and the conditions for an stationary state are set, in which the temperature of the building are constant and equal to the external temperature, who is also constant.
Under that conditions, an unitary step in external temperature is applied. The finite differences method, explained more below, allows to know the evolution of internal temperature. The step response of the temperature inside the building is showed in **figure 3.2.** Once calculated the regulator, the temperature inside the building with heating is also calculated and shown in the figure. As observed, the regulator eliminates the disturbance.

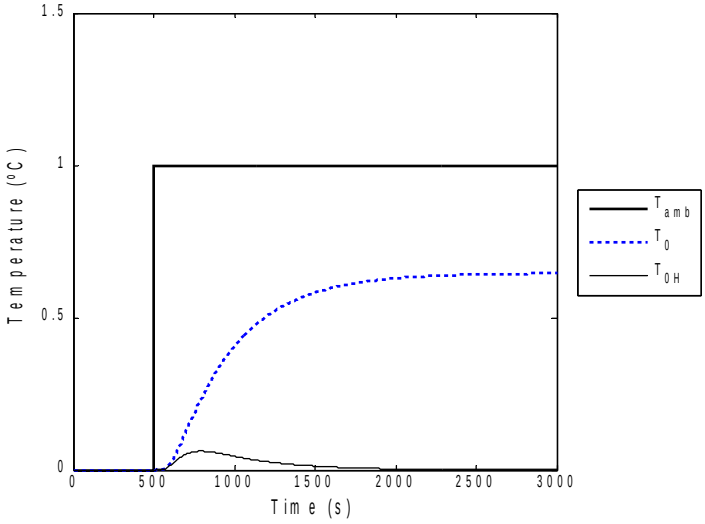

Figure 3.2. *Answer of the system face up an unitary steep input*

This curve corresponds with a second-order behaviour. It is approximated into a first-order system plus a lag-delay, with the form

$$G(s)=\frac{K_{system}}{1+\tau_p s}\cdot e^{-\tau_0 \cdot s} \qquad \textit{(3.26)}$$

where

G(s) = model of the house, in the Laplace variable
s = variable of Laplace
K_{system} = relationship between the output and the input.
$\tau_p = 1.5\ (t_2 - t_1)$
$\tau_0 = t_2 - \tau_p$
t_1 = time to raise the 28.3 % of the final value of the output
t_2 = time to raise the 63.2 % of the final value of the output

Since it is supposed that the disturbances will be relatively slow (the maximal variation in external temperature per day is about 10 ºC), a Proportional-Integral will be designed to calculate the value of $\dot{Q}_H$ every Δt, during all the year.

For that purpose, the Ziegler-Nichols method set the next values for the parameters of the controller

The value of these parameters are only an approximation. It haven been adjusted in several simulations until getting satisfactory results. For this project it is accepted

$T_{Integrer} = 20$
$K_{Proportional} = 1$

Controller Mode	Parameters	Estimation
P	$K_{Proportional}$	$\frac{\tau_P}{K \cdot \tau_0}$
PI	$K_{Proportional}$	$\frac{0.9 \cdot \tau_P}{K \cdot \tau_0}$
	$T_{Integrer}$	$\frac{\tau_0}{0.3}$
PID (standard)	$K_{Proportional}$	$\frac{1.2 \cdot \tau_P}{K \cdot \tau_0}$
	$T_{Integrer}$	$2 \cdot \tau_0$
	$T_{Derivative}$	$\frac{\tau_0}{2}$

Table 3.8. *Values of the parameters of the controller* ***[18]***

With the parameters of the controller, it is possible to calculate the value of the action like follows:

$$u = K_{Proportional} \cdot \left[e + \frac{1}{T_{Integrer}} \cdot \int e \cdot dt \right]$$

where

e = error (difference between the output and the design temperature).

The implemented equation in the simulation, according to the nomenclature explained before, is

$$\dot{Q}_H^{t+\Delta t} = \frac{V_{house}}{\Delta t} \cdot c_{p,air} \cdot \rho_{air} \cdot \left[(T^t_{design} - T^t_0) + \frac{1}{T_{Integrer}} \cdot \sum_{i=1}^{t} (T^i_{design} - T^i_0) \cdot \Delta t \right] \qquad \textbf{(3.27)}$$

where

$\dot{Q}_H$ = Transient power to meet the designed temperature [W]

3.8. Results of the simulation

The results of the evolution of temperatures and the needed power for heating and air conditioning are shown in **figures 3.3** and **3.4**. Negatives values in **figure 3.3**. represent power for cooling, which must be extracted from the house.

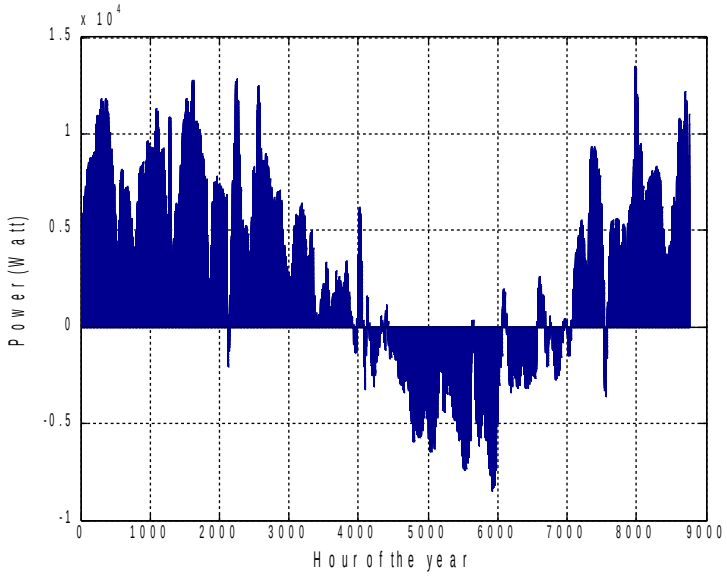

Figure 3.3. *Needed power to maintain the temperature inside the building*

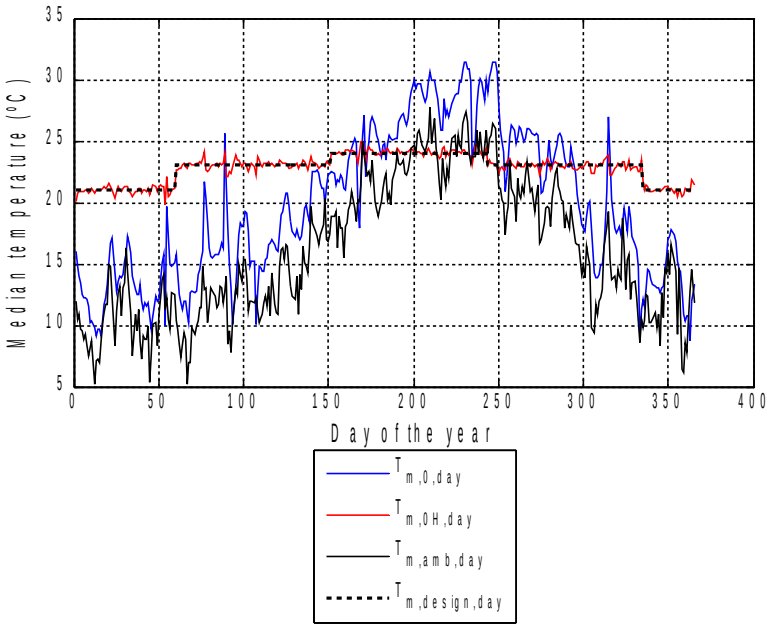

Figure 3.4 *– Temperatures profile during a year*

4. SOLAR INSTALLATIONS

4.1. Photovoltaic Installations

4.1.1. Introduction

A photovoltaic installation takes the energy from the solar radiation and transforms it directly into electric energy by means of the photovoltaic panels.
A basis schema of an isolated installation is shown in **figure 4.1**. The description of each element is made below.

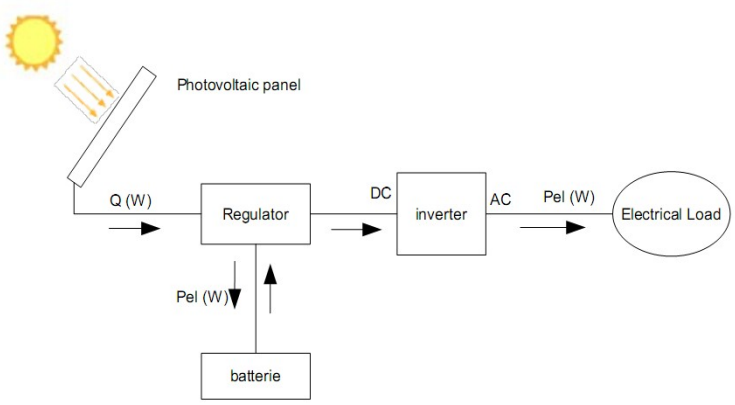

***Figure 4.1** – Photovoltaic isolated installation elements*

4.1.2. Design Conditions

The maximal power and the energy consumed by the appliances was calculated in **chapter 3.1.2**. as

$P_{max,appliances} = P_{installed} \cdot K_{simult} = 6200 * 0.3 = 1860$ W

$E_{appliances} = 6200.3600$ (J) $= 22.32\ 10^6$ (J)

If the energy needed to feed the heat pump, $E_{heatpump}$ is included, the theoretical electric energy consumed by the photovoltaic installation, $E_{T,photo}$ (W) will be

$$E_{T,photo} = E_{heatpump} + E_{appliances} \quad [J] \qquad (4.1)$$

The electrical energy consumed by the heat pump depends on the concret equipments chosen for this application. Therefore, the variable $E_{heatpump}$ is calculated in **chapter 5.2.2**.
The energy required by the installation is affected by a general efficiency factor of the installation, η_{photo} . This factor involves some looses for Joule's effect or looses in the batteries. Therefore, the energy needed by the installation is

$$E_{photo} = \frac{E_{T,photo}}{\eta_{photo}} \quad [J] \qquad (4.2)$$

This value will allow to size correctly the installation.
The parameter η_{photo} is also needed to size the batteries installation. The method to calculate η_{photo} is described in the **chapter 4.1.4**.

4.1.3. Photovoltaic Panels

The photovoltaic panels transform the solar radiation into direct current (DC) through the photoelectric effect which was described the first time in 1905 by Albert Einstein.
Although the efficiency of the panels is nowadays not very high (around 15 %), its use allows to get electrical energy in remote locations where other sources are not available.

The chosen panels for this installation are the SolvisPico PI-AE/210 Wp, whose characteristics are shown in **tables 4.1 , 4.2, 4.3** and **4.4**. See also **Appendix D.**

Dimensions and weight	Unit	All modules
Surface	m²	1.65
Length	mm	1,655.00
Width	mm	991.00
Thickness with frame	mm	43.00
Diameter of frame hole	mm	6.50
Weight (approx.)	kg	22.00
Cell size (square)	mm	156 x 156

***Table 4.1** – Dimension and Weight*

Characteristics	All modules
Number of cells	60
NOCT (*) [°C]	49.5 ± 2
Aluminium frame, colour	Bright anodised
Connection	MC type 3
Cable length +/- [cm]	94/94
Number of bypass diodes	3
Structure of the front side (glass/foil)	Solar glass/EVA

***Table 4.2** – Cell characteristics*

Limit values	Unit	All modules
Max. permitted system voltage	V	1,000
Max. compressive loading	Pa	5,400
Max. tensile loading	Pa	2,400
Permitted module temperature	°C	-40 – +80

***Table 4.3** – Operating limits*

The next development and its equations is an extract from reference **[10]**.
NOCT (nominal operating cell temperature) is the cell temperature with 800 W/m² irradiance, perpendicular to the module, when the ambient temperature is 20°C and the wind speed is 1 m/s.
The value of NOCT is used to determine the operating cell temperature. It is assumed, according to **[10]**, that the difference between the temperature of the cell, T_{cell} and the temperature of the air, T_{amb} , depends linearly on the irradiation on the panel G_{panel} (W/m2), according to:

$$T_{cell} - T_{amb} = \frac{NOCT - 20\,^{\circ}C}{800} \cdot G_{panel} \quad [^{\circ}C] \qquad (4.3)$$

Designation	Abbreviation	Unit	Modules (2) SolvisPico PI-AE/...			
			210 Wp	215 Wp	220 Wp	225 Wp
Rated output (STC)	P_{MPP}	W_P	210.00	215.00	220.00	225.00
Max. deviation from P_{MPP}	–	%	+2.00	+2.00	+2.00	+2.00
Voltage for P_{MPP}	V_{MPP}	V	27.60	28.00	28.40	28.80
Current at P_{MPP}	I_{MPP}	A	7.60	7.70	7.80	7.80
Open circuit voltage	V_{OC}	V	36.10	36.30	36.40	36.60
Short circuit current	I_{SC}	A	8.30	8.30	8.40	8.40
Temperature coefficient for P_{MPP}	T_cP_{MPP}	%/°C	-0.452	-0.452	-0.452	-0.452
Temperature coefficient for V_{OC}	T_cV_{OC}	%/°C	-0.340	-0.340	-0.340	-0.340
Temperature coefficient for I_{SC}	T_cI_{SC}	%/°C	0.074	0.074	0.074	0.074
Module efficiency (STC)	η	%	12.70	13.00	13.30	13.60
Max. protection at serial voltage	–	A	15.00	15.00	15.00	15.00
Manufacturer	–	–	REC	REC	REC	REC

***Table 4.4** – Electrical Specifications*

These electrical specifications are valid under the standard test conditions (STC) (airmass 1.5; irradiation 1,000 W/m²; cell temperature 25°C).

In this conditions, the power of the panel is called *peak power* and is expressed in *peak watts* (Wp).
This characteristics are modified according the irradiation on the panel.

The Open Circuit Voltage, $V_{el,OC}$ (V), is the voltage produced by the panel when there is no charges connected. It is affected by the temperature which is affected by the irradiation, as shown in the following relation

$$\frac{dV_{el,OC,panel}}{dT} = -0.0023 \cdot N_{S,cell} \quad [V/°C] \qquad (4.4)$$

where

$N_{Series,cell}$= number of cell in series connection

The Short Circuit Current ,$I_{el,SC}$ (A), is also proportional to the irradiation and is given like

$$I_{el,SC,panel} = \frac{I_{el,SC,(1000\,W/m^2)} \cdot G_{panel}}{1000} \quad [A] \qquad (4.5)$$

where

$I_{el,SC,(1000\ W/m2)}$ = Short Circuit Current when the panel receives 1000 W/m^2 (see **table 4.2**)

To characterize the cell it is also needed to know its Form Factor, *FF*, which is a measure of the *rectangularity* of the $V_{el,OC}$ – $I_{el,SC}$ curve.

$$FF = \frac{I_{el,MPP,panel} \cdot V_{el,MPP,panel}}{I_{el,SC,panel} \cdot V_{el,OC,panel}} \qquad [dimensionless] \qquad (4.6)$$

where $I_{el,MPP,panel}$ and $V_{el,MPP,panel}$ are given in **table 4.4**

The bigger is this factor, the nearer are the two curves shown in **figure 4.2** and bigger is the quality of the cell.

It is now possible to know the power generated by the panel and its efficiency as

$$P_{panel} = FF \,.\, V_{el,OC,panel} \,.\, I_{el,SC,panel} \quad [W] \qquad (4.7)$$

$$\eta_{panel} = \frac{P_{panel}}{G_{panel} \cdot A_{panel}} \qquad (4.8)$$

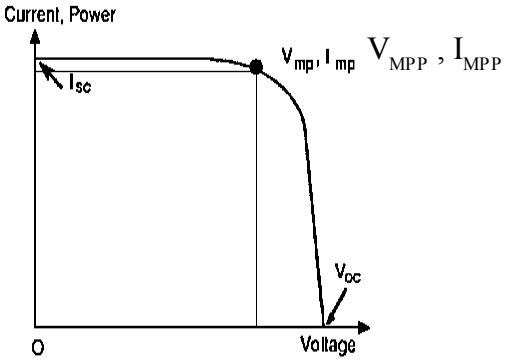

Figure 4.2 – *Open Circuit voltage* **VOC** *– Short Circuit current* **ISC**

On the other hand, the energy produced by the photovoltaic panels installation will be

$$E_{P,panel} = P_{panel} \cdot \Delta t \cdot N_{panel} \quad [J] \qquad \textbf{(4.9)}$$

where

P_{panel} = Power given by one panel (W)
N_{panel} = number of panels

4.1.4. Batteries

The mathematical procedure here explained to size the batteries installation is an extract from reference **[10]**.

4.1.4.1. Autonomy Days

This parameter (N_{day}) sets the number of days in which the energy stored in the batteries is able to provide all the energy consumed by the installation. In cloudy regions it is desired until 10 days of autonomy **[10]**.
The region of Baleares enjoy a very sunny wetter almost all the year. According the climatic dates of 2005 **[2]**, the longest period with the minimum of solar radiation is two days (40 hours).

4.1.4.2. Depth of discharge (DOD)

A full discharge of the batteries could damage its storage capacity and reduce its operating life. Therefore it is defined the parameter *depth of discharge*, as the percentage of the stored energy that the battery is able to provide. According to the use of this installation, the depth of discharge is considered like 80% in relation with the nominal capacity of the battery. This is the typical value for Pb batteries with a long ratio of discharge used in photovoltaic applications **[10]**.

That means that the battery will not be able to give the 100% of the kept energy but only the 80%.

4.1.4.3. Accumulated energy

The energy provided by the accumulation system, E_{batt} is defined as

$$E_{batt} = \frac{E_{T,photo} \cdot N_{day}}{\eta_{photo} \cdot DOD} \quad [J] \qquad \textbf{(4.10)}$$

where

η_{photo} = global efficiency factor of the installation.

$$\eta_{photo} = \eta_{regulator} \cdot (1 - k_{batt} - k_{convert} - k_v) \cdot (1 - k_a \cdot \frac{N_{day}}{DOD}) \quad \text{[dimensionless]} \qquad \textbf{(4.11)}$$

where

$\eta_{regulator}$ = efficiency of the charge controller (or regulator), given by the manufacturer.

k_a = daily self-discharge coefficient, normally defined by the manufacturer

0.002 days → batteries with low self-discharge, Ni-Cd or Pb-Cd, without maintenance.

0.005 days → stationary batteries Pb (normally used in solar installations)

0.012 days → high self-discharge batteries (automobiles)

k_{batt} = loss factor due to the efficiency of the batteries. In absence of more information, it is taken 0.05 for this factor

$k_{convert}$ = loss factor in DC/AC converter, normally defined by the manufacturer.

k_v = this factor groups another losses (efficiency of the Net, Joule losses...). Reference values are set between 0.05 and 0.15.

4.1.4.4. Capacity of batteries

$$C_{batt} = \frac{E_{batt}}{3600 \cdot V_{el,batt}} \quad [A.h] \qquad \textbf{(4.12)}$$

where

$V_{el,batt}$ = working voltage of the batteries [V]

4.1.5. Charge controller

The function of the charge controller is to drive the energy that comes from the panels into the batteries or into the inverter to be consumed, according to necessity. It regulates the voltage and the current according to the state of charge of the battery. Its objective is also to ensure that the battery will be charged without suffering dangerous overloads.
The charge controller will also protect the batteries against excessive discharges.

The charge controller is chosen among the current offer by taking in consideration the characteristics of the installation, the working voltage of the batteries and the maximum operating current. The operating current is given as the product of the operating current of one panel for the number of panels connected in parallel, $N_{Panel,parallel}$.

$$I_{el,regulator} = I_{el,MPP} \cdot N_{panel,\ parallel} \quad [A] \qquad (4.13)$$

4.1.6. DC/AC Inverter

The function of this equipments is to convert the direct current (DC), from the photovoltaic panels or the batteries into alternating current, needed for most of electrical appliances.
The election of the inverter depends on the maximum of power required by the installation. The smallest inverter able to meet this power will be chosen because the efficiency of this kind of equipments decrease quickly for lower working loads.

4.2. Hot sanitary water installation

4.2.1. Introduction

The hot sanitary water (HSW) installation should supply hot sanitary water for domestic applications.

The main elements of this kind of installation are shown in **figure 4.3.**

According to the Spanish recent legislation **[4]**, all new buildings must to cover a percentage of its consumption of HSW by means of a solar installation.
The value of this percentage depends on the climatic zone where the installation is located and the used system of auxiliary heating. The **tables 4.5** and **4.6** are an extract of **[4]**, (section HE 4).

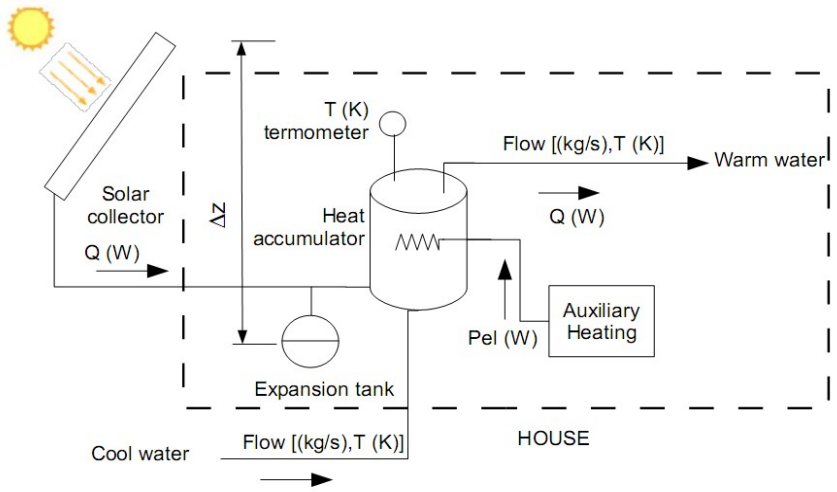

Figure 4.3 *– Elements of a hot sanitary water Installation*

Consumption of HSW (liters/day)	Climatic zone				
	I	II	III	IV	V
50 – 5000	30	30	50	60	70
5000 – 6000	30	30	55	65	70
6000 – 7000	30	35	61	70	70
7000 – 8000	30	45	63	70	70

Table 4.5 – *Minimal solar contribution (%) – General case*

Consumption of HSW (liters/day)	Climatic zone				
	I	II	III	IV	V
50 – 5000	50	60	70	70	70
5000 – 6000	50	63	70	70	70
6000 – 7000	50	66	70	70	70
7000 – 8000	51	69	70	70	70

Table 4.6 – *Minimal solar contribution (%) – Auxiliary heating with Joule's effect*

4.2.2. Design Conditions

The installation is located in Soller (Mallorca). It is planned for a domestic use for 4 persons. **Table 3.4** (see **section 3.1.3** of the present project), showed the needed flow of hot sanitary water, $\dot{V}_{HSW}$ (liters/day.person), for each application of the building.
According to **[4]** the temperature of storage will be 60 ºC

If the installation is designed with a different storage temperature, T_{acc} , the required flow, $\dot{V}_{HSW(T_{acc})}$ must be modified, every month, using the equation **(3.3)**

The daily energy needed to increase the temperature of water from the temperature of the net to the storage temperature is given as following

$$Q_{HSW} = \dot{V}_w \cdot \rho_w \cdot c_{p,w} \cdot N_{Persons} \cdot (T_{acc} - T_w) \quad [\text{J/day}] \qquad \textit{(4.14)}$$

where

$\dot{V}_{HSW}$ = Flow of Hot Sanitary Water (l/s)
ρ_W = density of water (kg/l)
$N_{Persons}$ = number of persons
T_{acc} = Temperature of storage in the accumulator (ºC)
T_W = Temperature of water from the public net (ºC)

It is evident that it will be related with the temperature of water in public net.

4.2.3. Thermal Collectors

The thermal collector receives the energy from the sun and converts it into thermal energy by means of a thermal fluid (water with antifreeze).

The chosen collector is the SolvisCala C-253-I. The most important properties are shown in the **table 4.7**. For more details, see **Appendix D**

Magnitude	Measurement	Units
Dimensions	2170 x 1168 x 93	mm
Absorber area	2.378	m^2
Gross area	2.535	m^2
Solar absortance	95	%
Stagnation temperature	209	ºC
Maximum pressure	4	bar

Table 4.7 – *Properties of solar collector.*

The energy that arrives to the collector, $G_{collector}$, is given by the equation **(3.4)**, for the same inclination and orientation of the roof. But not all this energy takes advantage on the collector. The real energy that arrives to the installation depends on the efficiency of the collector.
The efficiency of the collector is given by the manufacturer by means of experimental test in laboratories. The mathematical expression for the efficiency is given in **Appendix D** like

$$\eta_{collector} = \eta_0 - a_1 \cdot \frac{(T_{m,collector} - T_{amb})}{G_{collector}} - a_2 \cdot \frac{(T_{m,collector} - T_{amb})^2}{G_{collector}} \qquad (4.15)$$

where

η_0= optic factor = 0.798
a_1 = first order loss coefficient = 3.42 (W/m^2.K)
a_2 = second order loss coefficient =0.016 (W/m^2.K)
T_{amb} = Temperature of the air (ºC)
$T_{m,collector}$ = Medium temperature in the collector (ºC)
$G_{collector}$ = Irradiance who arrives to the collector (W/m^2)

$$T_{m,collector} = \frac{T_{out,collector} + T_{in,collector}}{2} \quad [ºC] \qquad (4.16)$$

A solar collector works very similarly to a heat exchanger in which the primary circuit is the solar radiation whereas the secondary is the circuit across the collector. To calculate the efficiency of the collector every instant of time it is also needed a thermal balance between

the two circuits. See **[15]** for more information about the efficiency of thermal collectors.

$$Q_{P,collector} = \eta_{collector} \cdot Q_{S,collector}$$
$$\dot{m}_w \cdot c_{p,w} \cdot (T_{out} - T_{in}) = \eta_{collector} \cdot G_{collector} \cdot N_{collector} \cdot A_{collector} \qquad \textit{(4.17)}$$

where

$Q_{P,collector}$ = energy produced by the collector
$Q_{S,collector}$ = solar energy arriving at the collector
$\dot{m}_{water}$ = mass flow of heat transfer fluid (kg/s)
$c_{P,water}$ = specific heat of heat transfer fluid (J/kg.°C)
$T_{out,collector}$ = output temperature of the collector (°C)
$T_{in,collector}$ = intput temperature of the collector (°C)
$G_{collector}$ = irradiance that arrives to the collector (W/m^2)
$N_{Collector}$ = number of collectors
$A_{Collector}$ = surface of each collector (m^2)
$\eta_{collector}$ = efficiency of the collector

4.2.4. Storage Tank

The sizing of the storage tank or accumulator is a decisive factor in the designing of the solar installation.
It depends basically on three factors

- Surface of the collectors
- Working temperature.
- Gap of time between the production and the consumption of the HSW.

The storage tank must agree with the current legislation **[4]**. This one set the next relation between the volume of storage and the surface of the collectors:

$$50 < \frac{V_{acc}}{A_{collector}} < 180 \qquad \textit{(4.18)}$$

where

V_{acc} = volume of the storage tank (liters)
$A_{collector}$ = surface of the collectors (m^2)

With this criterion the storage tank will be chosen among the current offer of the manufacturers.

Some authors **[10]**, set the next orientations to chose a correct volume of storage according to the gap of time between the production and the consumption:

1) Coincidence between the caption and the consumption. The specific volume of the accumulator will be from 35 to 50 liters/m^2 of collector.

2) Gap of time not bigger than 24 h. The specific volume of the accumulator will be from 50 to 75 liters/m^2 of collector.
3) Gap of time bigger than 24 h and smaller than 72 h. The specific volume of the accumulator will be from 75 to 150 liters/m^2 of collector.

Considering the storage temperature, the relationship is not evident. If the temperature increases, the specific volume will be smaller.
Figure 4.4 shows a graphic with some tentative values.

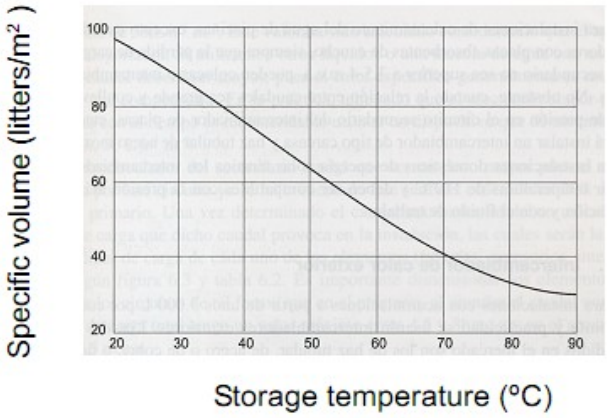

Figure 4.4 - Dependence between the storage temperature and the volume of the accumulator

4.2.5. Expansion Tank

The expansion tank must be able to absorb the 6% of increase of water volume produced when the temperature of the system rise 120 ºC.
The maximum volume of the expansion tank will be 8 % of the total volume of the hydraulic circuit.
The next empiric formula **[10]**, is useful to estimate the volume of the expansion tank

$$V_{tank} = V_{circuit}\,(0.2 + 0.01\,\Delta z) \quad \text{[liters]} \quad \textbf{\textit{(4.19)}}$$

where

$V_{circuit}$ = total volume of hydraulic circuit across the collector (liters)
Δz = difference of altitude between the highest point of the circuit and the expansion tank (m), shown in **figure 4.3**

4.2.6. Auxiliary Heating

In this project, the use of electrical auxiliary heaters is contemplated . For this case, the recommendations given in **[10]** are accepted.
Electrical auxiliary heaters based on Joule's effect can be placed inside the storage tank.
This application is acceptable under the next conditions:

- It will be located on the superior part of the storage tank to ensure that it will only

heat a maximum of 50 % of water stored in the accumulator.
- A thermostat should limit the storage temperature at 50 ºC.
- The operation programming should be made out of the sunny hours.
- It is recommended a maximum of 300 W installed power for the heater per square meter of solar collector.

4.3. Adsorption Machine Installation

4.3.1. Introduction

Technology of solar cooling starts from an apparent contradiction, namely to use heat to get cool.
The equipments based on absorption and adsorption principles are able to produce air conditioning by means of a thermal installation.

In the case of the *absorption* technology, the operation is based on the property of certain liquid substances – called absorbent – to dissolve the steam of the others. The more usually pairs are water like absorbent and ammonia. But it presents some risk of toxicity.
In the case of the *adsorption*, the principle of operation is the same in which the absorbent is a solid. The present study will focus on this kind of technology.

4.3.2. Description of the installation.

The basic operation of the installation is shown in **figure 4.5**, which is an adaptation from an original picture from Solvis (see reference **[30]**).
The solar radiation is collected by the thermal collectors and it is taken by a fluid (water with antifreeze) to the stratification accumulator.
In summer, hot water from the accumulator is driven to the adsorption machine, where a thermodynamic cycle takes place to produce cold water. Cold water gets the fan coil and the building can be conditioned by air.
In winter, hot water arrives directly into the fan coil, by-passing the adsorption machine.
On the other hand, a hot domestic water supply is available from the accumulator during the whole the year.
Finally, in a last circuit, warm water is driven from the adsorption machine to the dissipater to be cooled. The dissipater or condenser gives off the heat from the house.

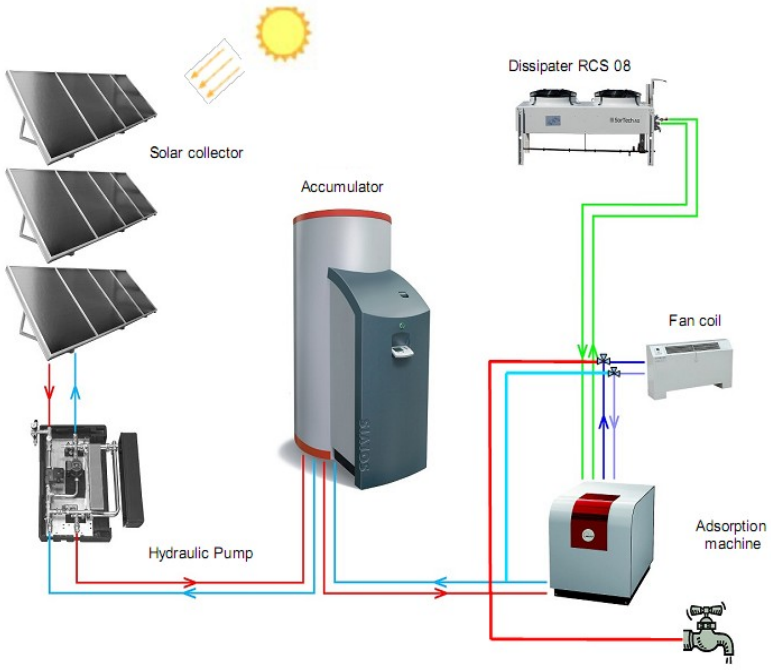

Figure 4.5 *– Elements of an Adsorption Machine Installation. Source: SOLVIS*

4.3.3. Thermal Collectors

Chapter 4.2.3. describes the working principles of thermal collectors for a domestic hot water installation. On this respect, there is no difference between the function of the collectors in the two installations, and what was said on that chapter is also valid for this one.

4.3.4. Storage Tank

In **chapter 4.2.4**. were described the specifications of the storage tank for a domestic hot water installation. The function of storage tank is the same in both cases. However there will be some differences between the operation of the storage tank in the two installations which are needed to take in consideration

For this installation, there will be only one accumulator providing HSW and hot water to feed the adsorption machine. Therefore the volume of storage will be quite bigger than the accumulator for a single HSW installation.

On the other hand, the temperature of water to fed the adsorption machine will be also greater. That means that the flow for HSW must to be modified like showed in equation **(3.3)**. Sometimes the expansion tank for these applications is placed inside the storage tank.

4.3.5. Adsorption Machine

This machine is the cornerstone of solar cooling technologies.

The basis of its operation is the property of certain highly porous substances to retain atoms or molecules of steam into their structures. The combinations are numerous. The mostly used are silica-gel (SiO_2) with water steam, Lithium Bromide (LiBr) with water steam and activated coal with ethanol.
Due to its porosity, one gramme of activated coal has a superficial area of 500 m^2/g, with the possibility to arrive until 2500 m^2/g.
The superficial area of Silica-gel is around 800 m^2/g
The union of the two materials is only physic. There is no chemical reaction. During the adsorption some heat is produced because the process is exothermic. The steam is released by heating the adsorbent in a process called desorption.

The way to producing cool by using this effect is developed in four phases and explained with help of **figures 4.6 a** to **4.6 d**.

1. Heating and pressurizing (**figure 4.6 a**). In this process the adsorption chamber remains closed while it is heated from the thermal solar energy. The adsorbent temperature increases. Therefore its pressure increases also from the vaporizer pressure to the condenser pressure. This process is equivalent to a mechanical compression in the basic mechanical compression cycle.

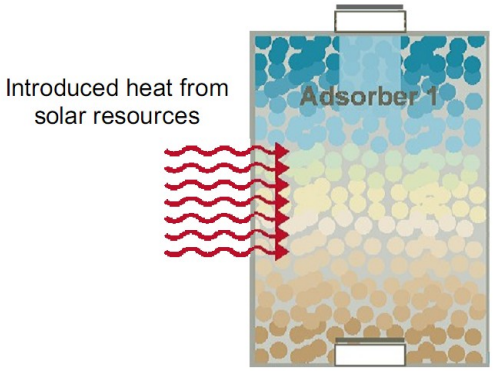

Figure 4.6 a *– Heating and pressurizing process. Source: SOLVIS*

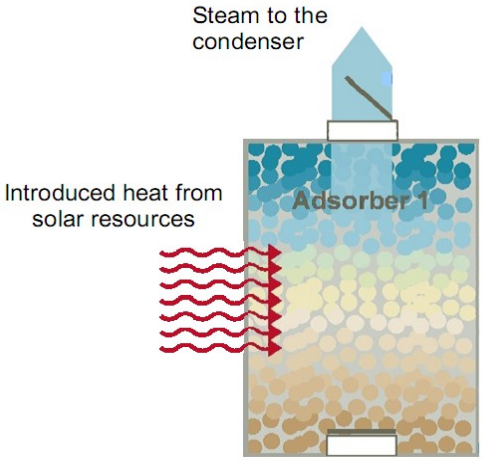

Figure 4.6 b *– Heating and desorption process. Source: SOLVIS*

2. Heating and desorption (**figure 4.6 b**). In this phase the chamber is still receiving thermal energy while the way through the condenser remains opened. The condenser imposes its working pressure. The adsorbent temperature increases and the desorption process takes place. The steam arrives at the condenser to be liquefied by transferring its energy to the dissipater which is located outside the building.

3. Cooling and pressurizing (**figure 4.6 c**). In this phase the adsorption chamber is cooled while remaining closed. The adsorbent temperature decreases and the pressure decreases from the condenser pressure to the vaporizer pressure. This phase is similar to the expansion phase in basic mechanical compression cycle.

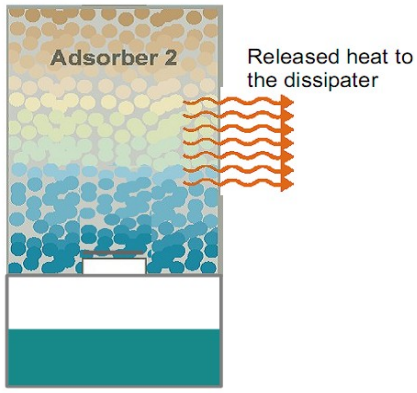

***Figure 4.6 c** – Cooling and pressurizing process. Source: SOLVIS*

4. Cooling and adsorption (**figure 4.6 d**). In this phase the chamber transfers energy to the dissipater while the valve through the vaporizer remains opened. The temperature reduction induces the adsorption of steam generated in the vaporizer. In this phase the energy needed to vaporize the steam is extracted from the building producing cooling.

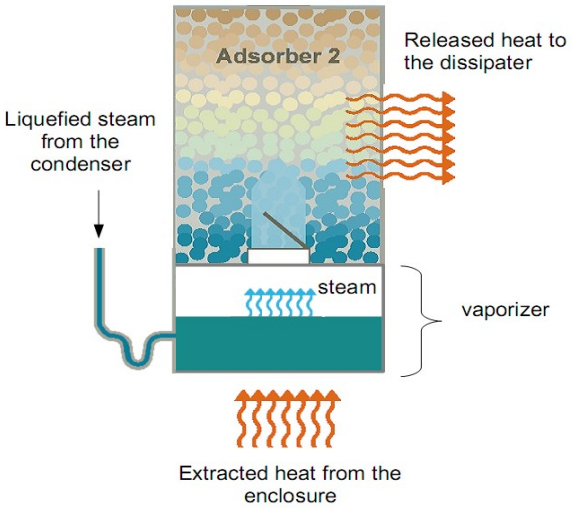

***Figure 4.6 c** – Cooling and adsorption process. Source: SOLVIS*

The adsorption cycle is similar to the traditional compression cycle, where the mechanical compression has been replaced by a thermal compression. **Figure 4.7** shows the thermodynamic cycle which takes place

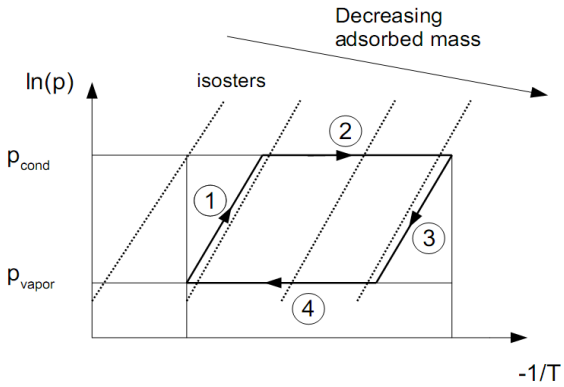

Figure 4.7 *– Diagram of Clapeyron of the adsorption machine thermodynamic cycle,* **[10]**

In commercial equipments, two adsorption chambers are placed, instead of only one. That allows to make the process continuous as long as the heat resource is available.
In **figure 4.8**, the steam from the vaporizer is going to chamber 2, where adsorption is taking place. On the other hand, the heat resource is driven into chamber 1, where desorption is produced. The released steam is going into the dissipater or condenser.

Note that the heat resource is provide by the thermal collectors, by means of an hydraulic circuit, and it can be directed into the chamber 1 or 2, according to necessity.

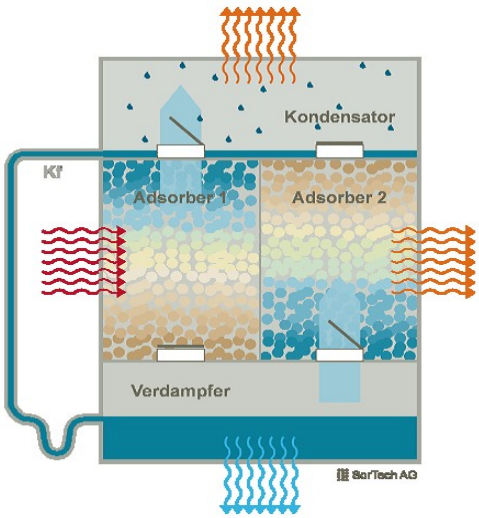

Figure 4.8 *– Complete schema of the adsorption machine. Source: SOLVIS*

4.3.6. Dissipater

The steam leaving the adsorption chamber is driven into the condenser, where will transfer the liquefaction heat into the environment. The dissipater is provided of two ventilators and a fresh water atomizer, which will enhance the energy dissipation. The minimal theoretic reachable temperature would be the wet-bulb temperature

Figure 4.9 shows a dissipater from Solvis.

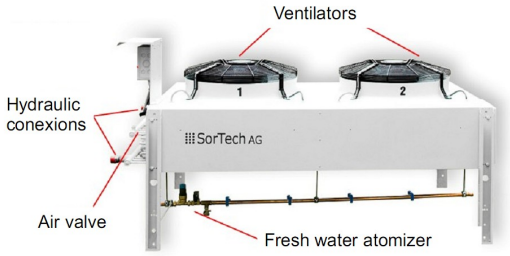

***Figure 4.9** – Dissipater. Source: SOLVIS*

5. INSTALLATION SIZING

In this chapter the design of installations which will provide hot sanitary water, electricity for appliances and energy for heating and air conditioning is made taking into account what has previously been stated in relation with solar installations.

Basically two cases are going to be studied:
In the first one warm water will be produced by thermal collectors. Heat and cooling for heating and air conditioning respectively will be provided by a reversible heat pump. Electricity to feed the heat pump will be produced by a photovoltaic generator. Heating (or cooling) distribution inside the rooms is made by means of fan coils.

In the second case, the study of viability for the absorption machine SolvisCool 08 providing air conditioning will be made in order to compare it with the heat pump solution. The solar collectors will provide hot water in summer to feed the adsorption machine as well as hot sanitary water.
Heating distribution in winter is made by means of hot water coming directly from thermal collectors to fan coils. The adsorption machine is not used in winter. The thermal collectors installation will provide hot sanitary water as well.

As established in **chapter 4**, the variations during a day in electric consumption for appliances or in hot water consumption are not known. It is either not possible to know the variations in electrical consumptions between summer and winter. In summer, the number of sunny hours is higher and the use of lighting inside the building decrease respect its value in winter. Likewise, it is possible to think that the required temperature of hot water is smaller in summer than in winter. Nevertheless, it is only possible to suppose the consumption in one day according to the obtained information and extend this value for all the year.

This fact doesn't take place in the load calculation of air conditioning because it is direct related with the climatic information likewise the energy produced by the installation (see also **chapter 4**). Therefore, they are hourly known during all the year. That means that there is a great difference between the precision in the energy requirements and the energy

production which must be accepted in this work.

5.1. CASE 1: HEAT PUMP INSTALLATION: AIR CONDITIONING AND HEATING THERMAL COLLECTORS INSTALLATION: HOT SANITARY WATER

The main resource of energy should be the solar radiations. Heat pump for heating and air conditioning likewise the electrical appliances will be fed by photovoltaic panels. On the other hand, the thermal collectors will provide warm water. In cases where the solar radiation is not enough to feed the installation, the lack of energy will be taken from the electric grid.
The photovoltaic panels and the thermal collectors will be placed on the roof. The surface of the roof is 45 m^2 and it is all on principle usable.
A scheme of the installation is shown in **figure 5.1.**

5.1.1. Design Conditions for the heat pump installation

The starting point for this section is the evolution on power consumption for heating and air-conditioning and the variations of the temperature inside the building. They were shown in **figures 3.2** and **3.3** respectively.
On the other hand, the energy needed for the electrical appliances, set in chapter **3.1.2**. is also considered.

The addition of the two variables gives the variation of theoretic electrical consumed energy by the building during all the year called E_T

$$E_{T,photo} = E_{Appliances} + E_{HeatPump} \quad [J] \qquad (5.1)$$

where

$E_{appliances}$ = Energy consumed by the electrical appliances (calculated on **chapter 3**) [J]
$E_{heatPump}$ = Energy consumed by the heat pump (calculated in **chapter 5.2.2**) [J]

The energy produced by the installation is affected by the efficiency of the regulator, the efficiency of the inverter and the looses by keeping energy in the batteries. Therefore, the energy consumed by the building, coming from the photovoltaic installation, is given like

$$E_{photo} = \frac{E_{T,photo}}{\eta_{photo}} \quad [J] \qquad (5.2)$$

where

η_{photo} = global efficiency of the photovoltaic installation.

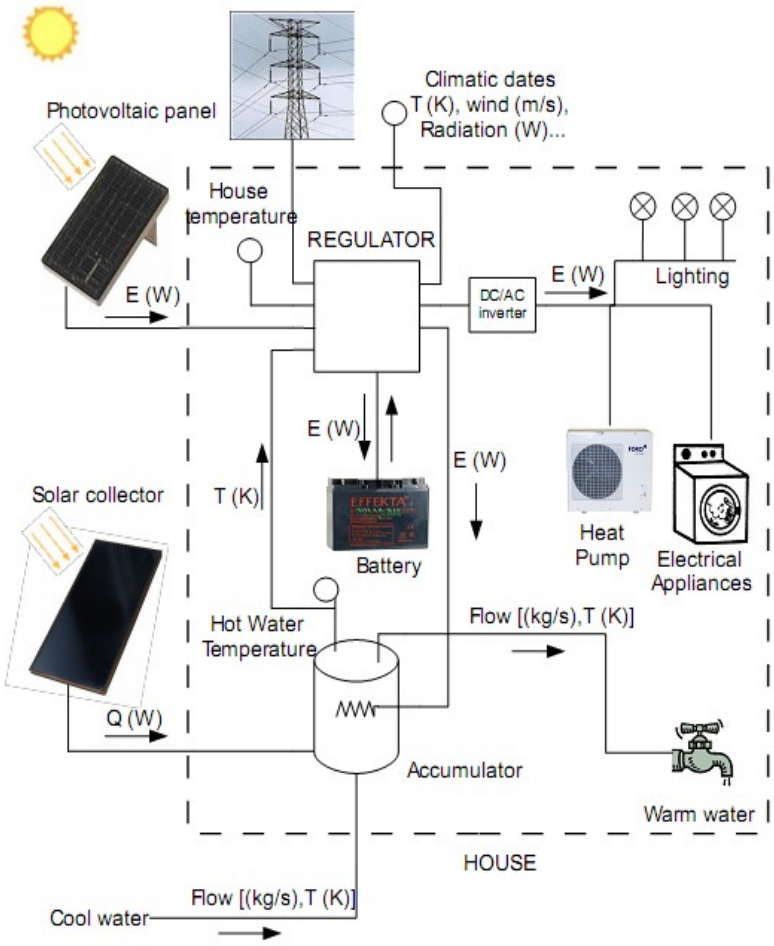

Figure 5.1 *– Photovoltaic and HSW installation. Case 1*

5.1.2. Selection of Equipments

5.1.2.1. photovoltaic panels.

The chosen panels for this installation are the SolvisPico PI-AE/210 Wp, whose the characteristics were shown in **tables 4.1 , 4.2, 4.3** and **4.4.** (see **chapter 4** and **Appendix D**). 24 photovoltaic panels are going to be placed on the roof in series of 4.

To get the maximum profit of the available surface of the roof, a total of 24 panels will be installed on the roof. The covered surface is:

Covered Surface = Surface of one panel (A_{panel}) x number of panels (N_{panel})

$1.65 \times 24 = 39.6\ m^2$

The rest of the surface will be used to place the thermal collectors.

The inclination (δ) and orientation (θ) of the panels will be the same as the roof. In that case there will be no shadow projected from one panel to the other.

$\delta_{panel} = 12.41°$

$\theta_{panel} = 0°$

The energy which arrives to the panels, $E_{S,panel}$ [J], coming from the solar radiation is given as

$$E_{S,panel} = N_{panel} \cdot G_{panel} \cdot \Delta t \quad [\,J\,] \qquad \textbf{(5.5)}$$

where

N_{panel} = number of panels

G_{panel} = solar irradiance over the panel (W/m^2), given by the equation **3.4**

The energy produced by the panels will be

$$E_{P,panel} = P_{panel} \cdot \Delta t \cdot N_{panel} \quad [\,J\,] \qquad \textbf{(5.6)}$$

where

P_{panel} = Power given by one panel (or module) (W), given by equation **4.5**

N_{panel} = number of panels

In **Appendix C** is shown the arrangement of the panels on the roof.

5.1.2.2. charge controller

The charge controller or regulator will be chosen according the short circuit current in the panels field. There is 4 panels in series, each one with I_{SC} = 8.30 A (see **Appendix D**).
The evolution of the maximal power raised in field panels every day is shown in **figure 5.2**.
In this installation 6 charge controllers *Tarom 235* are going to be connected in parallel, each one with 35 A maximal working current. The efficiency of each one is >95 %
See **Appendix D** for more information about the charge controller.

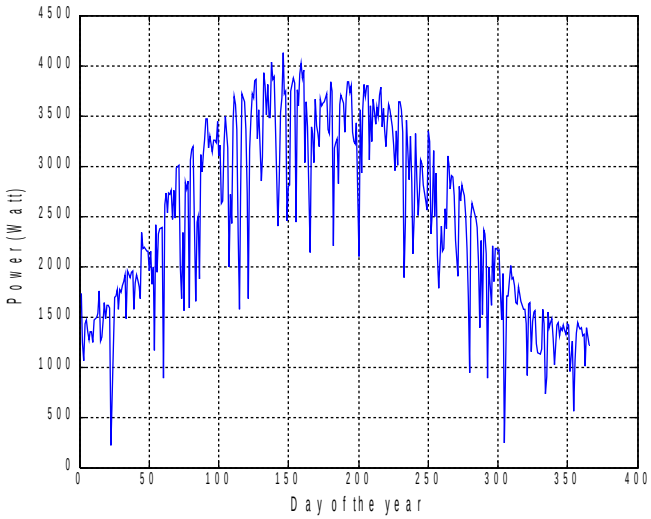

Figure 5.2 *– Maximal Power produced by the photovoltaic panels field*

5.1.2.3. Batteries

Figure 5.3 shows the evolution during a year of the energy that the batteries should accumulate, E_{batt} (J) , in order to supply completely the necessities of the building, and the energy really produced by the photovoltaic installation, $E_{P,photo}$ (J).
The capacity of the batteries will not be higher than the energy which the installation is able to produce in one day. In summer the solar production raise the maximum of energy, and the most of this energy is consumed during the solar hours. Therefore, the capacity of the batteries will be calculated with the equation **4.12**, for E_{batt} equal to the maximal difference between the produced and the consumed energy, $E_{batt} = 0.4\ 10^8$ [J].

$$C = \frac{E_{batt}}{3600 \cdot V_{batt}} = \frac{0.53 \cdot 10^8 J}{3600 \frac{s}{h} \cdot 12 V} = 926 \quad [\text{Ah}]$$

This capacity will be provided for a pack of four batteries *Monoblock Power 12 V, 250 Ah*, connected in parallel in groups of two, with a capacity of 250 Ah each one. The deep of discharge, DOD, is 80 % for this kind of battery. See also the characteristics of the product in **Appendix D**.

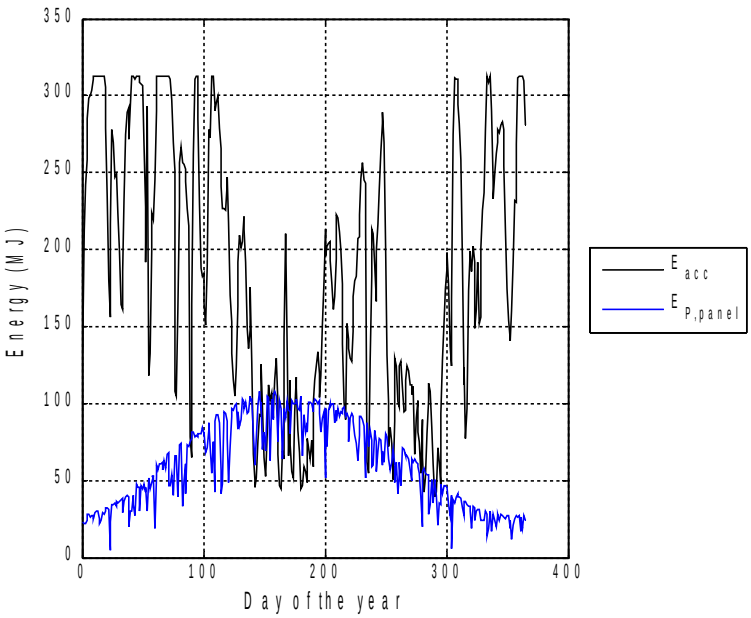

Figure 5.3 *– Stored energy and Produced energy*

5.1.2.4. DC/AC Inverter

The DC/AC inverter is chosen is chosen according to the maximal power consumption of a day. **Figure 5.4** shows the maximal power consumed by the installation every day including the auxiliary energy for Hot sanitary water.
The chosen inverter is therefore *Inversor Senoidal Solener ISC 4000 24V* , (see also the characteristics of the product in **Appendix D**), with a working power of 4000 W and the possibility to increase it during short intervals of time.

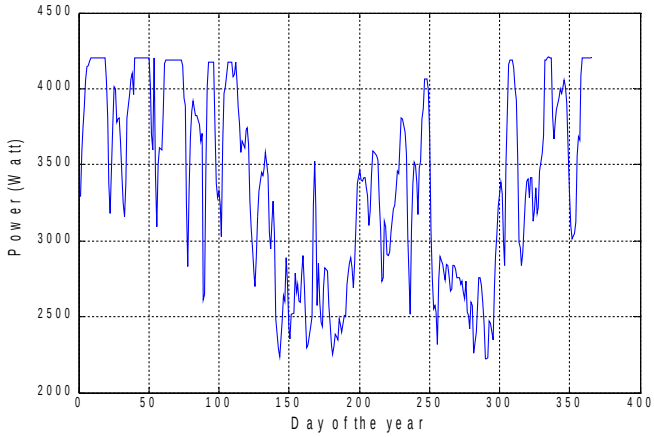

Figure 5.4 *– Maximal values of required power*

5.1.2.5. Heat pump

In **chapter 3** where calculated the maximal consumption of energy needed to maintain a constant temperature inside the building. From this data it is possible to chose a heat pump from a manufacturer catalogue.
The chosen equipment is the heat pump SAP – CMRV 2446 EH, which characteristics are shown in **table 5.2**. (see also **Appendix D** for more information).

Unidad Exterior		SAP-CMRV2446EH	
Función		Frío	Calor
N° de Uds. Interiores		4	
Capacidad	kW	2,9/6,8/8,1	3,4/8,6/9,0
Consumo	W	2.000	2.000
E.E.R/C.O.P.	W/W	3,40	4,30
Clase energética		A	A
Intensidad Nominal	A	8,87	8,87
Nivel Sonoro	dB-A	47	49
Conexión Líq/Gas	mm(p)	4x6,4(1/4)/3x9,5(3/8)/12,7(1/2)	
Long. de tubería TOTAL	m	60	
Long. de tubería Ud. Int	m	25	
Elevación	m	15	
Precarga válida para	m	45*	
Dimensiones AlxAxP	m	740x900x320	
Peso neto	kg	65	
Fuente de alimentación	V, F, Hz	230, 1+N, 50	

***Table 5.2** – Technical Characteristics of the heat pump*

The electrical consumption of heat pump, $E_{HeatPump}$, will be

$$E_{heatpump} = \frac{P_{HeatPump} \cdot \Delta t}{COP} \quad [J] \qquad (5.3)$$

where

COP = Coefficient of performance (given by the manufacturer)
$P_{HeatPump}$ = working power of the heat pump

The spin of the compressor of the heat pump is adjusted to provide the energy needed each moment. In that case it is possible to receive from the heat pump the energy q_H calculated on chapter 3. In that case, the energy consumed by the heat pump will be

$$E_{heatpump} = \frac{\dot{Q}_H \cdot \Delta t}{COP} \quad [J] \qquad (5.4)$$

where

$$\dot{Q}_H \leq P_{HeatPump}$$

On the other hand, three internal units (fan-coil) are chosen to distribute the energy for heating or air conditioning in the three main rooms of the house. The characteristic of fan-coils are given in **table 5.3**. (see more details in **Appendix D)**.

Unidad Mural		SAP-KMRV76EH		SAP-KMRV96EH	
Función		Frío	Calor	Frío	Calor
Capacidad	kW	2.2	2.5	2.65	3.6
Circulación de aire (A)	m³/h	440	480	460	480
Nivel de presión de sonido (Silencioso/B/M/A)	dB-A	23/27/30/33	23/27/30/33	22/30/35/38	22/30/35/38
Diam. de Tubos Estr./Ancho	mm	6.35(1/4) / 9.5(3/8)		6.35(1/4) / 9.52(3/8)	
Dimensiones AlxAxP	m	285x825x213		285x825x213	
Peso neto	kg	10		10	
Fuente de alimentación V, F, Hz					

Table 5.3 *– Characteristic of fan coils*

The chosen units are 2 x SAP-KMRV76EH for the sleeping rooms. And 1 x SAP-KMRV96EH for the main room.
This combination shows a good correspondence between the operating power of the heat pump and the operating power of the three elements together, for summer and for winter.

5.1.3. Results of the Simulation for the heat pump.

In **figure 5.5** are represented the electrical energy needed by the building, E_{photo} (MJ) , the solar radiative energy which arrives to the installation, $Q_{S,panel}$ (MJ) , and the electrical energy produced by the photovoltaic installation, $E_{P,panel}$ (MJ) every day through all the year.

It is interesting to observe that the net energy which arrives at the installation is much higher than the electrical energy demand of all the building almost during all the year. But due to the short efficiency of the photovoltaic panels not all this energy is available.

The difference between E_{photo} and $E_{P,panel}$ is the auxiliary energy $E_{aux,\ panel}$ that the installation must to take from the grid. **Figure 5.6** represents E_{photo} (MJ) , $E_{P,panel}$ (MJ) and $E_{aux,\ panel}$ (MJ). The solar radiative energy which arrives at the photovoltaic panels field is not any more represented in the figure.

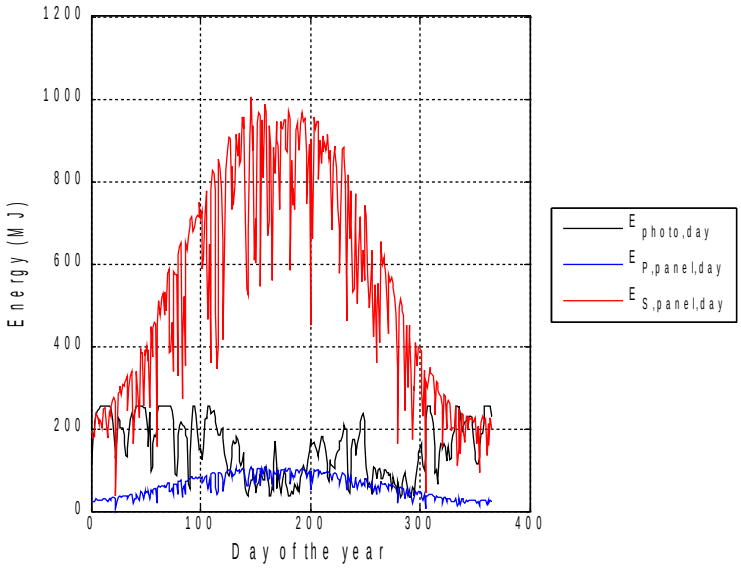

Figure 5.5 *– Energy received – Energy produced – Energy consumed*

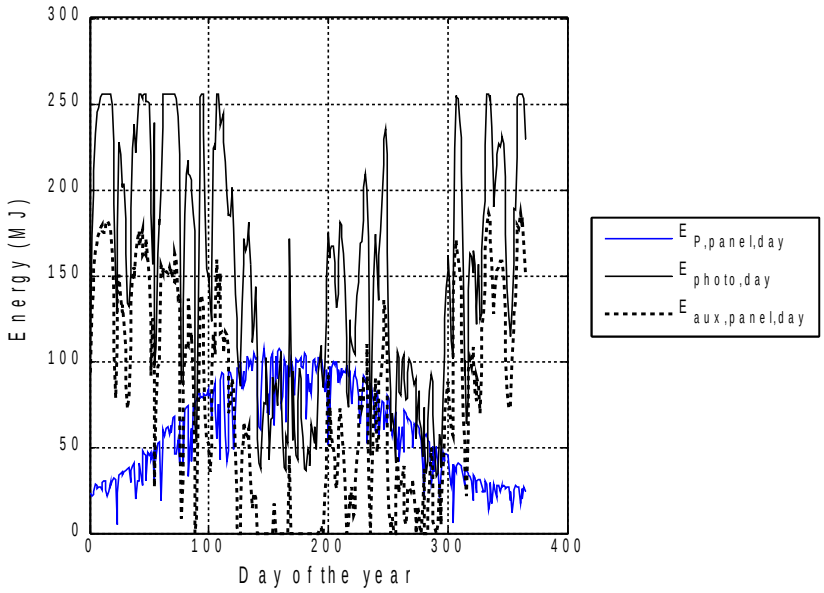

Figure 5.6 – *Auxiliary energy – Energy produced – Energy consumed*

As observed, in summer, from day 140 to day 196, auxiliary energy consumption is needed only in shorts periods of time or not needed at all.

It is also interesting to study the relationship between the two curves, E_{photo} and $E_{P,panel}$, to obtain the fraction of energy, F_{photo} (%), which describes the coverage of the photovoltaic installation of the whole year

$$F_{photo} = 100 \cdot \frac{\sum_{i=1}^{365} E_{P,\,panel}}{\sum_{i=1}^{365} E_{photo}} \quad [\%] \qquad \textbf{(5.7)}$$

where

E_{photo} = Electrical energy required by the building in one day [J]
$E_{P,panel}$= Electrical energy produced by the photovoltaic installation [J] in one day.

If the equation (**5.7)** is applied for all the year (i=365) the fraction of covered energy with the solar installation results.

$F_{photo,year}$ = 40.34 %

In **figure 5.7** are showed the values of F_{photo} for each day and for each month.

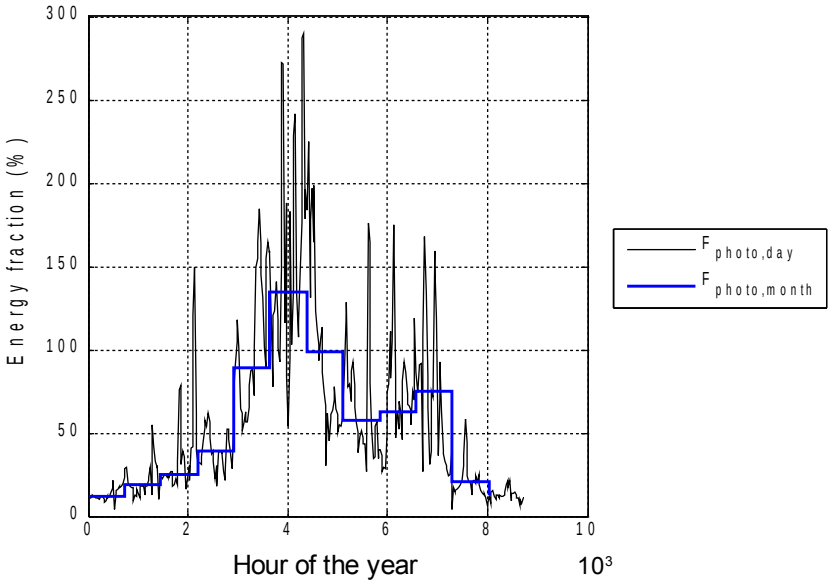

Figure 5.7 – *Fraction of electrical energy (%) covered by the installation*

As shown, the fraction of energy covered by the installation exceeds the 50 % from the begin of May to the end of October (from hour 2901 to hour 7094 of the year). And this percentage exceeds the 100 % during a great part of June and July.

There is some periods in summer in which the produced energy exceeds the sum of the consumption of the building and the capacity of the batteries. This excess of energy is wasted and the value of $F_{photo,year}$ become smaller.
The equation (**5.7)** can be rewritten like

$$F_{photo} = 100 \cdot \frac{\sum^{365} min\left(E_{photo}, E_{P,panel}\right)}{\sum^{365} E_{photo}} \quad [\%] \qquad \textbf{(5.8)}$$

This equation gives $F_{photo,year}$ = 37.31 %

5.1.4. Design conditions for thermal collectors installations

The installation is located in Soller (Mallorca) and it is planned for a domestic use for 4 persons.
According to **[4]**, the water consumption of hot sanitary water at for a family house is 30 l/person.day. And the minimal solar contribution of the installation will be 70 % (see also **chapter 4.2.1**)
The consumption of hot water will be

$$\dot{V}_{HSW} = 4 \text{ x } 30 = 120 \text{ [liters/day]} \qquad \textbf{(5.9)}$$

In absence of more detailed dates, the temperature of water, $T_{W,net}$ (°C) in public net, will be considered constant during each month. For the Baleares Islands it is given in **table 5.4**.

Month	January	February	March	April	Mai	June	July	August	Sept	Oct	Nov	Dec	Year
T_W (°C)	8	9	11	13	14	15	16	15	14	13	11	8	12,3

***Table 5.4** – Temperature of water in public net*

The energy needed in one day to increase the temperature of water from the temperature of the net to the storage temperature is given by the equation **4.14**.

5.1.5. Selection of equipments for the thermal collectors installations

5.1.5.1. Thermal Collectors

In a first steep, it is supposed the use of one collector ($N_{Collector} = 1$), with a surface $A_{Collector} = 2.378$ m^2 **Appendix D**
The three equations **(4.15), (4.16)** and **(4.17)**, which describe the performance of the thermal collector have been solved simultaneously with the assumption that the input temperature of the collector is always 20 °C.

But not all the energy produced in the collector is transferred into the accumulator. There is a efficiency coefficient in the heat transfer, called $\eta_{transfer}$
The energy really stored in the accumulator will be:

$$Q_{acc,\,HSW} = \eta_{transfer} \cdot Q_{P,\,collector} \quad [\,J\,] \qquad \textit{(5.10)}$$

In absence of more details, is accepted in this project the value

$$\eta_{transfer} = 0.8$$

The chosen collector is the SolvisCala C-253-I, whose characteristics were described in **chapter 4.1.3** (see also **Appendix D**).

In **Appendix C** is shown the arrangement of the collector on the roof.

5.1.5.2. Accumulator

It is considered a gap of time between the production and the consumption not bigger than 24 hours. This parameter must be considerd according to **[10]**.
On the other hand, according to **[4]**, the relation between the volume of storage and the surface of the collectors is given by the equation **(4.18)**

Therefore, the chosen accumulator is the SolvisMini with 150 liters capacity.

$$\frac{V_{acc}}{A_{collector}} = \frac{150}{2.378} = 63.08$$

5.1.5.3. Expansion Tank

To estimate the volume of the expansion tank, according to **[10],** it can be useful the empiric formula **(4.19)**

The volume of heat transfer liquid inside the collector is $V_{collector}$ = 1.06 liters. The diameter of the conduction is d = 8 mm (see characteristics of the collector in **Appendix D**).
The estimated long of the hydraulic conduction is 10 meters, according the geometric description given in **chapter 2**, with a 1/2" diameter.

The total volume of hydraulic circuit across the collector will be

$$V_{circuit} = V_{collector}(l) + 10(m) \cdot \frac{\pi \cdot (d/1000)^2}{4}(m^2) \cdot 1000 \frac{(l)}{(m^3)} \quad = 6.127 \text{ liters}$$

The maximal difference of altitude between the highest point of the circuit and the expansion tank, Δz , will be

Δz = 4 m

The volume of the expansion tank will be

$V_{tank} = V_T (0.2 + 0.01\ \Delta z) = 1.47 \approx 1.5$ [liters]

5.1.5.4. Auxiliary Heating

It is recommended for the heater a maximum of 300 W installed power per square meter of solar collector (recommended value given in reference [10]).
In this installation there is one collector ($N_{Collector}$ = 1), with a surface $A_{Collector}$ = 2.378 m^2 (see **Appendix D** for more information about the characteristic of thermal collectors)
The maximal power of heater will be.

$P_{auxHeater,max}$ = 300 . 2.378 = 713.4 W

For this application, the working power of the heater will be

$P_{auxHeater}$ = 700 W

5.1.6. Results of the simulation.

In **figure 5.8** are represented the solar energy which arrives at the collector $Q_{S,collector}$, the energy consumed by the installation, Q_{HSW} , and the energy stored in the accumulator $Q_{acc,HSW}$ which is produced by the collector, every day.

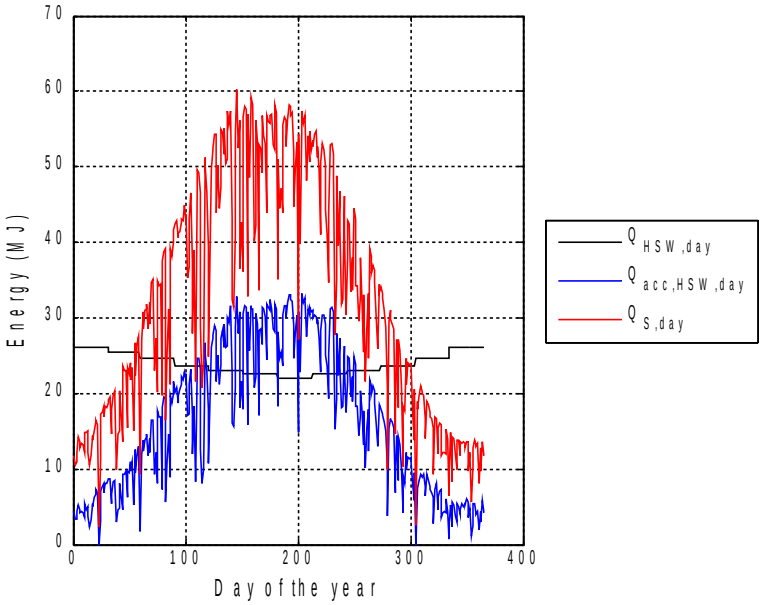

Figure 5.8. *Energy consumed – Energy produced – Energy received*

As shown, the fraction of profitable energy with the thermal technology is higher than the photovoltaic technology. The photovoltaic panels field receives until 1004 MJ the day 146, but the installation can just produce 107 MJ, according to the **figures 5.5**. This is a 9.7 % of efficiency

According to **figure 5.8**, The thermal collector receives 57 MJ and produces 33 MJ, the day 204. This is 57.9%

There is some periods of time at the beginning and at the end of the year where the energy supply is not ensured. Therefore it is needed to use the auxiliary heater. The energy that it should provide is represented in **figure 5.9**

The relation between the two curves, Q_{HSW} and $Q_{acc,HSW}$, has been made in order to obtain the fraction of energy, F_{HSW} (%), covered by the HSW installation during all the year

$$F_{HSW} = 100 \cdot \frac{\sum_{day,\,month} Q_{acc,\,HSW}}{\sum_{day,\,month} Q_{HSW}} \quad [\%] \qquad \textit{(5.11)}$$

where

$Q_{acc,HSW}$ = Energy produced by the HSW installation (J) in one day
Q_{HSW} = Energy required by the building in one day (J)

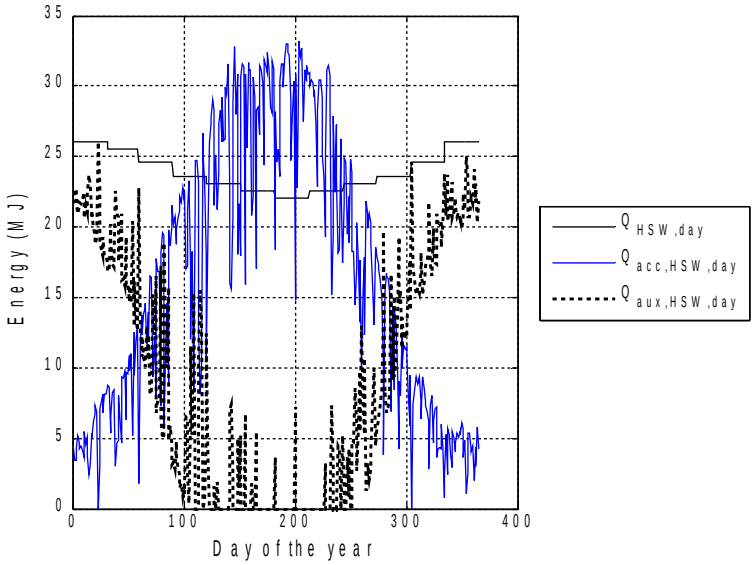

Figure 5.9. *Auxiliary Energy in the HSW installation.*

The fraction of energy the whole year is also calculated like the relation between the energy produced and the energy received during all the year. It gives

$$F_{HSW,year} = 100 \cdot \frac{\sum_{365} Q_{acc,HSW}}{\sum_{365} Q_{HSW}} = \frac{5.995 \cdot 10^9 J}{8.739 \cdot 10^9 J} \cdot 100 = 68.60[\%] \qquad \textit{(5.12)}$$

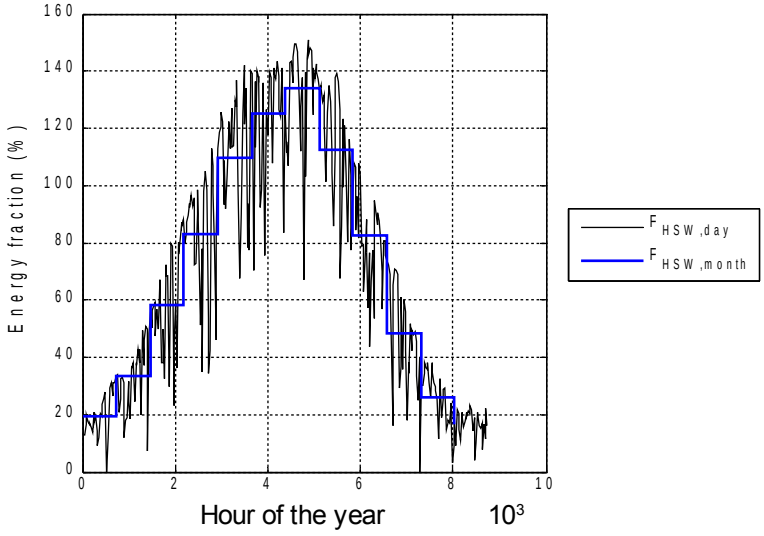

Figure 5.10. Solar Fraction in HSW installation.

The obtained fraction of energy does not achieve the value of 70 % , set in **[4]**, section HE 4 – "minimal solar contribution for hot sanitary water". This circumstance is however justifiable because of the photovoltaic installation of the building.

Finally it is also represented, in **figure 5.11**, the efficiency of the thermal collector during all the year.

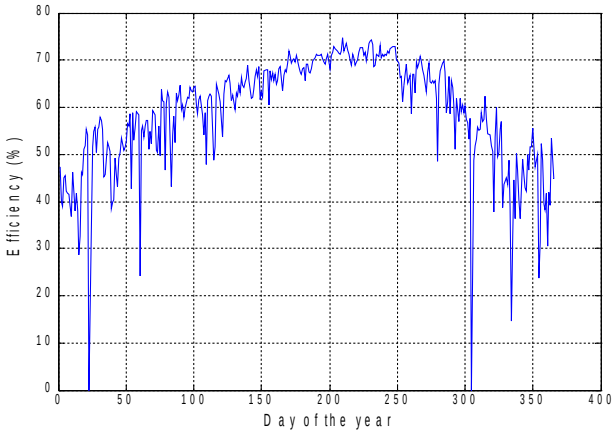

Figure 5.11. *Efficiency of the thermal collector.*

5.2. CASE 2: ADSORPTION MACHINE INSTALLATION: AIR CONDITIONING, HEATING & HOT SANITARY WATER

The solar energy will be captured by means of solar thermal collectors.
In Summer, they will provide the hot water flow needed to feed the adsorption machine. The adsorption machine produce a cold water flow which will allow to get air conditioning by using a fan-coils installation.
In winter, hot water coming from the solar collectors and stored in the accumulator will feed directly the fan coils without going through the adsorption machine. The schema of the installation was shown in **figure 4.5**.

It is important to note that the only power supply for electrical appliances come from the grid.

5.2.1. Design Conditions for adsorption machine

5.2.1.1. Heating and cooling

The adsorption machine needs a 1.6 m^3/h heat water flow at 72 °C temperature. In prevision of looses between the accumulator and the adsorption machine, a temperature of 75°C is

chosen to be the design temperature of storage.
The loads for heating and air conditioning are calculated from the estimation of loads made in **chapter 3**.
In this case, the energy supply for air conditioning will be made from the adsorption machine. But the energy supply for heating will be made directly from stored hot water into the fan-coils. Therefore the loads for heating and for air conditioning are going to be treated separately.

$Q_{heating} = \dot{Q}_H \cdot \Delta t$ if $\dot{Q}_H > 0$ ***(5.13)***

$Q_{cooling} = \dot{Q}_H \cdot \Delta t$ if $\dot{Q}_H < 0$ ***(5.14)***

where

$\dot{Q}_H$ = needed power (W) to meet the design temperature , calculated in chapter 3.

5.2.1.2. Hot sanitary water

The values of flows estimated in **chapter 5.3.1** for domestic hot water were given for a 60 ºC storage temperature. The new temperature of storage is 75 ºC for the adsorption installation. Therefore those values must be modified as seen in equation **(3.3)**, and according to the temperature of water in public net in Mallorca, given in **table 5.4.**
The needed flow of hot sanitary water every month is shown in **table 5.5**

Month	January	February	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Year
l/pax.day	23,3	23,2	23	22,7	22,6	22,5	22,4	22,5	22,6	22,7	23	23,3	22,8

Table 5.5. *Flow design (litters/day) of Hot sanitary water every month*

The value of $\dot{V}_{HSW}$ = 23 l/person.day is chosen for this application during all the year.

The power to provide hot sanitary water, according to explained in chapter 4.2.2 is given in MJ/month in **table 5.6.**

January	February	March	April	May	June	July	August	Sept	Oct	Nov	Dec
809.93	717.48	763.21	708.44	716.48	678.29	685.33	700.9	693.37	732.06	738.59	809.93

Table 5.6 *– Energy requirements (MJ) for HSW every month*

5.2.1.3. Appliances

Power for electrical appliances is not taken in consideration in this chapter since it will be provided directly from the electrical grid. It will be included in **chapter 6** for making a comparison with the **case 1**.

The energy consumed by the installation will be

$$Q_{ads} = Q_{heating} + Q_{cooling} + Q_{HSW} \qquad (5.15)$$

5.2.2. Selection of equipments

5.2.2.1. Thermal Collectors

The used solar collectors for this application are the SolvisCala C-253-I, whose properties are in great detail described in **Appendix D**.
To get the maximum profit of the available surface, a total of 16 thermal collectors will be installed on the roof. The covered surface is:

Covered Surface = Surface of thermal collector ($A_{collector}$) x number of thermal collector ($N_{collectors}$)

2.378 x 16 = 38.05 m^2

The collectors will be connected in series of two. This arrangement will allow a grater temperature of storage. See A**ppendix C** for more details about the arrangement and connection of collectors.

The involved equations and the method to calculate the energy generated by the thermal collectors were described in **chapter 5.3.2**. It is important to note that in this case, are two collectors connected in series. That means that the output temperature for the first one is the input temperature for the second one.

$$T_{in2,ads} = T_{out1,ads} \qquad (5.16)$$

The used notation is the next one:

$Q_{P,ads1}$ = thermal energy produced by one of first collectors in series in the adsorption machine installation

$Q_{P,ads2}$ = thermal energy produced by one of second collectors in series in the adsorption machine installation

$Q_{P,ads}$ = thermal energy produced in each branch of the adsorption machine installation

$$Q_{P,ads} = Q_{P,ads1} + Q_{P,ads2} \ [J] \qquad (5.17)$$

The energy which will be stored in the accumulator, $Q_{acc,ads}$, will be

$$Q_{acc,ads} = \eta_{transfer} \cdot \frac{N_{collector}}{N_{series}} \cdot Q_{P,ads} \ [J] \qquad (5.18)$$

where

$\eta_{transfer}$ = 0.8 heat transfer efficiency in accumulator

$N_{collector}$ = 16 number of collectors in the installation

N_{series} = 2 number of collectors connected in series

The input temperature on the first collector is here also considered constant and equal to 20 ºC.

The efficiency factor of collectors will not be the same. First collectors of the series have a input temperature lower than second ones. Therefore the medium temperature is lower, there is lower losses into the environment and its efficiency is greater. This effect can be better observed by examining the equations **4.15** and **4.16** about thermal collector efficiency.

$$\eta_1=\eta_0-a_1\cdot\frac{(T_{m1,ads}-T_{amb})}{G_{ads}}-a_2\cdot\frac{(T_{m1,ads}-T_{amb})^2}{G_{ads}} \quad \rightarrow \quad T_{m1,ads}=\frac{T_{out1,ads}+T_{in1,ads}}{2} \quad [ºC]$$

$$\eta_2=\eta_0-a_1\cdot\frac{(T_{m2,ads}-T_{amb})}{G_{ads}}-a_2\cdot\frac{(T_{m2,ads}-T_{amb})^2}{G_{ads}} \quad \rightarrow \quad T_{m2,ads}=\frac{T_{out2,ads}+T_{in2,ads}}{2} \quad [ºC]$$

Finally, the energy produced by each collector will be also different between the first and the second one collector of the series

$$Q_{P,ads1}=\dot{m}_w\cdot cp_w\cdot\Delta t\cdot(T_{out1}-T_{in1}) \quad [J] \qquad \textbf{(5.18)}$$

$$Q_{P,ads2}=\dot{m}_w\cdot cp_w\cdot\Delta t\cdot(T_{out2}-T_{in2}) \quad [J] \qquad \textbf{(5.19)}$$

5.2.2.2. Accumulator

Since the installation is planned to supply the heating and air conditioning necessities, the production of energy and its consumption will take place at the same time or with smaller gaps of time. Therefore, the storage volume will be ranged from 35 to 50 litters/m^2 of collector surface according to the recommendations given in reference **[10]**.
For this installation it is chosen the accumulator SolvisMax, with 950 litters capacity.

5.2.2.3. Adsorption Machine

The chosen adsorption machine is the SolvisCool SC 08, whose characteristics are shown in **table 5.7**. See also **Appendix D** for more information.

Type	SC 08
Maximal cooling power	11 kW
COP_{max}	0.65
Operating cooling power	8 kW
Electrical consumption	7 W
Working parameters	
Temperature of cooling circuit	6 – 20 °C
Temperature of dissipater circuit	22 – 37 °C
Temperature of heating circuit	55 – 95 °C
Cooling power	5 – 11 kW

Table 5.7 *– Technical Characteristics of the adsorption machine. Source: SOLVIS*

5.2.2.4. Condenser

The chosen condenser is the SolvisCool RCS 08, whose main characteristics are shown in **tables 5.8** and **5.9.** See also **Appendix D** for more information.

PARAMETER	Unit	RCS 08
Energy dissipation power	kW	21
Noise level at 10 meters distance	Db (A)	43
Water consumption	m^3 / year	20
Working flow	m^3 / h	3.7
Operating pressure of the atomizers	bar	min. 3 – 6

Table 5.8 *– Working characteristics of SolvisCool RCS 08. Source: SOLVIS*

PARAMETER	Unit	RCS 08
Width	mm	2000
High	mm	1145
Depth	mm	950
Empty Weight	kg	ca. 188

Table 5.9 *– SolvisCool RCS 08 Dimensions. Source: SOLVIS*

The efficiency of the adsorption machine is strongly affected by climatic conditions around the condenser . This effect is shown in **figure 5.13** provided by the manufacturer where the COP and the working power, $P_{cooling}$ (dQ_NT, according the nomenclature of the

manufacturer), change with the external temperature for the two possible operating modes of the machine: ECO Mode and Power Mode. In this study it is only considered the Power Mode.

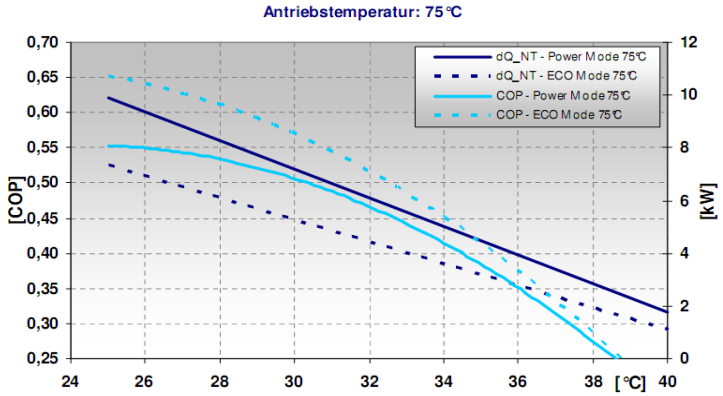

Figure 5.13 – *Experimental measurement in variation of efficiency in adsorption machine. Source: SOLVIS*

These curves have been approximated to several equations to be implemented in the simulation. The results are given in **table 5.10**.

Power Mode 75°C	$COP = -0.00145\ T^2_{amb} + 0.0715\ T_{amb} - 0.33$
ECO Mode 75 °C	$COP = -0.00145\ T^2_{amb} + 0.0638\ T_{amb} - 0.0435$
Power Mode 75 °C	$P_{cooling} = 23.2 - 0.53\ T_{amb}$ (kW)
ECO Mode 75 °C	$P_{cooling} = 17.2 - 0.4\ T_{amb}$ (kW)

Table 5.10 – *Mathematical approximation of efficiency curves in the adsorption machine*

5.2.2.5. Expansion Tank

The expansion tank is placed inside the accumulator. It is already sized by the manufacturer to agree the specifications.

5.2.2.6. Auxiliary heater

It is recommended a maximum of 300 W installed power for the heater per square meter of solar collector (recommended value in reference **[10]**).
In this installation there is 16 panels ($N_{Collector} = 16$), with a surface $A_C = 2.378\ m^2$ (properties in **Appendix D**)
The maximal power of heater will be.

$P_{auxHeater,max}$ = 300 x 16 x 2.378 = 11414 W

For this application, it is imposed as design condition a working power of the heater as

$P_{auxHeater}$ = 8000 W

5.2.3. Results of the simulation

In **figure 5.14** are shown: incident solar energy $Q_{S,ads}$, energy stored in the accumulator $Q_{acc,ads}$ and consumed energy for heating and air conditioning in the adsorption machine installation Q_{ads} . The consumption of appliances is not included in this graphic.

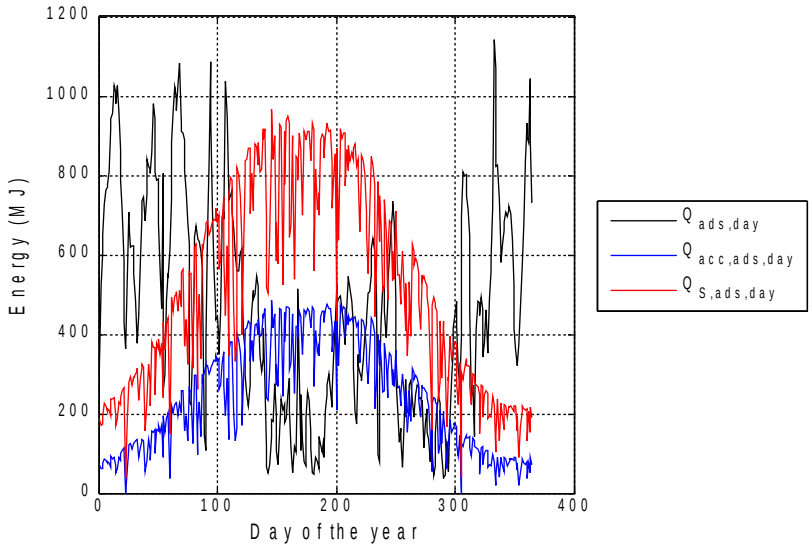

Figure 5.14– Variations in energy for the adsorption machine installation

As shown in **figure 5.14** thermal collectors technology requires in cold months much more energy than incident energy to provide heating if compared with **case 1**. On the other hand, the fraction of usable solar energy is quite bigger than photovoltaic panels technology. To cite just one fact, the day 146 the thermal collectors field receives 965 MJ, that is a little bit less than the 1004 MJ received by the photovoltaic installation (see chapter 5.3.3), because the surface of panels in **case 1** is bigger. The energy produced by the installation in **case 2** is 484 MJ. This is a 50.2 %.
This fact allows to get an overproduction in summer months.

In **figure 5.15** is shown the evolution of auxiliary energy needed for heating and air conditioning, as the difference between needed and produced energy. The consumption of appliances is not included in this graphic.

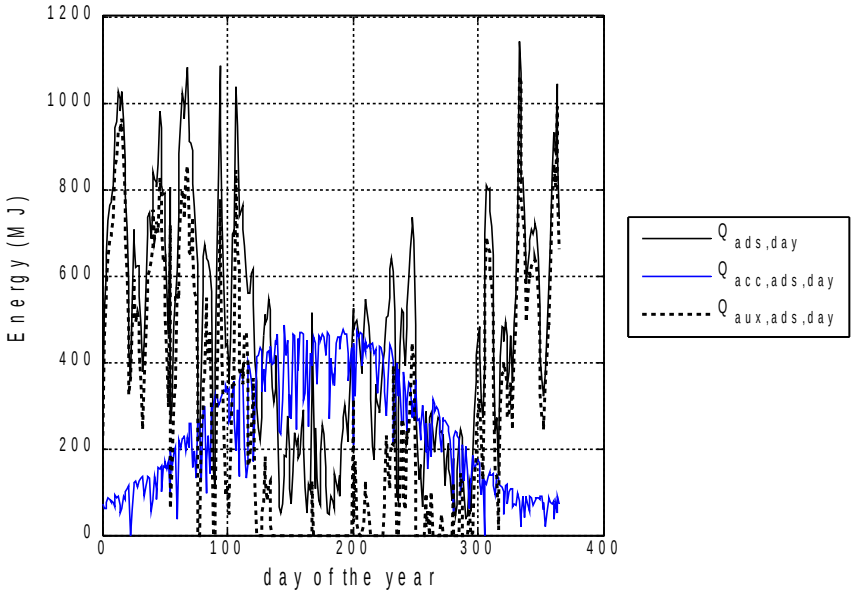

Figure 5.15 *– Auxiliary energy in relation with the production and the consumption.*

Figure 5.15 does not consider the efficiency variation effect in the adsorption machine due to external air temperature, as shown in **figures 5.13 and table 5.10** during summer months. This effect is shown in **figure 5.16.**

As shown, the available energy during the summer months, $Q_{machine}$ is much greater than the consumed energy for cooling, $Q_{cooling}$.

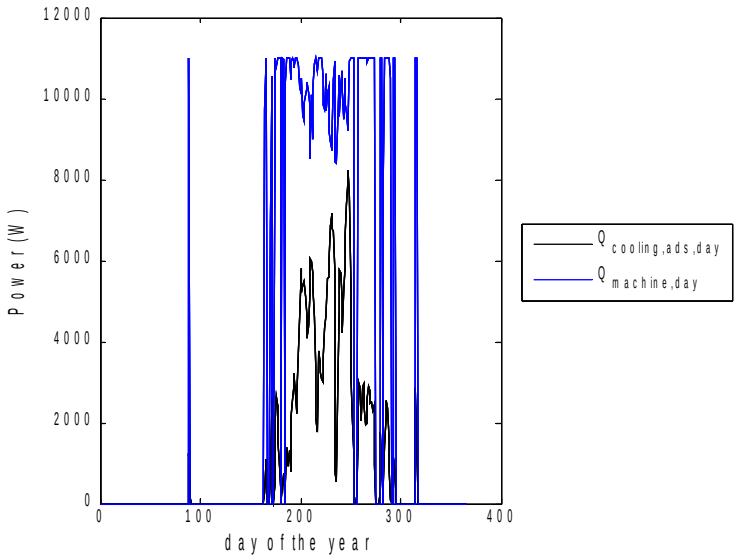

Figure 5.16 *– Consumed energy for air conditioning and in relation with the energy produced in the adsorption machine*

The fraction of energy for all the year is also calculated like the relation between the energy produced and the energy consumed during all the year. It gives

$$F_{ads} = 100 \cdot \frac{\sum_{month,day} Q_{acc,ads}}{\sum_{month,day} Q_{ads}} = \frac{8.957 \cdot 10^{10} J}{1.638 \cdot 10^{11} J} \cdot 100 \quad = 54.67 \ [\%] \qquad \textit{(5.20)}$$

The fraction of produced energy with the solar installation, in relation with the consumption for heating or air conditioning, is shown in **figure 5.17**. The consumption of appliances is not included in this graphic.

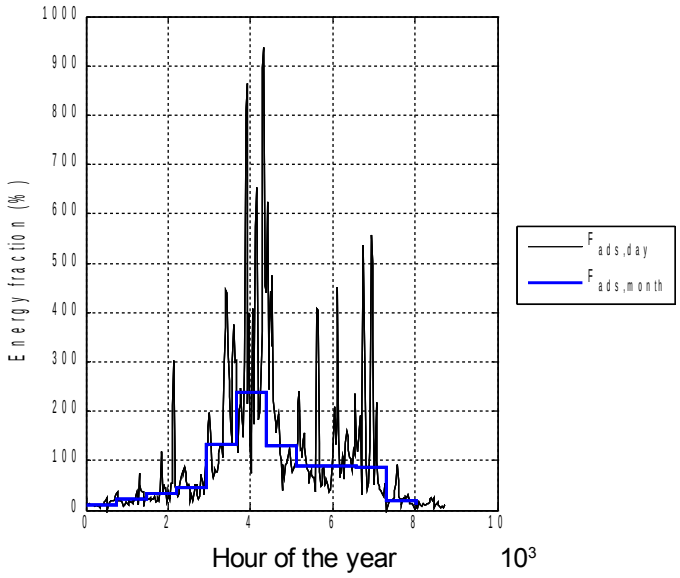

Figure 5.17 – *Fraction of consumed energy covered with the solar installation.*

If we include the consumption of electrical appliances in equation **5.20** , the value of F_{ads} decreases:

$$F_{ads} = \frac{Q_{P,ads,year}}{(Q+E)_{consumed,year}} \cdot 100 = \frac{8.957 \cdot 10^{10}}{1.708 \cdot 10^{11} + 8.147 \cdot 10^{9}} \cdot 100 \quad = 50.08\ \%$$

Finally, the efficiency of collectors placed on the same file is shown in **figure 5.18**. As explained in **chapter** ***5.2.2.1*** – *Thermal collectors* – note that the efficiency of first collector of the series is higher than the second one because its input temperature is lower.

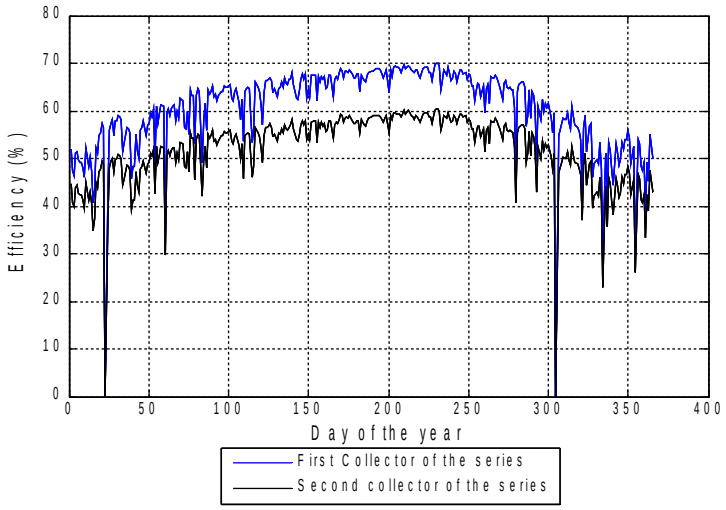

Figure 5.18 *– Efficiency of thermal collectors from the same series*

6. COMPARATIVE STUDY FOCUSING ON CASE 1 AND CASE 2

In **chapter 5** were analysed and calculated the main installation elements according to the proposed alternatives given in **case 1** and **case 2**. The purpose of each installation is to obtain heating, air conditioning, hot sanitary water and electrical power supply from solar resources.
In situations where that was not possible, the lack of energy was supply with electrical power from the net.

The objective of present chapter is to make a comparative between the two alternatives considering the produced energy, the efficiency and the economical cost.
Until said otherwise, the expression of energies or prices are referenced to square meter of collector surface.
All the comparisons are made from **case 1** to the **case 2**, both described in last chapter.

6.1. Criterion of energy production

The energy produced in each concreted proposed installation, **case 1** and **case 2**, will be compared. In both cases,the energy received (MJ/m^2) by the panels or collectors, respectively, placed on the roof is always the same because the inclination and orientation of all them is the same in each case.

The thermal energy produced by the installations in **case 1** and **case 2** is shown in **figure 6.1**.
To obtain the curve of **case 1**, it is needed to consider the COP of the chosen heat pump. In this curve it is also included the thermal energy provided by the single thermal collector of the installation.
The curve of **case 2** is directly the representation of the thermal energy produced by the field of thermal collectors and stored in the accumulator.
The represented curves are mathematically given by equations **6.1** and **6.2**

$$\frac{E_{P,case1}}{A_{case1}} = \left[\frac{\eta_{photo} \cdot E_{P,panel} \cdot COP + Q_{acc,case1}}{N_{panel} \cdot A_{panel} + N_{collector,case1} \cdot A_{collector}} \right] \cdot \frac{1}{10^6} \quad [MJ/m^2] \qquad (6.1)$$

$$\frac{E_{P,case2}}{A_{case2}} = \frac{Q_{acc,case2}}{N_{collector,case2} \cdot A_{collector}} \cdot \frac{1}{10^6} \quad [MJ/m^2] \qquad (6.2)$$

where

$E_{P,case1/2}$ = energy produced in **case 1**/**case 2** (MJ/m^2)
$A_{case1/2}$ = occupied surface in **case 1**/**case 2** (m^2)
η_{photo} = global efficiency the of photovoltaic installation
$E_{P,panel}$ = energy produced by the photovoltaic panels field.
COP = coefficient of performance of heat pump
N_{panel} = number of photovoltaic panels in the installation.
$N_{collector}$ = number of thermal collectors
A_{panel} = surface of the one photovoltaic panel
$Q_{acc,case1/2}$ = thermal energy produced by the thermal collectors in **case 1**/**case 2**

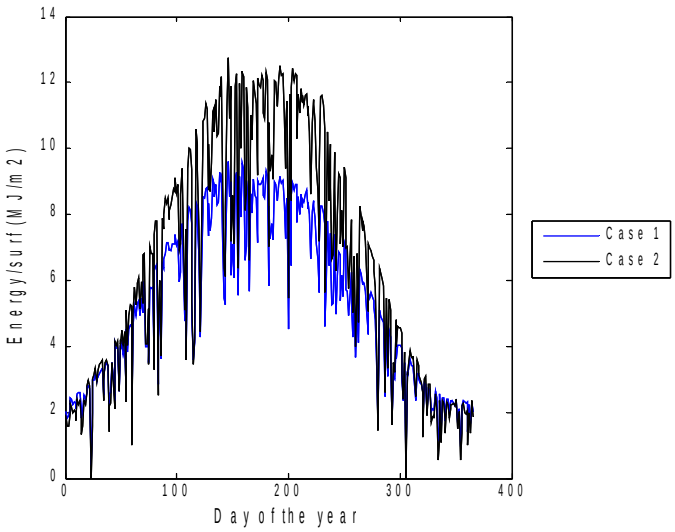

Figure 6.1** – Produced energy (MJ/m^2) in **case 1** and **case 2

As known, the efficiency of thermal collector is bigger than the efficiency of photovoltaic panels. On the other hand, the used heat pump from **case 1**, due to its COP, is able to produce heat more than four times the electrical consumption. Therefore, the two curves in **figure 6.1** are so close. In summer, the thermal collectors take advantage from the hight temperatures.

Figure 6.2 shows the need of energy to maintain the design conditions in both cases. In **case 1**, one part of the energy is electrical in order to feed the heat pump and the appliances. The other part is thermal for hot sanitary water. In **case 2**, the electrical energy is used for appliances whereas the thermal energy is used for heating – or air conditioning with the adsorption machine – and hot sanitary water. The proportion of each type of energy is shown

in chapter 5. Here is only represented the total of energy. These curves are not related with the surface of the installation.
Figure 6.2 represents mathematically:

case 1 → $$Energy_{case1} = \left(E_{photo} + Q_{HSW}\right) \cdot \frac{1}{10^6} \quad \text{[MJ / day]} \qquad (6.3)$$

case 2 → $$Energy_{case2} = \left(Q_{ads} + E_{appliances}\right) \cdot \frac{1}{10^6} \quad \text{[MJ / day]} \qquad (6.4)$$

where

E_{photo} = Electrical energy demanded by the heat pump and the appliances
Q_{HSW} = Energy consumption for Hot Sanitary Water Energy
$E_{appliances}$ = Electrical Energy consumption by Appliances
Q_{ads} = Energy consumption in the adsorption machine installation (HSW included)

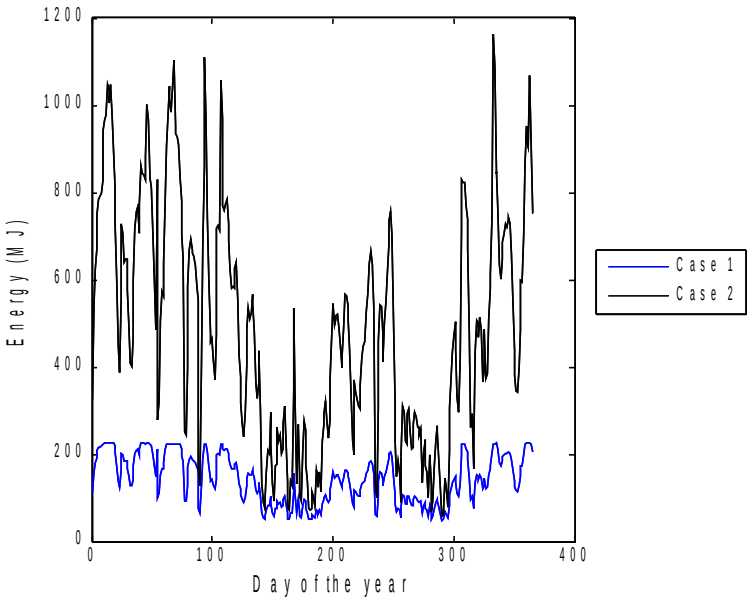

***Figure 6.2** – Total energy consumption of the building*

Finally, **Figure 6.3** shows the auxiliary energy necessary to face up the consumption when the solar resources are not able to do it. The power supply is made in both cases with electrical energy from the electric grid. It was considered that the efficiency in conversion from electrical energy to thermal energy is 100%. These curves are not related with the surface of the installation. As shown, the auxiliary energy in **case 2** is much higher than the auxiliary energy in **case 1** in cold month. As observed, the consumption from the grid from day 140 to day 196, is almost equal to zero. In **case 2** there is at least the consumption of the electrical appliances during the same period.
The auxiliary electrical energy taken from electrical grid in a whole year is given as
case 1 → $E_{aux,photo} + E_{aux,HSW}$ = 3.426 10^{10} + 3.412 10^{9} J = 3.767 10^{10} J = 1.047 10^{4} kWh
case 2 → $E_{aux,ads}$ = 9.346 10^{10} J = 2.596 10^{4} kWh

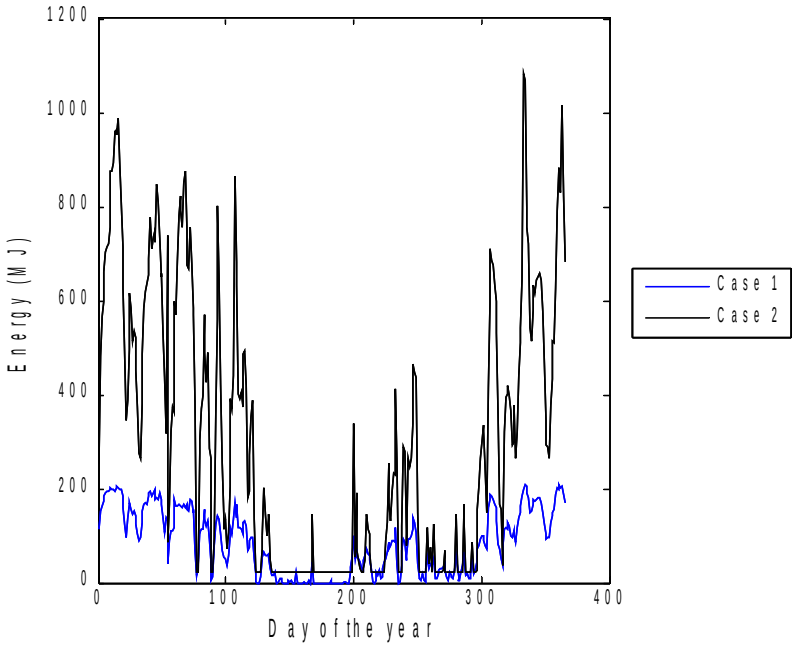

Figure 6.3 *– Auxiliary energy to face up the consumption*

Figure 6.4 is the superposition of **figures 6.2** and **6.3**. It shows the energy consumption together with the auxiliary energy consumption for both cases.

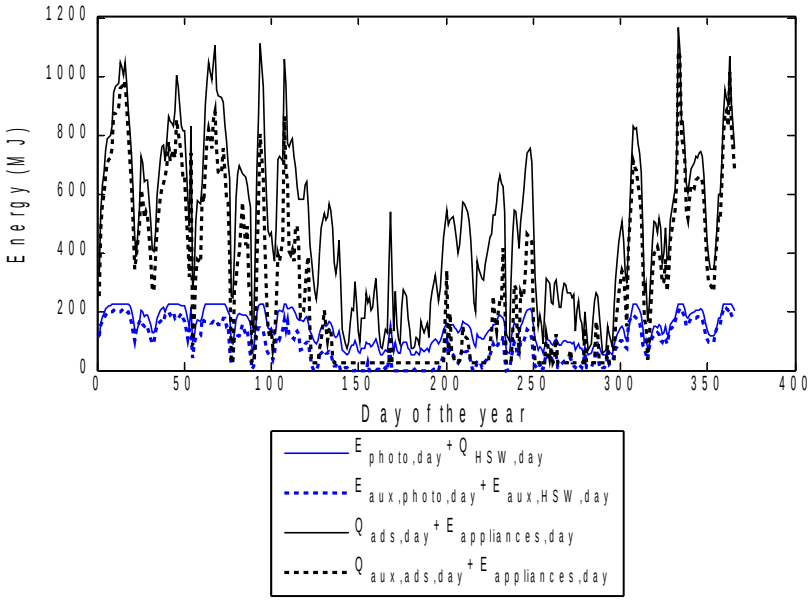

Figure 6.4 *– Comparative between the consumed and auxiliary energy*

Note that the demand in winter must be covered almost completely by the auxiliary energy in both cases. In summer, almost no auxiliary energy is needed.

As seen in **figure 6.1,** the rate of energy production per square meter in **case 2** is bigger than in **case 1.** However, there is a minimal consumption of auxiliary energy during the summer, because the solar energy is only used for heating and cooling and can not support the appliances.

6.2. Efficiency comparative

This section try to set the more efficient installation which allows to get the proposal purposes, in relation with the received energy from solar radiation and the used technology to transform it.
The efficiency of one installation can be defined like the relation between the useful energy with the primary energy. Primary energy is solar energy in both cases.

$$\eta_{installation} = \frac{E_{useful}}{E_{primary}} \qquad (6.5)$$

For **case 1** and **case 2**, these expressions become:

$$\eta_{case1} = \frac{\eta_{photo} \cdot E_{P,\,panel} \cdot COP + Q_{acc,\,case1}}{N_{panel} \cdot Q_{S,\,panel} + N_{collector,\,case1} \cdot Q_{S,\,collector}} \cdot \frac{1}{10^6} \qquad (6.6)$$

$$\eta_{case2} = \frac{Q_{acc,\,case2}}{N_{collector,\,case2} \cdot Q_{S,\,collector}} \cdot \frac{1}{10^6} \qquad (6.7)$$

where

$Q_{S,panel/collector}$ = Solar energy received by the panels / collectors field
Q_{acc} = Stored Energy in water accumulator

In **figure 6.5** are represented efficiencies of both installations.

The efficiency of the installation in **case 2** lower than the efficiency of thermal collectors shown in **figure 5.18,** because here is also taken into account the efficiency in heat transfer, whereas **figure 5.18** does not.
On the other hand, the efficiency of installation in **case 1** is higher than expected for photovoltaic panels (around 12-15 %). The reason is that the **figure 6.5** represents the efficiency of the complete installation and not only the efficiency of photovoltaic panels. The rate of heat power produced with the heat pump in relation with the consumed electric power is more than 4 times. It corresponds to the COP of the heat pump. Is clearly observed in **Figure 6.5** that the efficiency of photovoltaic installation decreases in summer because de produced power decreases, as shown in equation **4.4**. On the other hand, the efficiency of thermal collector decreases with the temperature (see equation 4.15), but the installation benefits from higher temperatures in summer.

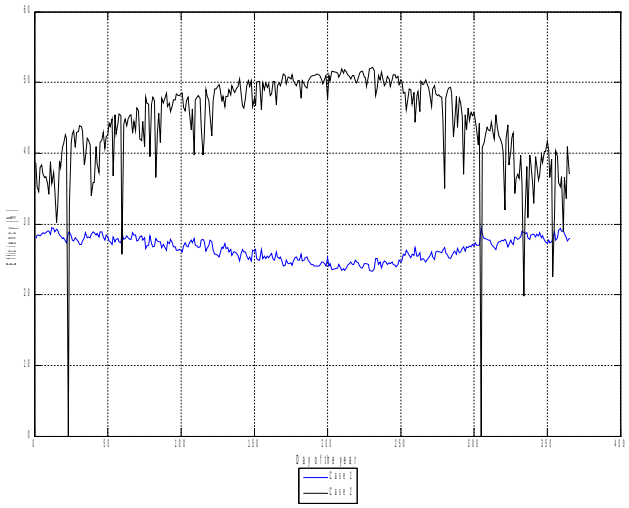

Figure 6.5 – Global Efficiency of installations

6.3. Economical Criterion

6.3.1. Operating Costs

Operating cost are related with the auxiliary electrical consumption when the solar energy is not sufficient.
The values of the highest daily auxiliary power consumption [kW] during a year, for both cases, are shown in **figure 6.6**.

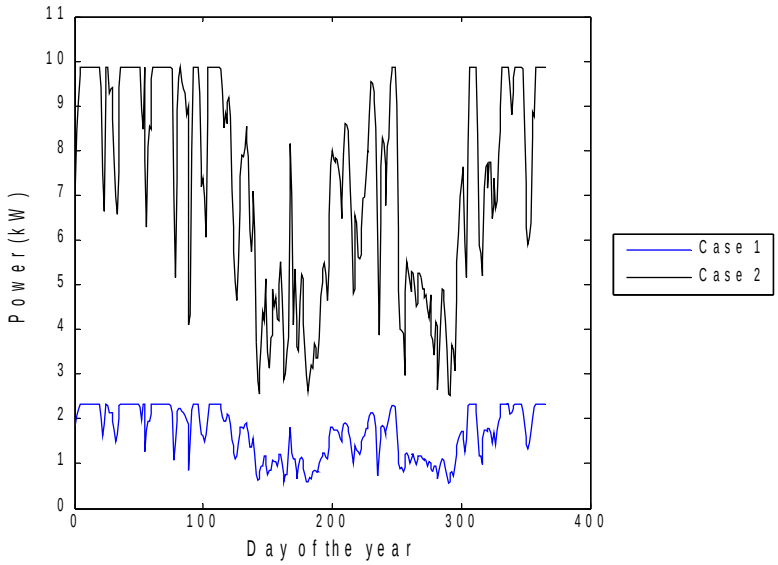

Figure 6.6 – Evolution of power consumption from the net

This leads to the deduction that contracted tariff should be until 2.5 kW and until 10 kW for cases 1 and 2 respectively.

The price of power for a tariff <10 kW in year 2010 is 1.642355 €/kW source: ENDESA **[32]**
The price of energy for a tariff <10 kW in 2010 is 0.11248 €/kWh source: ENDESA **[32]**

In **figure 6.7** are represented the daily electrical consumption from the electric grid due to the operating costs b_j (€) and according the prices given by ENDESA **[32]** for year 2010.

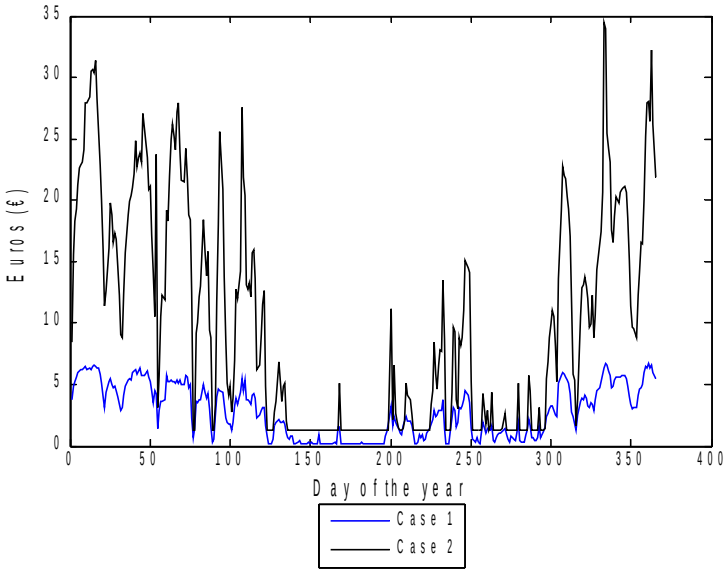

Figure 6.7 *– Operating costs: auxiliary electrical consumption*

The total value for the complete year results is:

Operating Cost for **case 1**, $B_{op,case1} = \sum_{year} b_{j,case1} = 1220.9$ € / year

Operating Cost for **case 2**, $B_{op,case2} = \sum_{year} b_{j,case2} = 3374.5$ € / year

The National Institute of Statistics (INE, according its initials in Spanish), collects the evolution of Consumer Prices Index (CPI) in Spain from September 1991 to September 2010 (20 years). The accumulated increases for this period is 81.0 % (see the website www.ine.es in reference **[28]**). That means a CPI median, i, given as:

$$\left(1+\frac{i}{100}\right)^{20}=1.81$$

solving for i we have

$$i = 3.01\ \%$$

Since the installations are planned for a 20 years operating life, this value of prices increase will be extrapolated for 20 years and will be used as a reference to calculate the operating

cost of the installations.

On the other hand, it is supposed a granted loan from a bank to cover the investment cost, with an interest, *j*, of 5 %.

$j = 5\ \%$

6.3.2. Investment Costs

Prices of equipments are shown in **tables 6.2** and **6.3**, for **case 1** and **case 2** respectively, extracted from references **[30]** and **[31]**.

Units	Description	€ / ud	subtotal
24	Photov Panel SolvisPico PI – AE / 210 Wp	1470	35280
6	Regulator Tarom 235	261	522
4	Battery Monoblock Power 12V, 250 Ah	299	1196
1	Senoidal inverter Solener ISC 4000, 24 V	1430	1430
24	Panels structure	79.41	1905.84
1	heat pump SAP – CMRV 2446 EH	2200	2200
1	Fan coil SAP-KMRV96EH	415	415
2	Fan coil SAP-KMRV76EH	400	800
1	Kit Hot Sanitary Water 4 persons	3000	3000
		TOTAL	47792.84

Table 6.2 *– Price of equipments for* ***case 1***

Units	Description	€ / ud	subtotal
16	Thermal Collector Solvis Cala C-235-I	880	14080
16	Collector structures	150	2400
1	Accumulator SolvisMaxFutur 950	6000	6000
1	Adsorption Machine SolvisCool ACS 08	10000	10000
1	Fan coil SAP-KMRV96EH	415	415
2	Fan coil SAP-KMRV76EH	400	800
		TOTAL	33695

Table 6.3 *– Price of equipments for* ***case 2***

6.3.3. Total Cost

The installations are planned for a 20 years life. The calculation of total cost at the end of their life must consider investment costs, operating costs and maintenance costs.
It is considered that the efficiency of equipments does not decreases with the time.
The cost for the year zero, B_0 , is the investment cost.
Operating cost for following years are given as a geometric progression of energy prices and bank interest, according to the rates estimated in **chapter 6.4.1**.
Maintenance cost for solar installations, B_M , could be ignored in this analysis. Nevertheless, the price of electrical batteries, B_{batt} , will be also included in **case 1** since its replacement every 8-10 years is recommended by the manufacturer.
The total cost for the operating life of the installations can be calculated as

$$B_0 \cdot \left(1+\frac{j}{100}\right)^{20} + \sum_{n=1}^{20}\left[B_{op}\cdot\left(1+\frac{i}{100}\right)^{n}\right] + B_M \quad € \qquad (6.8)$$

where

B_0 = Investment cost (€)

B_{op} = Operating cost (€)

$B_M = B_{batt}\cdot\left(1+\frac{i}{100}\right)^{10}$ (€) . Maintenance cost in 10th year (6.9)

B_{batt} = current cost of the batteries [€]

Figures 6.8. and **6.9.** show the annual payment and the total amount at the end of the installations life for **case 1** and **case 2** respectively. The arrows size is not done to scale.

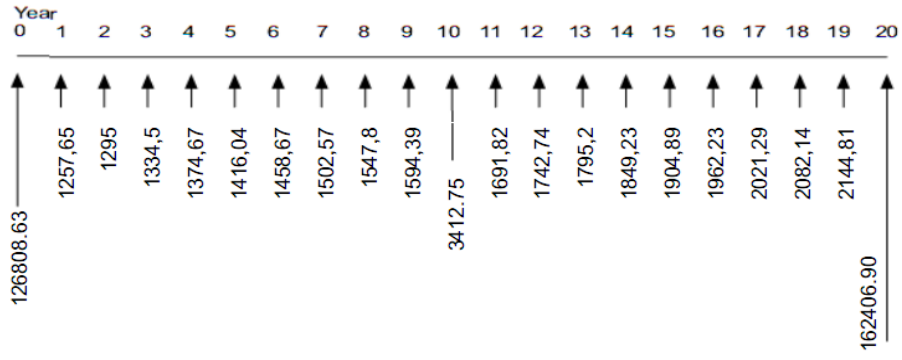

Figure 6.8 *- Annual payment and total amount in 20 years in* ***case 1***

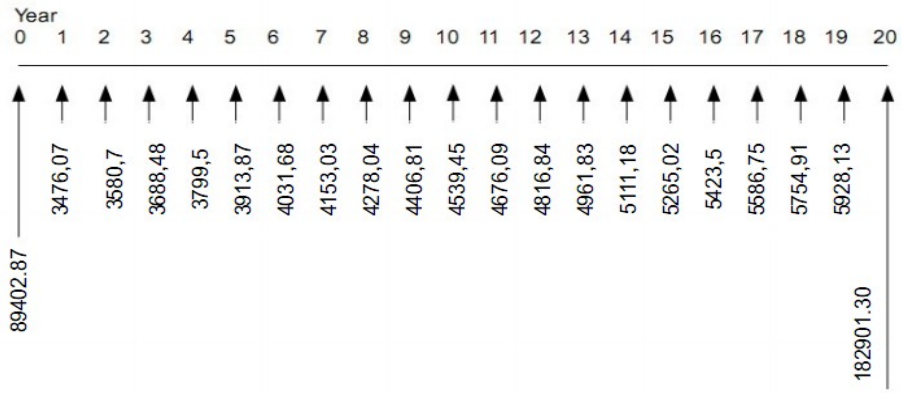

*Figure 6.9 – Annual payment and total amount in 20 years in **case 2***

Figure 6.10 is a graphic representation of these values.
As shown, the investment cost for **case 2** is lower than for **case 1**. On the other hand, the operating cost are much greater. The reason for that can be found in the huge electrical consumption in winter months shown in **figure 6.3**.

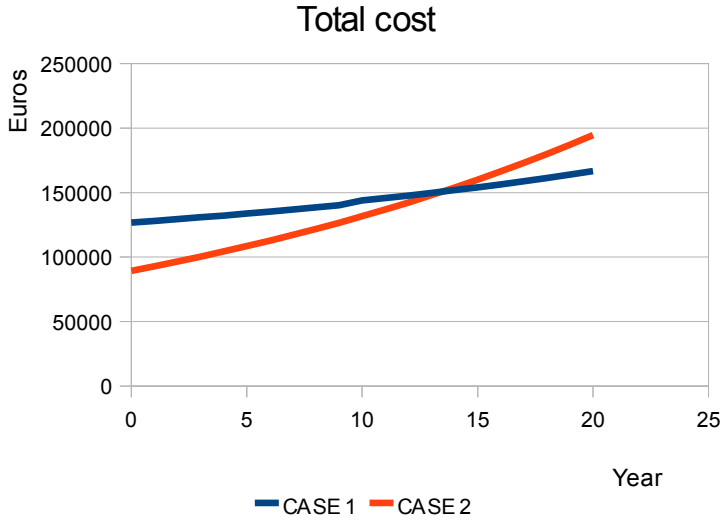

*Figure 6.10 – comparative in operating costs for **case 1** and **2***

It is necessary to include the interest j in calculation of operating cost if it is planned to pay it with the loan from the bank.

Equation **6.8** must be rewritten as

$$B_0 \cdot \left(1+\frac{j}{100}\right)^{20} + \sum_{n=1}^{20}\left[B_{op} \cdot \left(1+\frac{i}{100}\right)^{n} \cdot \left(1+\frac{j}{100}\right)^{(20-n)}\right] + B_M \quad € \qquad (6.10)$$

where

$$B_M = B_{batt} \cdot \left(1 + \frac{i}{100}\right)^{10} \cdot \left(1 + \frac{j}{100}\right)^{10} \quad (€) \qquad \textit{(6.11)}$$

Figure 6.11 shows the annual payment of the installations for **case 1** and **case 2** respectively.

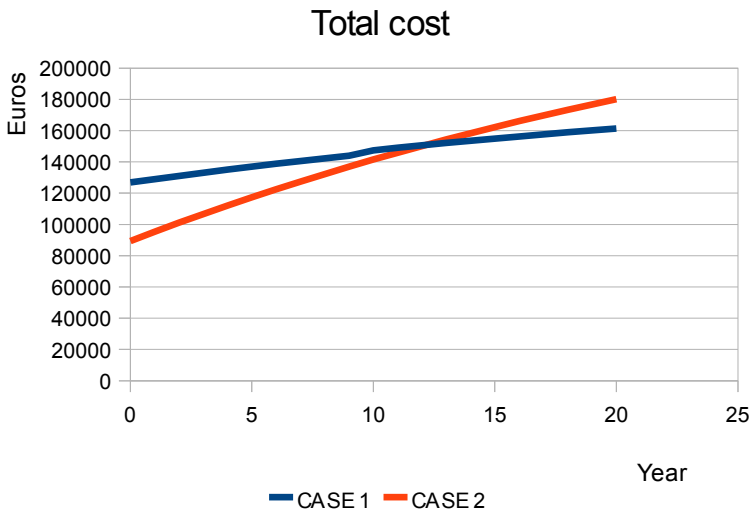

Figure 6.11 *– comparative in operating costs for* ***case 1*** *and* 2 *if operating costs are included in the banking loan*

7. CONCLUSIONS

The main objective of this study is to calculate the necessities of power, heat and warm water of a building. The used method to tackle this problem – finite differences – has proved to be appropriate for this purpose. It is relatively easy to be implemented in the simulation software MATLAB (see **Appendix E**), and allows a high precision in calculations. This method requires a huge number of iterations, but it is not any more a problem with current computers. The implemented code takes around 30 minutes for a whole year.

A best knowledge of energy consumptions rates and loads cycles would be necessary to improve the simulation. For example, it is supposed in this study that the ventilation flow is constant during all the year. But it depends strongly from human decisions and is clearly inconstant. Likewise, the consumption in electrical power and in HSW are also supposed constants each day.

The second objective of this study is the design of regenerative generator systems with solar-thermal and photovoltaic technology to provide the power, heat, cooling and warm water demanded of the building. It have been also reached in this project with proposed installations in **case 1** and **case2**.

There is however some important considerations which are commented in following chapters.

7.1. Efficiency of the Installations

The proposed solar installations studied in this project present a great limitation providing energy supply in winter for the normal use of the house.

Two factors contribute mainly to this fact:
Irradiance in summer is about four times bigger than irradiance in winter for this latitude.

The power demand in winter is more than two times higher than in summer.

Therefore, it is very difficult with the current technology to cover 100 % of the necessities from solar resources without using a huge collectors surface. The design criterions are more restrictive in winter and therefore the installations for both cases are oversized in summer.
A better design of the house could improve the use of available space by using bio climatic architecture techniques like *Trombe* walls or greenhouses built onto the house (see references **[20]** and **[21]** for more information about bio climatic architecture).
In principle there is no problem to satisfy the energy needs in summer. However, loads in summer could be likewise reduced by using parasol elements on top of the windows at the south side or by controlling the ventilation flow during the hottest hours of the day.

On the other hand, the proposed installations have another handicap, because the low tilt of panels favors the solar energy collection in summer and penalizes it in winter when the energy need is the highest. To cite just one fact, energy production in winter months would be of 28 % more if the tilt of the panels were 50°, according to the results of the simulation made in this project. The current tilt of the panels of 12.41° was chosen in accordance to architectonic and aesthetic conditions.
In relation with the adsorption machine installation, the results show a very good correspondence between the solar resources and energy demand in the summer period.
As a result of this simulation, the technology is appropriate as an air conditioning system with a very low operating cost and very good results in summer months.
On the other hand, in this case the proposed 8 kW power machine is oversized for the energy requirements of the house as shown in **figure 5.16.**

7.2. Auxiliary System

The need of an auxiliary power system is proven to be evident through the simulation.
Only electrical energy from the electric grid has been proposed in this project as auxiliary power.
Other energy resources like any combustible should be compared in subsequent studies.
For example, the price of natural gas for 2010 is 0,041307 €/kWh (source: IBERDROLA **[33]**).
This price is less than a half of the price of electricity.

In **case 2**, the use of a thermal collectors installation for heating and air conditioning combined with an adsorption machine, allows a great number of solutions to get an auxiliary energy supply from different resources. Some different types of boilers or heaters can be placed inside the main accumulator favoring the flexibility and the safety of the energy supply.
Contrarily, the use of a heat pump allows just the use of electricity from the grid as auxiliary resource.

7.3. Economical Considerations

The use of solar technologies can yield large profits if they are placed in sunny areas and correctly planned for one specific application. However, it is also evident that the investment costs can be a handicap and dissuade people from the use of this technology.
It would be possible to get profit from state subsidies for this kind of installations. The Government of Baleares offers every year several incentives as shown on its web site www.caib.es, **[27]**

On the other hand, since both proposed installations have an energy storage system (batteries and an accumulator with capacity for 150 litters in **case 1**; and one accumulator with capacity for 950 litters in **case 2**), it would be possible to contract a night rate in which the day is divided in two different periods, peak period and off-peak period, according to reference **[23]**.
The night rate would allow to charge the batteries or to "charge" the water accumulator during the off-peak period to be used in peak hours. In that case the storage capacity of the batteries in **case 1** and of the water accumulator in **case 2** should be higher because of the gap of time between the production and the consumption of energy.

For the photovoltaic installation in **case 1**, the following possibility could be interesting within the framework of current Spanish law (see reference **[19]**). It could be possible to drive the produced electrical energy from the photovoltaic installation to the electric grid. Electricity companies are bound to buy the produced energy for 0.321967 €/kWh (price for 2010 for installations smaller than 20 kW power and placed on the roof from website www.mityc.es **[29]**), whereas a parallel traditional installation could provide the house with power supply for a cheaper price (see **chapter 6** for energy prices).
The photovoltaic installation will inject the energy into the grid independently of the use of the building and generating profits for that. Moreover, the installation of batteries wouldn't be necessary any more, reducing the investment costs.
The energy requirements to inject electricity into the electric grid are set by the electricity company that manages the local grid (see reference **[32]**).

7.4. General conclusion

From results of this project, the best solution for this application could probably come from a combination of the two proposed installations.
As shown in **tables 6.1** and **6.5**, the thermal installation from **case 2** can provide more energy and presents a better efficiency compared with **case 1**. Current photovoltaic panels have a poor efficiency which damage the efficiency of the whole installation. Moreover, the investment cost in **case 2** are much lower than in **case 1**.
On the other hand, the use of the heat pump in **case 1** to provide heat in winter lead to very low electrical consumption and operating cost, compared with **case 2**.
A way to take advantage of both installations could be a thermal collectors installation

producing hot water for heating and domestic use, and a heat pump as auxiliary heater. The batteries installation would be not necessary either.
The use of combustibles as auxiliary heaters and the use of a night rate would be also possible.

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Appendix A: Summary of climatic data results - METEONORM version 6.0

Nombre del lugar = Soller

Latitud [°] = 39,760, Longitud [°] = 2,700, Altitud [m] = 13, Zona climática = IV, 1

Modelo irradiancia = Standard (hora); Modelo temperatura = Standard (hora)

Modelo irrad. incl. = Perez

Temperatura: Periodo viejo = 1961-1990

Radiación: Período nuevo = 1981-2000

Solamente 4 Estacion/es para interpolar

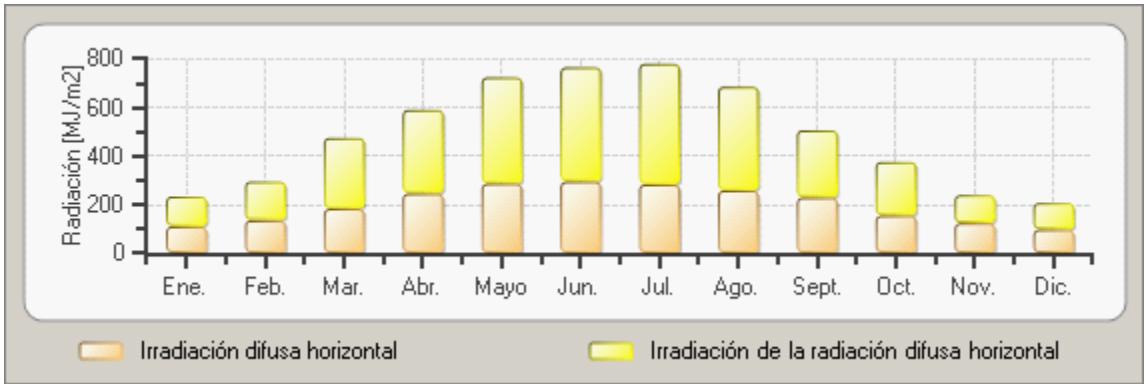
3 estaciónes más proxima: Gh: Palma De Mallorca (24 km), Ibiza/Es Codola (151 km), Valencia Airp. (273 km)

3 estaciónes más proxima: Ta: Palma De Mallorca (24 km), Palma De Mallorca (24 km), Mahon/ Menorca Isl (132 km)

Mes	H_Gh	H_Dh	Bh	FF	DD	Ta	Ts	Tp	Td
	[MJ/m2]	[MJ/m2]	Bh	[m/s]	[deg]	[C]	[C]	[C]	[C]
Ene.	234	110	124	4,6	68	10,5	10,0	8,2	6,1
Feb.	296	135	160	4,6	68	10,6	10,3	8,3	6,3
Mar.	475	183	292	5,1	68	10,8	11,2	8,9	7,4
Abr.	590	246	344	4,6	68	12,1	12,7	10,3	9,1
Mayo	723	286	437	4,6	68	15,8	16,9	13,6	12,3
Jun.	765	294	471	5,1	68	20,0	21,2	17,1	15,7
Jul.	779	283	496	5,1	225	23,4	24,6	20,1	18,6
Ago.	685	258	427	4,6	68	24,1	25,2	20,9	19,5
Sept.	507	229	277	4,1	68	22,0	22,2	19,0	17,8
Oct.	376	155	221	4,6	68	18,3	18,2	15,7	14,1
Nov.	239	123	116	4,6	68	13,9	13,2	11,4	9,8
Dic.	207	97	110	4,1	68	11,7	11,1	9,3	7,2
A□ o	5858	2396	3472	4,6	70	16,1	16,4	13,6	12,0
Mes	p	RH							
	[hPa]	[%]							
Ene.	1012	74							
Feb.	1011	75							
Mar.	1012	79							
Abr.	1011	82							
Mayo	1012	80							
Jun.	1011	76							
Jul.	1011	74							
Ago.	1011	75							
Sept.	1012	77							
Oct.	1011	77							
Nov.	1011	76							
Dic.	1012	74							
A□ o	1012	77							

Leyenda:
H_Gh: Irradiacion global horizontal

H_Dh: Leg_H_Dh
Ta: Temperatura del aire Td: Temperatura del punto de roc□ o
Tp: Temperatura del termometro h□ medo RH: Humedad relativa
FF: Velocidad del viento DD: Direccion del viento
p: Presion atmosferica Ts: Temperatura de la superficie
H Bh: Irradiacion de la radiacion difusa horizontal



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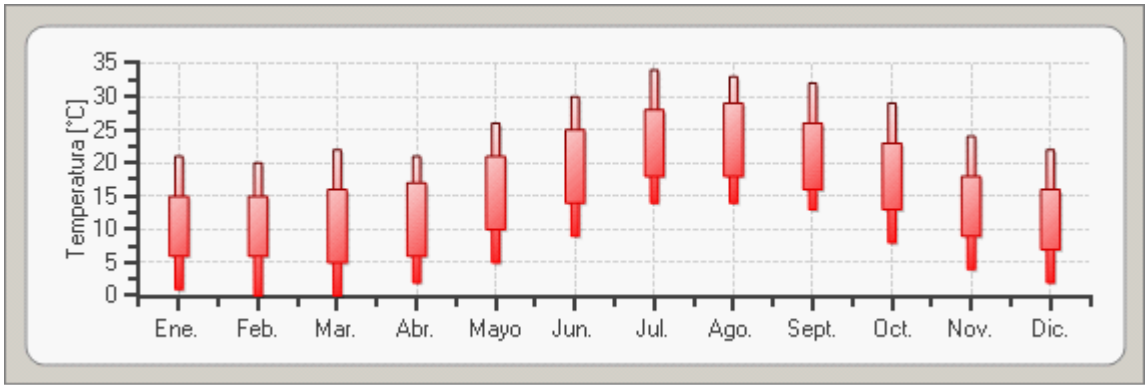

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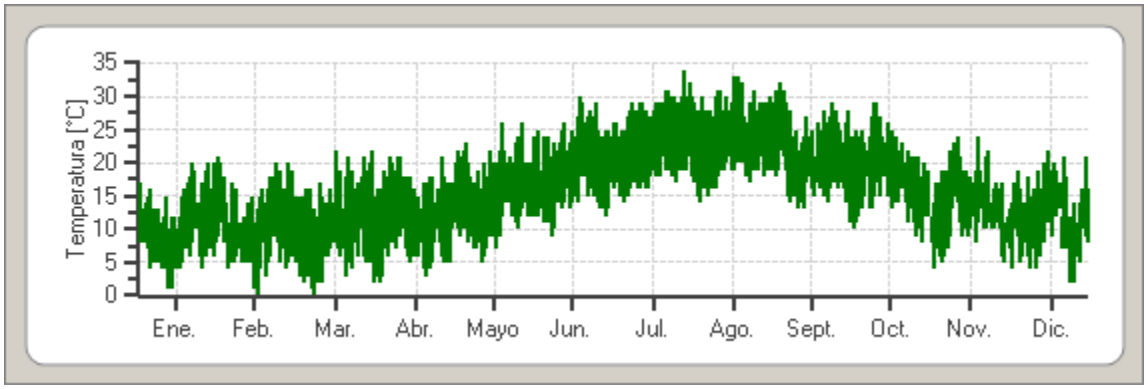

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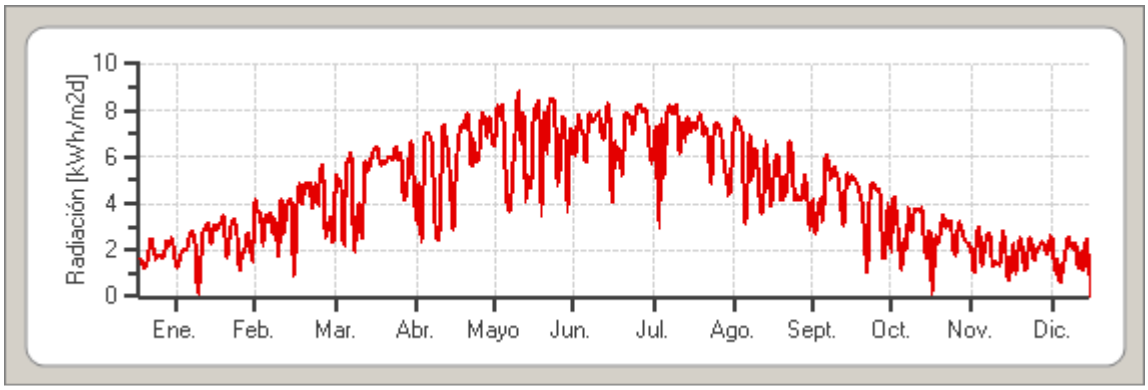

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Appendix B: House Figures

Appendix B – House Figures

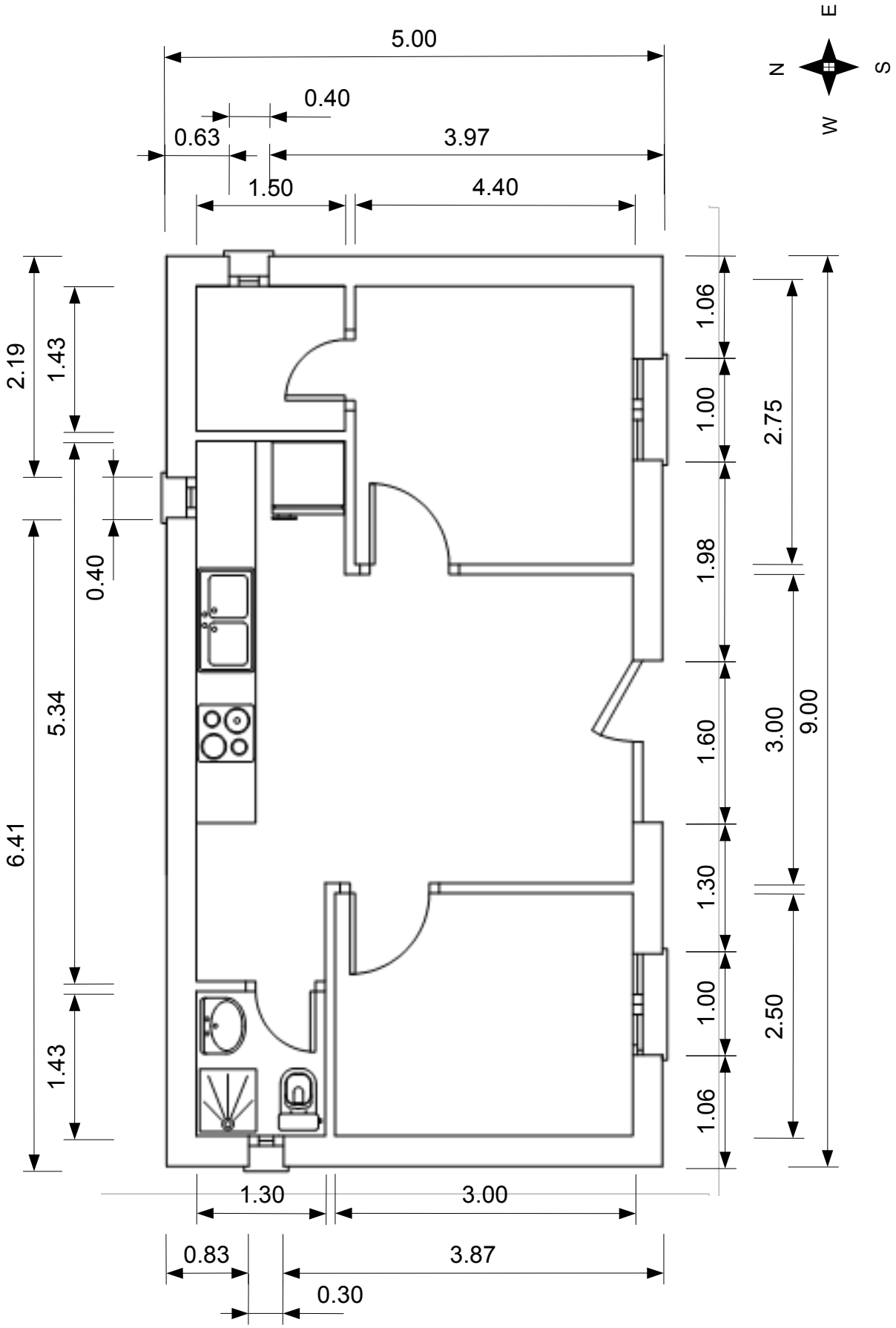


Figure B.1 - Floor plan

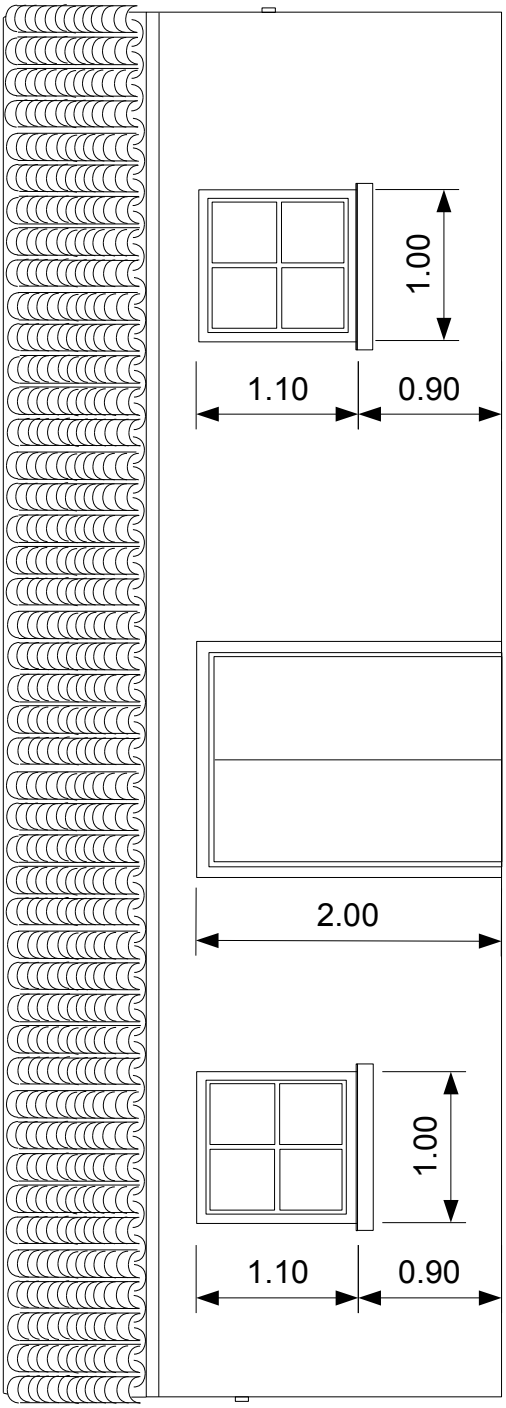


Figure B.2 – South side view

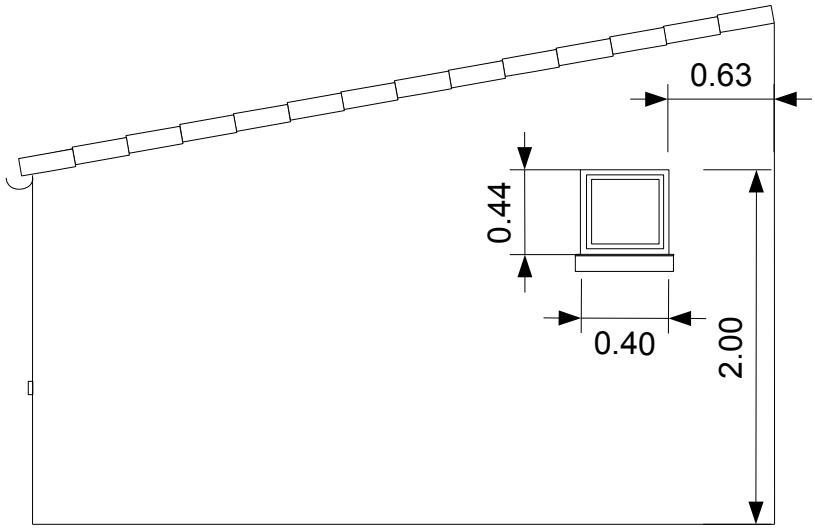


Figure B.3 – East side view

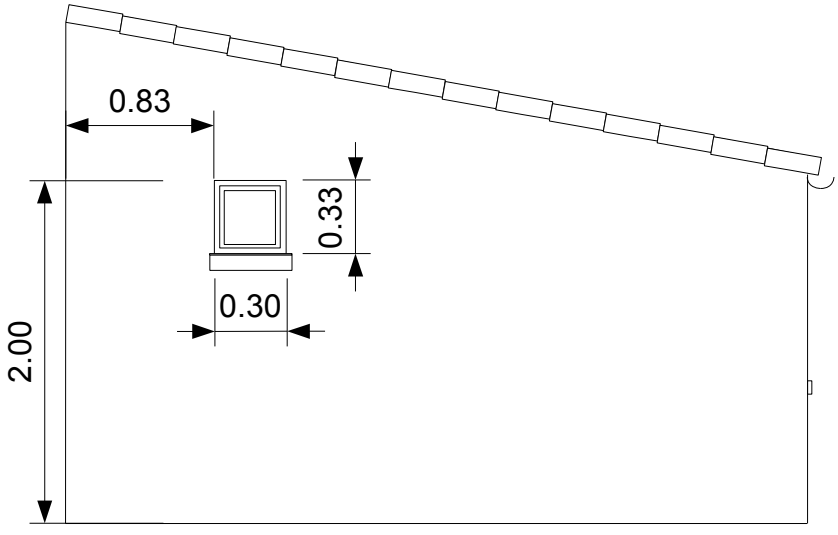


Figure B.4 – West side view

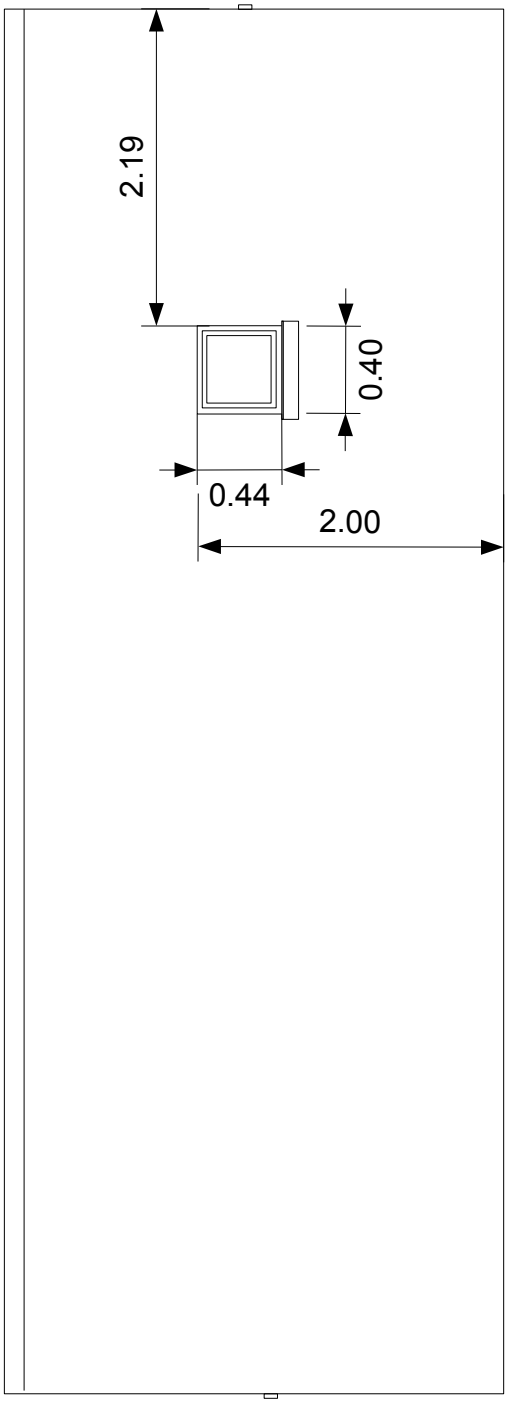


Figure B.5 – North side view

Appendix C: Arrangement and connection of panels and collectors on the roof

Appendix C – Arrangement of panels and collectors

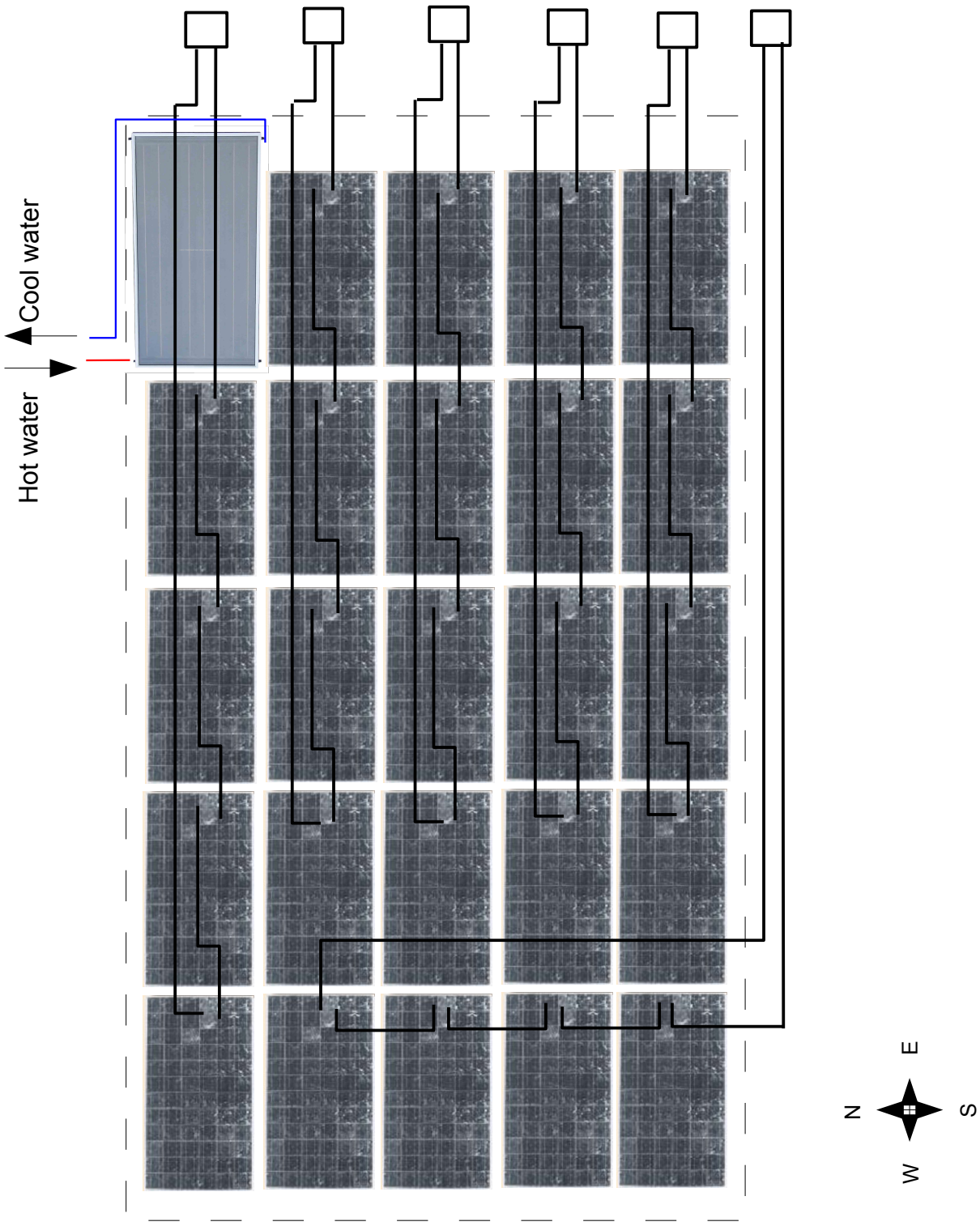


Figure C.1
Arrangement of photovoltaic panels and thermal collector on the roof – CASE 1

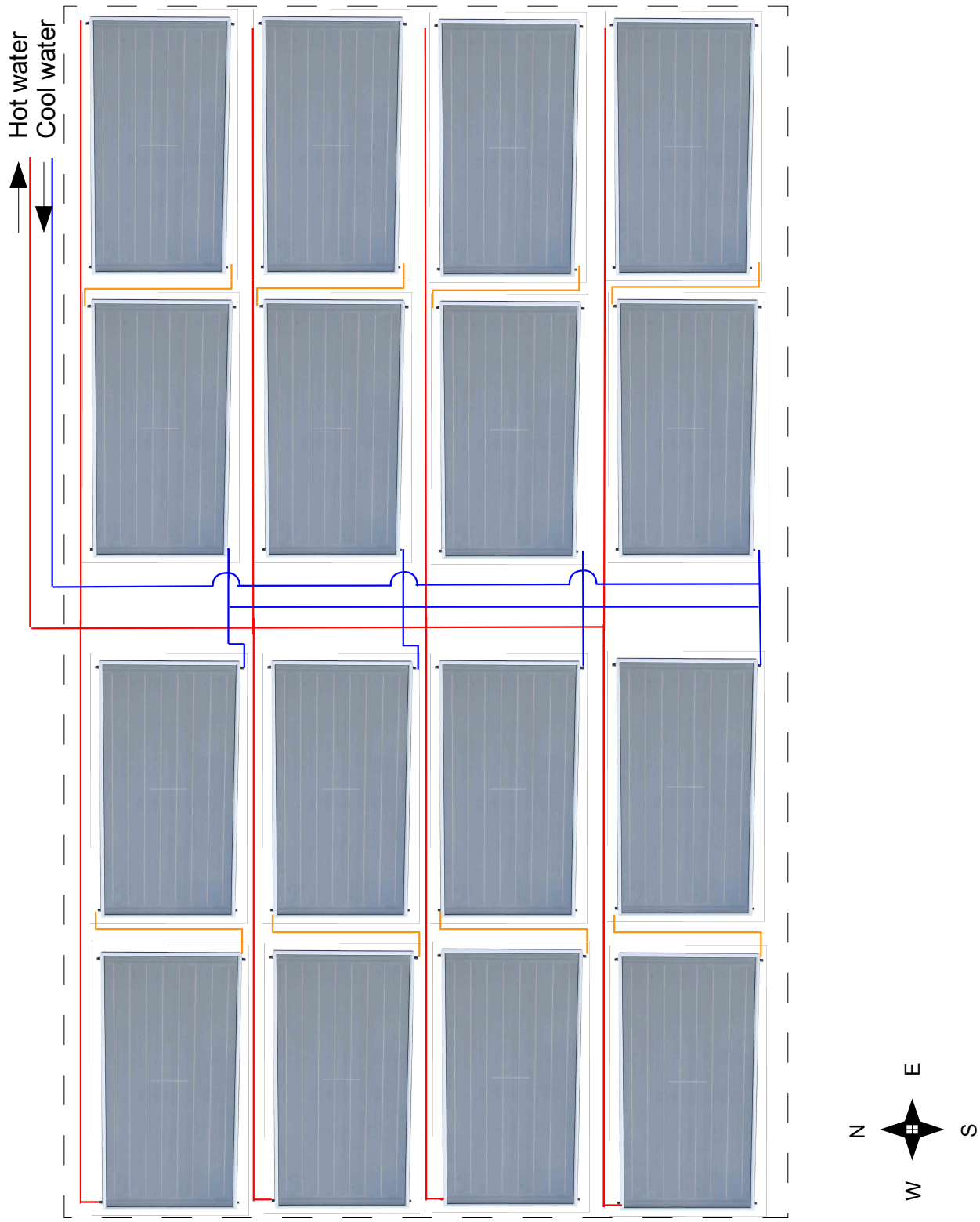
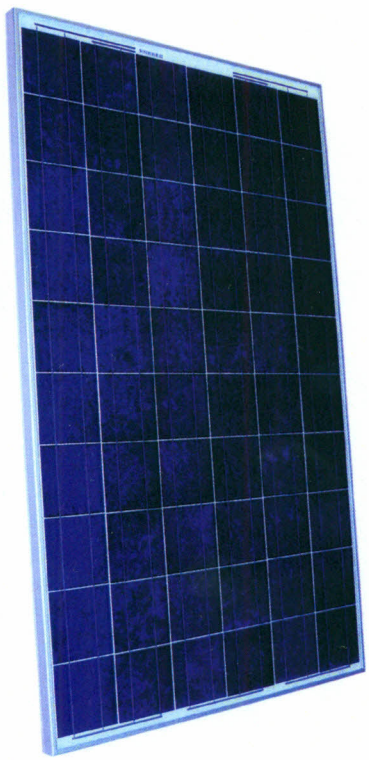


Figure C.2
Arrangement of thermal collectors on the roof – CASE 2

Appendix D: Technical sheets of products

SolvisPico Premium

DE	Technische Informationen	2
EN	Technical Information	5
IT	Informazioni tecniche	8



	Art. Nr.: 14611	D 10-M	Technische Änderungen vorbehalten 03.10 / 14611-2e

1 Description

SolvisPico Premium – The Power Package

This high-quality module is manufactured in Europe and designed to deliver particularly high yields.

Solvis, with its 20 years of expertise in the solar industry, has designed a perfectly-tailored system: from the high-quality module with anti-reflective glass to the snow-safe stainless steel and aluminium support structure designed using Solvis's tried and tested structural calculations and the high-efficiency Sunny Boy inverter.

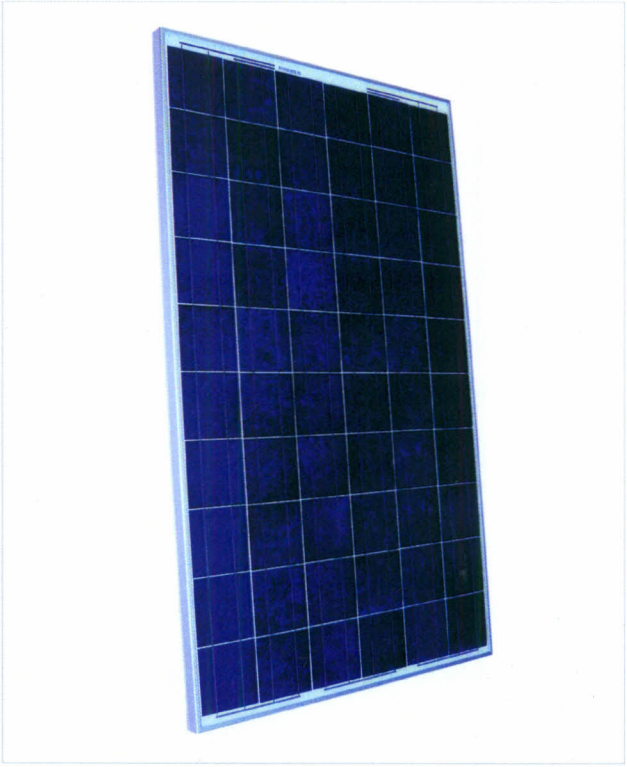


Fig. 4: SolvisPico Premium

Quality without compromise

The SolvisPico Premium product series consists of high-quality, high-efficiency solar modules that each measure up to the highest standards of quality.

The entire production process – from the silicon all the way to the finished module – complies with the strictest quality control standards. The solar cells have been optimised to increase light absorption, even under poor lighting conditions.

The high-quality modules have an innovative design that reduces shadows while improving performance. The power output tolerance of +3 % minimises mismatch losses.

Environmentally friendly products and processes

The Premium series generates reliable, environmentally friendly power. The process of producing cells and modules is designed to allow for a high degree of recycling and prevent damage to the environment.

Features

- Superb efficiency with a power tolerance with exclusively positive sorting
- 25-year warranty at 80 % of the output power
- 10-year warranty at 90 % of the output power
- 10-year warranty on materials and workmanship
- High max. permitted system voltage (1,000 V)
- Measuring log: Each individual module is measured electrically (documentation available upon request)
- Seamless quality control
- Minimum manufacturing tolerances
- Simple installation
- Finished cabling, fitted with MC-3 plugs.

Simple installation

The superb module performance and the minimal weight allow for an efficient and economical installation. The solar cables are fitted with MC plugs and pre-connected.

CE marking

SolvisPico PV modules comply with the requirements of the applicable EU directives. You may request the declarations of conformity.

2 Technical Data

2.1 SolvisPico Premium PI-AE/... Wp

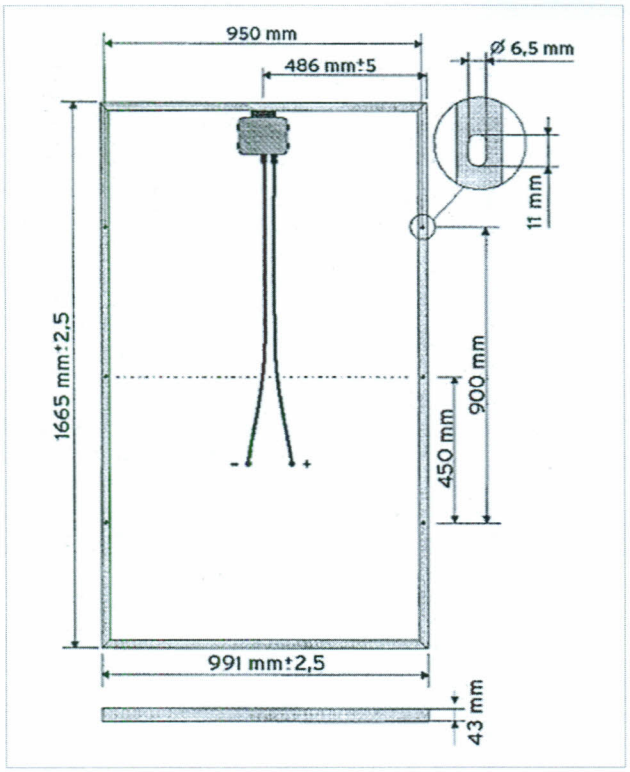


Fig. 5: SolvisPico Premium PI-AE/... Wp – Dimensions

Qualifications and certificates
CE marking • Protection class II • ISPRA CEC 503/IEC 61215 for hail, temperature, wind and snow load protection • RAL quality mark Solar P1

General specifications

Dimensions and weight	Unit	All modules
Surface	m²	1.65
Length	mm	1,655.00
Width	mm	991.00
Thickness with frame	mm	43.00
Diameter of frame hole	mm	6.50
Weight (approx.)	kg	22.00
Cell size (square)	mm	156 x 156

Limit values	Unit	All modules
Max. permitted system voltage	V	1,000
Max. compressive loading	Pa	5,400
Max. tensile loading	Pa	2,400
Permitted module temperature	°C	-40 – +80

Characteristics	All modules
Number of cells	60
NOCT (*) [°C]	49.5 ± 2
Aluminium frame, colour	Bright anodised
Connection	MC type 3
Cable length +/- [cm]	94/94
Number of bypass diodes	3
Structure of the front side (glass/foil)	Solar glass/EVA

(*) NOCT = "Nominal operating cell temperature" = cell temperature with irradiation of 800 W/m² (ambient temperature 20 °C and wind speed 1 m/s).

Electrical specifications (1)

Designation	Abbreviation	Unit	Modules (2) SolvisPico PI-AE/...			
			210 Wp	215 Wp	220 Wp	225 Wp
Rated output (STC)	P_{MPP}	W_P	210.00	215.00	220.00	225.00
Max. deviation from P_{MPP}	–	%	+2.00	+2.00	+2.00	+2.00
Voltage for P_{MPP}	V_{MPP}	V	27.60	28.00	28.40	28.80
Current at P_{MPP}	I_{MPP}	A	7.60	7.70	7.80	7.80
Open circuit voltage	V_{OC}	V	36.10	36.30	36.40	36.60
Short circuit current	I_{SC}	A	8.30	8.30	8.40	8.40
Temperature coefficient for P_{MPP}	T_cP_{MPP}	%/°C	-0.452	-0.452	-0.452	-0.452
Temperature coefficient for V_{OC}	T_cV_{OC}	%/°C	-0.340	-0.340	-0.340	-0.340
Temperature coefficient for I_{SC}	T_cI_{SC}	%/°C	0.074	0.074	0.074	0.074
Module efficiency (STC)	η	%	12.70	13.00	13.30	13.60
Max. protection at serial voltage	–	A	15.00	15.00	15.00	15.00
Manufacturer	–	–	REC	REC	REC	REC

(1) These electrical specifications are valid under the standard test conditions (STC) (airmass 1.5; irradiation 1,000 W/m²; cell temperature 25 °C).
(2) Sizes and availability: The modules are available in the sizes listed above, pending availability based on the manufacturing tolerance of the production. Make sure to enquire about the availability of different sizes before placing an order.

2.2 SolvisPico Premium PI-SK/... Wp

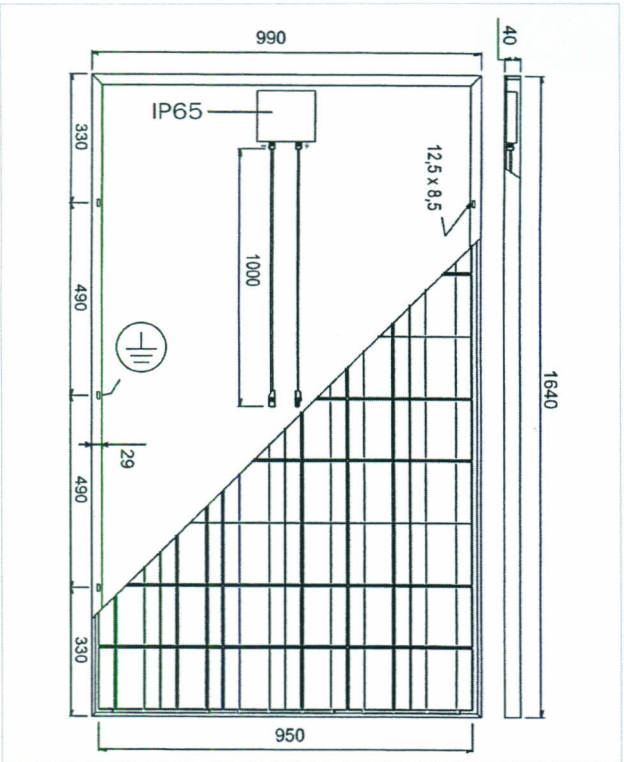


Fig. 6: SolvisPico Premium PI-SK/... Wp – Dimensions (length ± 2 mm)

Qualifications and certificates
CE marking • Protection class II • ISPRA CEC 503/IEC 61215 for hail, temperature, wind and snow load protection

General specifications

Dimensions and weight	Unit	All modules
Surface	m²	1.62
Length	mm	1,640.00
Width	mm	990.00
Thickness with frame	mm	40.00
Diameter of frame hole	mm	8.50
Weight (approx.)	kg	19.00
Cell size (square)	mm	156 x 156

Limit values	Unit	All modules
Max. permitted system voltage	V	1,000
Max. compressive loading	Pa	5,400
Max. tensile loading	Pa	2,400
Permitted module temperature	°C	-40 – +85

Characteristics	All modules
Number of cells	60
NOCT (*) [°C]	49.0 ± 2
Aluminium frame, colour	Bright anodised
Connection	MC type 3
Cable length +/- [cm]	100/100
Number of bypass diodes	3
Structure of the front side (glass/foil)	Solar glass/EVA

(*) NOCT = "Nominal operating cell temperature" = cell temperature with irradiation of 800 W/m² (ambient temperature 20 °C and wind speed 1 m/s).

Electrical specifications (1)

Designation	Abbreviation	Unit	Modules (2) SolvisPico PI-SK/...				
			215 Wp	220 Wp	225 Wp	230 Wp	235 Wp
Rated output (STC)	P_{MPP}	W_P	215.00	220.00	225.00	230.00	235.00
Max. deviation from P_{MPP}	–	%	+3.00	+3.00	+3.00	+3.00	+3.00
Voltage for P_{MPP}	V_{MPP}	V	29.00	29.20	29.30	29.50	29.50
Current at P_{MPP}	I_{MPP}	A	7.41	7.54	7.68	7.79	7.97
Open circuit voltage	V_{OC}	V	36.60	36.70	36.80	36.90	36.90
Short circuit current	I_{SC}	A	8.02	8.10	8.20	8.32	8.47
Temperature coefficient for P_{MPP}	T_cP_{MPP}	%/°C	-0.430	-0.430	-0.430	-0.430	-0.430
Temperature coefficient for V_{OC}	T_cV_{OC}	%/°C	-0.356	-0.356	-0.356	-0.356	-0.356
Temperature coefficient for I_{SC}	T_cI_{SC}	%/°C	0.062	0.062	0.062	0.062	0.062
Module efficiency (STC)	η	%	13.20	13.60	13.90	14.20	14.50
Max. protection at serial voltage	–	A	1.25 x I_{SC} (measured under STC)				
Manufacturer	–	–	Siliken	Siliken	Siliken	Siliken	Siliken

(1) These electrical specifications are valid under the standard test conditions (STC) (airmass 1.5; irradiation 1,000 W/m²; cell temperature 25 °C).

(2) Sizes and availability: The modules are available in the sizes listed above, pending availability based on the manufacturing tolerance of the production. Make sure to enquire about the availability of different sizes before placing an order.

Institut für Solarenergieforschung GmbH
Hameln / Emmerthal

Prüfzentrum für solarthermische
Komponenten und Systeme

Am Ohrberg 1 · D-31860 Emmerthal

Prüfbericht für Leistungsprüfungen an abgedeckten Sonnenkollektoren nach EN 12975

Report of Performance Test according to EN 12975 for a Glazed Solar Collector

Deutscher Akkreditierungs Rat DAR
DAP-PL-3662.00

ilac-MRA

DEUTSCHES AKKREDITIERUNGSSYSTEM PRÜFWESEN GMBH DAP
DAP-PL-3662.00

Prüfstelle *Test Centre*

Anschrift *Address*	Institut für Solarenergieforschung GmbH, Hameln/Emmerthal Am Ohrberg 1 D- 31860 Emmerthal
Ansprechpartner *Contact person*	Dipl.-Ing. D. Eggert Tel.: 05151/ 999-522; Fax: -500 E-Mail: Pruefstelle@isfh.de

Prüfgrundlage *Test Basis*

Prüfung nach *Test according to*	DIN EN 12975-2:2006 Abschnitt 6

Prüfbericht *Test Report*

Nummer *Number*	145-08/KD2
Berichtsdatum *Date*	02.06.2009
Seitenanzahl *Number of pages*	27

Auftraggeber *Customer*

Anschrift *Address*	Solvis GmbH & Co. KG Grotrian-Steinweg-Str. 12 D- 38112 Braunschweig
Ansprechpartner *Contact person*	Herr Gunther Hesse Tel.: 0531/28904-635, Fax: -649

Prüfkollektor *Test Collector*

Typ *Type*	SolvisCala C-253-I
Hersteller *Manufacturer*	Solvis GmbH & Co. KG
Serien- oder Prototyp *Serial- or Prototype*	Serientyp *Serial type*
Herstelljahr *Year of production*	2008
Herstellnummer *Serial number*	0012

Institut für Solarenergieforschung GmbH
Hameln / Emmerthal

Prüfzentrum für solarthermische Komponenten und Systeme

Am Ohrberg 1 · D-31860 Emmerthal

1. Zusammenfassung der Prüfergebnisse

Summary of the Results

Firma: *Company:*	**Solvis GmbH & Co. KG** Grotrian-Steinweg-Str. 12 D- 38112 Braunschweig	Prüfbericht-Nr.: *Report no.:* Prüfbericht-Datum: *Report date:*	145-08/KD2 02.06.2009
Typ: *Type:*	**SolvisCala C-253-I**	Herstell-Nr.: *Serial no.:* Herstell-Jahr: *Year of producion:*	0012 2008

Die nachfolgend aufgeführten Ergebnisse wurden bei einer **Prüfung der Wärmeleistung** von Sonnenkollektoren **nach DIN EN 12975-2:2006** ermittelt. Sie gelten für den im Prüfbericht Nr. 145-08/KD2 näher beschriebenen Kollektor sowie die dort beschriebenen Prüfungen und Prüfabläufe.

*The following results were obtained from a test of the thermal performance of a solar collector according to **DIN EN 12975-2:2006**. They apply to the collector, the tests and procedures described more precisely in the test report no. 145-08/KD2.*

Technische Daten des Prüfkollektors Description of the collector

Bauart *Type*	selektiver Flachkollektor *flat plate collector*	Aperturfläche *Aperture area*	2.388 m²
Zeichnung-Nr. *Drawing no.*	14938-2-c	Absorberfläche *Absorber area*	2.378 m²
Länge / Breite / Höhe *Length/Width/Height*	2170 / 1168 / 93 mm	Bruttofläche *Gross area*	2.535 m²
zul. Betriebsdruck *Max. operation pressure*	4 bar	empf. Massenstrom *Recommended flow rate*	65 kg/m²h
Leergewicht *Weight, empty*	37.6 kg	Stärke Absorberblech *Thickness of absorber sheet*	0.5 mm
zul. Wärmeträger *Heat transfer fluid*	Tyfocor LS rot	Abstand Fluidrohre *Tube distance*	93.5 mm

Prüfergebnisse Test results

Koeffizienten der Wirkungsgradkurve (ermittelt im Sonnensimulator unter stationären Bedingungen)
***Coefficients of efficiency** (determined in the sun simulator under steady state conditions)*

$$\eta = \eta_0 - a_1 \cdot (t_m - t_a)/G - a_2 \cdot (t_m - t_a)^2/G$$

Bezug: *Based on:*	Apertur *aperture area*	Absorber *absorber area*
η_0 =	0.798	0.801
a_1 =	3.42 W/m²K	3.43 W/m²K
a_2 =	0.016 W/m²K²	0.016 W/m²K²

Einstrahlwinkelkorrekturfaktoren (ermittelt im Freien)
***Incident angle modifier** (determined outdoor)*

$$K_{\theta b}(\theta) = 1 - b_0\,(1/\cos\theta - 1)$$

$K_\theta(50°)$ =	0.94, bei G_d/G = 0.15 *, at*
b_0 =	0.12
$K_{\theta d}$ =	0.86

Ausgangsleistung pro Kollektormodul, W
Power output per collector unit, W

	Bestrahlungsstärke *Irradiance*		
$T_m - T_a$	400 W/m²	700 W/m²	1000 W/m²
10 K	677 W	1249 W	1820 W
30 K	483 W	1055 W	1627 W
50 K	259 W	831 W	1403 W

Spitzenleistung pro Kollektormodul **1906 W_{peak}** **bei G = 1000 W/m² und $t_m - t_a$ = 0 K**
Peak power output per collector unit *at* *and*

Wärmekapazität (berechnet) *Thermal capacity (calculated)*	c =	4.4 kJ/(m²K)		C =	10.4 kJ/K		
Stillstandstemperatur *Stagnation temperature*	t_{stg} =	208 °C	bei *at*	G_S = 1000 W/m²	und *and*	t_{as} = 30 °C	

Emmerthal, 02.06.2009 i. A.

Dipl.-Ing. D. Eggert,
stellv. Leiter der Prüfstelle EN
Assisting head of Test Centre EN

SolvisCool SC 08 / SC 15

Máquinas enfriadoras por adsorción

Producción de frío mediante calor – refrigeración y calefacción

ecológica - compacta – silenciosa

SC 08

Tipo	SC 08	SC 15
Capacidad máxima de enfriamiento	11 kW	23 kW
$COP_{térmico}$, max.	0,65	0,65
Capacidad de enfriamiento nominal	8 kW	15 kW
$COP_{térmico}$, nominal	0,60	0,60
Consumo eléctrico Ø	7 W	14 W
Rango de utilización		
Temperatura del circuito de frío	6-20 °C	6-20 °C
Temperatura del circuito de disipación	22-37 °C	22-37 °C
Temperatura del circuito caliente	55-95 °C	55-95 °C
Capacidad de enfriamiento	5-11 kW	10-23 kW

Las enfriadoras compactas de adsorción están disponibles en dos tamaños: SC 08 con 8 kW y SC 15 y con 15 kW de capacidad de enfriamiento. Las aplicaciones principales son enfriamiento y climatización de viviendas privadas, pequeños edificios comerciales y procesos industriales. La máquina utiliza como fuente de energía paneles solares, calor residual, calefacción de distrito o cogeneración en lugar de la electricidad. Combinando varias unidades puede conseguirse mayor capacidad de enfriamiento.

Con temperaturas de alimentación de 55°C ya es posible generar frío. El uso de gel de silicio y agua como medio frigorífico, son la garantía de utilización de materiales especialmente respetuosos con el medio ambiente.

Las enfriadoras SC se ofrecen en combinación con los disipadores especiales RCS. Este subsistema ofrece un alto coeficiente de rendimiento. La SC es también compatible con otras soluciones de disipación (torre de refrigeración húmeda, sonda geotérmica, piscina, etc).

En el modo de bomba de calor la SC puede ser utilizada como soporte a calefacción, aumentando el grado de la eficacia de la caldera tradicional hasta un 50%. La temperatura exterior, (en conjunto con el RCS), calor solar o energía geotérmica pueden utilizarse como fuentes de energía de baja temperatura. La energía de alimentación, como en el modo de enfriamiento, es el agua caliente.

SC en modo "bomba de calor"

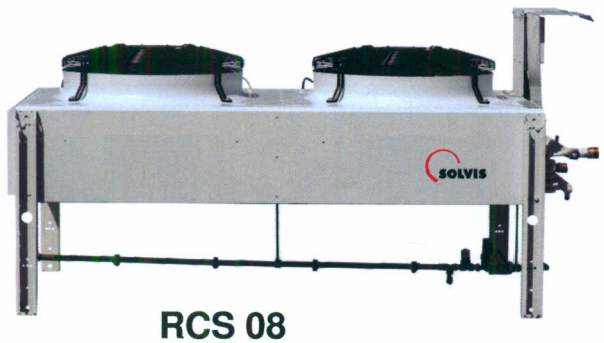
Rendimiento calefacción: 10 - 25 kW (SC 08)
20 - 50 kW (SC 15)

$COP_{térmico}$: 1,3 -1,5 *Solicite más detalles.*

			SC 08	SC 15
	Capacidad de enfriamiento, nominal	kW	8	15
	$COP_{térmico}$, nominal		0,60	0,60
Circuito de frío	Temperatura entrada/salida	°C	18/15	18/15
	Caudal	m³/h	2,0	4,0
	Pérdida de carga	mbar	300	500
	Presión de servicio	bar	4	4
	Conexión rosca exterior		1"	5/4"
Circuito de disipación	Temperatura entrada/salida	°C	27/32	27/32
	Caudal	m³/h	3,7	7,0
	Pérdida de carga	mbar	350	440
	Presión de servicio	bar	4	4
	Conexión rosca exterior		1"	5/4"
Circuito caliente	Temperatura entrada/salida	°C	72/65	72/65
	Caudal	m³/h	1,6	3,2
	Pérdida de carga	mbar	230	260
	Presión de servicio	bar	4	4
	Conexión rosca exterior		3/4"	5/4"
Suministro eléctrico	Voltaje	V	220 ... 240 ~	
	Frequencia	Hz	50 ... 60	
	Consumo eléctrico Ø	W	7	14
Dimensiones	Anchura	mm	790	790
	Profundidad	mm	1060	1340
	Altura	mm	940	1390
	Peso en vacío	kg	265	530
	Peso en orden de marcha	kg	295	590

SolvisCool RCS 08 / RCS15
Disipadores

Ventiladores EC – Control integrado con sistema de pulverización de agua



RCS 08

El disipador en seco RCS con la última tecnología de ventilación EC está optimizado para el funcionamiento en conjunto con la maquina enfriadora de adsorción. El disipador RCS está equipado con un sistema de pulverización de agua fresca de red para poder bajar la temperatura del circuito de disipación temporalmente. Debido a este sistema la enfriadora SC puede mantener un alto rendimiento a pesar de trabajar con temperaturas exteriores muy desfavorables.

El control integrado de la SC controla el disipador según sus necesidades.
El RCS es un subsistema optimo con una interfaz de conexión muy sencilla.

El subsistema RCS hace posible un alto rendimiento de la enfriadora SC y garantiza un uso optimo de la energía eléctrica y del agua de red. La velocidad variable de los motores se adapta exactamente a la demanda. Controlando las condiciones, es fácil obtener una eficiencia anual del sistema del 10 ó más. (producción de frío / consumo eléctrico).

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www.solvis.es

Datos técnicos en el punto de trabajo nominal

		RCS 08	RCS 15
Capacidad de disipación	kW	21	42
Tipo de ventiladores		2x EC- fan 650	3x EC-fan 650
Nivel de ruido a 10 metros de distancia	dB(A)	43	45
Medio de disipación		agua	
Consumo de agua de red	m³/año	20	30
Caudal nominal	m³/h	3,7	7,0
Perdida de carga a caudal nominal	mbar	150	100
Voltaje de la señal de control de velocidad	V	0-10	
Conexión hidráulica (entrada/salida)	mm	35,0 * 1,5	42,0 * 1,6
Presión de operación de los pulverizadores	bar	min. 3-6	
Conexión (sistemas de pulverización)	mm	22,0 * 1,0	
Voltaje y frecuencia	V	200 ... 277 ~	
	Hz	50 ... 60	
Consumo eléctrico máximo	kW	0,65	1,2
Anchura	mm	2000	4125
Altura	mm	1145	1145
Profundidad	mm	950	950
Peso en vacío	kg	ca. 188	ca. 330
Peso en orden de marcha	kg	ca. 225	ca. 390

Especificaciones sujetas a cambio sin previo aviso

Versión 05/2010

Made in Germany

Aquí encontrará el kit solar adecuado para Usted:

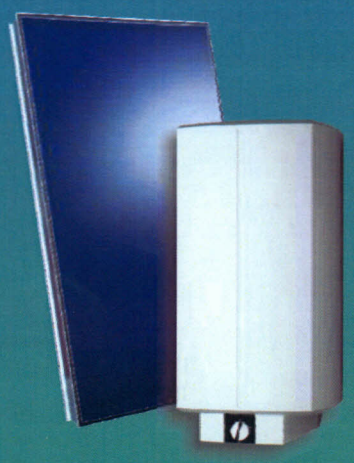
Personas en la vivienda	Kit solar	Volumen del acumulador	Colectores
	SolvisMini	150 l	1
	SolvisTherm 300	300 l	2
	SolvisTherm 500	500 l	3
	SolvisTherm 750	750 l	4

Cifras, datos y hechos que puede comparar:

Los acumuladores solares	SolvisMini	SolvisTherm 300	SolvisTherm 500	SolvisTherm 750
Volumen nominal	150 l	300 l	500 l	750 l
Altura total con aislamiento	1.100 mm	1.697 mm	1.710 mm	1.830 mm
Diámetro con aislamiento	510 mm	600 mm	760 mm	990mm
Inclinación del acumulador	–	1.860 mm	1.970 mm	1.930 mm
Intercambiador de calor solar (superficie)	1,2 m^2	1,2 m^2	1,7 m^2	2,1 m^2
Opcional: Intercambiador de calor para caldera de biomasa (superficie)	–	0,8 m^2	1,2 m^2	2,0 m^2

El colector solar	SolvisCala Eco
Altura del colector	2.174 mm
Anchura del colector	1.174 mm
Peso (con vidrio)	41 kg
Superficie bruta	2,55 m^2
Superficie de apertura	2,40 m^2

Preferentemente con sol.



El kit de inicio para familias: SolvisMini con colector solar.

Calderas con opción a energía solar | Acumuladores solares | Colectores solares | Calderas de pelletes | Sistemas de agua caliente "fresca" | Fotovoltaica

Art. n° 92418. Sujeto a modificaciones técnicas. Versión: 02.2010

Su especialista en calefacción eficiente:

SOLVIS

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Grotrian-Steinweg-Straße 12
D-38112 Braunschweig, Germany
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SANYO

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Doméstico

Flexi Multi (2x1, 3x1, 4x1, 5x1)
Inverter
Bomba de calor

SAP-CMRV1426EH · SAP-CMRV1926EH · SAP-CMRV1936EH
SAP-CMRV2446EH · SAP-CMRV3146EH · SAP-CMRV3656EH

Rango de potencia de 4,0 kW a 10 kW

nuevo

Características generales

Unidad Exterior		SAP-CMRV1426EH		SAP-CMRV1926EH		SAP-CMRV1936EH		SAP-CMRV2446EH		SAP-CMRV3146EH		SAP-CMRV3656EH	
Función		Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor
Nº de Uds. Interiores		2		2		3		4		4		5	
Capacidad	kW	2,0/4,0/5,0	2,2/4,5/5,5	2,1/5,6/6,8	2,4/7,3/8,4	2,9/5,6/6,8	3,4/7,3/8,4	2,9/6,8/8,1	3,4/8,6/9,0	2,9/8,0/9,2	3,4/9,4/9,8	1,6/10,0/11,5	1,6/12,0/14,5
Consumo	W	925	925	1.695	1.735	1.550	1.735	2.000	2.000	1.805	2.040	2.860	2.860
E.E.R/C.O.P.	W/W	4,32	4,86	3,30	4,21	3,61	4,21	3,40	4,30	4,62	4,61	3,50	4,20
Clase energética		A	A	A	A	A	A	A	A	A	A	A	A
Intensidad Nominal	A	4,10	4,10	7,52	7,70	6,88	7,70	8,87	8,87	7,58	8,96	12,6	12,6
Nivel Sonoro	dB-A	47	48	46	47	46	47	47	49	48	49	53/57 (modositec)	
Conexión Líq/Gas	mm(p)	2x 6,4(1/4)/2x 9,5(3/8)		2x 6,4(1/4)/2x 9,5(3/8)		3x 6,4(1/4)/3x 9,5(3/8)		4x6,4(1/4)/3x9,5(3/8)/12,7(1/2)		4x6,4(1/4)/2x9,5(3/8)/2x12,7(1/2)		5x6,35(1/4)/3x9,52(3/8)/2x12,7(1/2)	
Long. de tubería TOTAL	m	30		45		45		60		70		80	
Long. de tubería Ud. Int	m	20		25		25		25		30		30	
Elevación	m	15		15		15		15		15		15	
Precarga válida para	m	30		45		45		45*		45**		45	
Dimensiones AlxAxP	m	569x790x285		740x900x320		740x900x320		740x900x320		890x900x320		910x940x340	
Peso neto	kg	42		65		65		65		82		97	
Fuente de alimentación	V, F, Hz	230, 1+N, 50											

Notas: Al menos dos o más unidades interiores deben conectarse a la unidad exterior multi
Conexión (5/8) para unidad de potencia 7 kw con rosca adaptable (1/2)

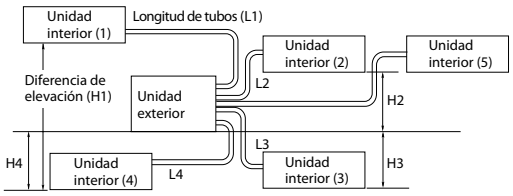
* Para llegar a los 60m. habrá que añadir 20 gr/m adicional.
** Para llegar a los 70m. habrá que añadir 20 gr/m adicional.
*** Para llegar a los 90m. habrá que añadir 20 gr/m adicional.

Especificaciones sujetas a cambios sin previo aviso

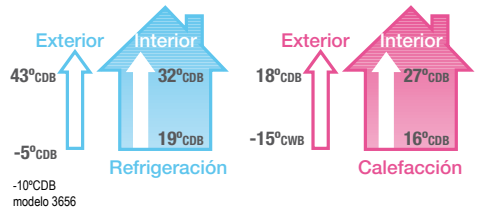
Condiciones nominales
Refrigeración: Temperatura aire interior 27°C DB/19°C WB; Temperatura aire exterior 35°C DB / 24°C WB
Calefacción: Temperatura aire interior 20°C DB; Temperatura aire exterior 7°C DB / 6°C WB

Distancias frigoríficas

Modelo	Longitud máxima de tubos por cada unidad interior (m)	Longitud máxima total de los tubos en el envío (L1+L2) o (L1+L2+L3 o (L1+L2+L3+L4) (m)	Límite de longitud total de los tubos (L1+L2) o (L1+L2+L3 o (L1+L2+L3+L4) (m)	Límite de diferencia de elevación (H1, H2, H3, H4) (m)
CMRV1426	20	30 (L1+L2)	30 (L1+L2)	15
CMRV1926	25	45 (L1+L2)	45 (L1+L2)	15
CMRV1936	25	45 (L1+L2+L3)	45 (L1+L2+L3)	15
CMRV2446	25	45 (L1+L2+L3+L4)	60 (L1+L2+L3+L4)	15
CMRV3146	30	45 (L1+L2+L3+L4)	70 (L1+L2+L3+L4)	15
CMRV3656	30	45(L1+L2+L3+L4+L5)	80(L1+L2+L3+L4+L5)	15



Rango de funcionamiento



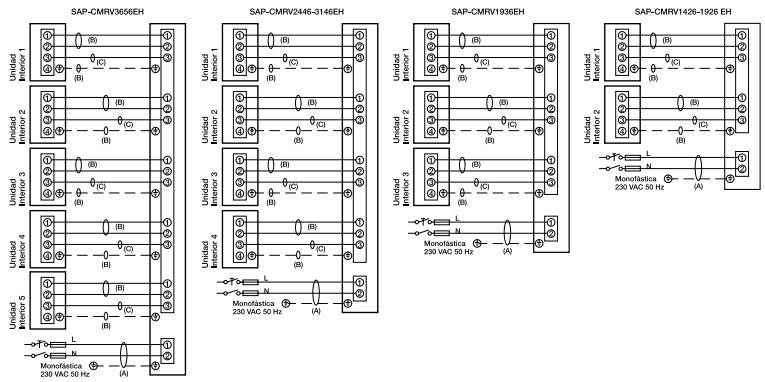
-10ºCDB
modelo 3656

Secciones eléctricas

Modelo Unidades	Sección A	Sección B	Sección C	Protección de línea
SAP-CMRV1426EH	2,5 mm²	1,0 mm²	1,0 mm²	16 A
SAP-CMRV1926EH	4,0 mm²	1,0 mm²	1,0 mm²	20 A
SAP-CMRV1936EH	4,0 mm²	1,0 mm²	1,0 mm²	20 A
SAP-CMRV2446EH	4,0 mm²	1,0 mm²	1,0 mm²	20 A
SAP-CMRV3146EH	4,0 mm²	1,0 mm²	1,0 mm²	20 A
SAP-CMRV3656EH	4,0 mm²	1,0 mm²	1,0 mm²	20 A

* Secciones calculadas para aproximadamente 30 m. de distancia.
* Para otras distancias, por favor rogamos consulten al departamento técnico.

Conexionado eléctrico



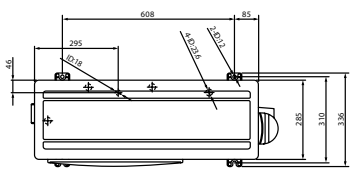
SAP

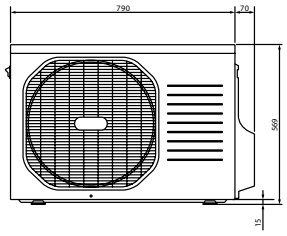
Control remoto

• Datos técnicos y precios de unidades interiores en la página siguiente

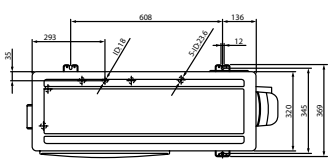
Dimensiones

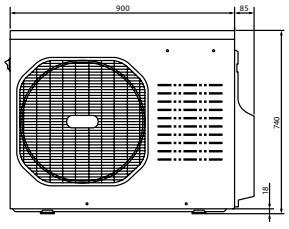
CMRV1426EH



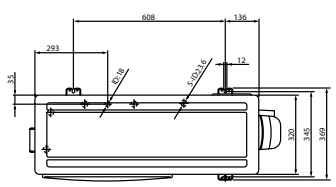


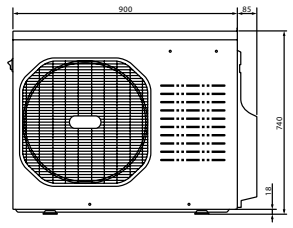
CMRV1926EH



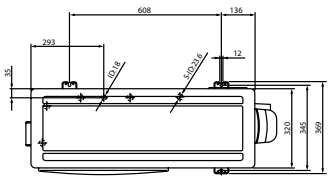


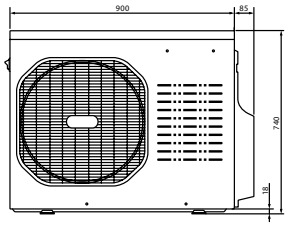
CMRV1936EH



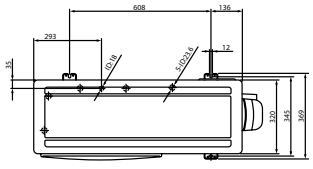


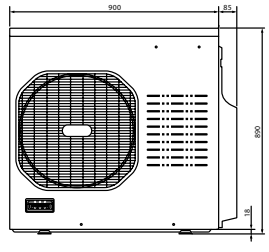
CMRV2446EH



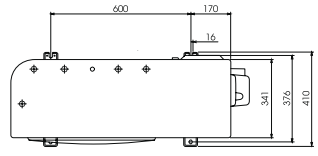


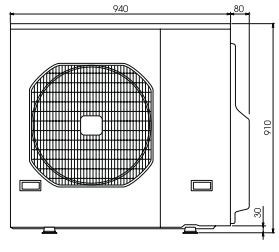
CMRV3146EH





CMRV3656EH





Precios

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-CMRV1426EH	4,0	4,5	1.250 €
SAP-CMRV1926EH	5,6	7,3	1.500 €
SAP-CMRV1936EH	5,6	7,3	1.650 €
SAP-CMRV2446EH	6,8	8,6	2.200 €
SAP-CMRV3146EH	8,0	9,4	2.970 €
SAP-CMRV3656EH	10	12	3.800 €

* Los precios arriba indicados no incluyen IVA.
* Suministraremos unidades de la serie 4 publicada en nuestra tarifa de precios Ref. 0801 hasta finalización de existencias.

Doméstico

DC Multi - Inverter (2x1, 3x1 4x1)
Unidades interiores para combinar con
unidades exteriores de página anterior

SAP-KMRV..EH · SAP-FTRV..EH
SAP-XMRV..EH · SAP-UMRV..EH

Rango de potencia de 2,2 kW a 7,1 kW

Unidades interiores

Unidad Mural		SAP-KMRV76EH		SAP-KMRV96EH		SAP-KMRV126EH		SAP-KRV186EH		SAP-KRV246EH	
Función		Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor
Capacidad	kW	2.2	2.5	2.65	3.6	3.5	4.2	5,15	6,0	7,1	8,5
Circulación de aire (A)	m³/h	440	480	460	480	480	500	840	880	890	930
Nivel de presión de sonido (Silencioso/B/M/A)	dB-A	23/27/30/33	23/27/30/33	22/30/35/38	22/30/35/38	25/29/33/36	25/29/31/34	28/34/38/41	28/34/37/40	30/38/41/44	30/37/40/43
Diam. de Tubos Estr./Ancho	mm	6.35(1/4) / 9.5(3/8)		6.35(1/4) / 9.52(3/8)		6.35(1/4) / 9.52(3/8)		(1/4)	(1/2)	(1/4)	(1/8)
Dimensiones AlxAxP	m	285x825x213		285x825x213		285x825x213		298x1065x234		298x1065x234	
Peso neto	kg	10		10		10		12		12	
Fuente de alimentación	V, F, Hz	230, 1+N, 50									

Unidad Mural		SAP-KRV184EH		SAP-KRV224EH	
Función		Frío	Calor	Frío	Calor
Capacidad	kW	5.15	6.0	7.1	8.5
Circulación de aire (A)	m³/h	850	850	920	920
Nivel de presión de sonido (Silencioso/B/M/A)	dB-A	28/34/41/44	28/34/37/40	30/38/41/44	30/37/40/43
Diam. de Tubos Estr./Ancho	mm	6.35(1/4) / 12.7(1/2)		6.35(1/4) / 15.88(5/8)	
Dimensiones AlxAxP	m	298x1065x231		298x1065x231	
Peso neto	kg	12		12	
Fuente de alimentación	V, F, Hz	230, 1+N, 50			

SAP-KRV96EHDS		SAP-KRV126EHDS	
Frío	Calor	Frío	Calor
2,65	3,6	3,5	4,8
480	500	510	560
22/28/35/41	22/28/35/41	22/28/35/42	22/28/35/42
6.35(1/4) / 9.5(3/8)		1/4	3/8
265x789x180		265x789x180	
9,5		9,5	
230, 1+N, 50			

Unidad Suelo y Suelo/Techo		SAP-FMRV94EH		SAP-FTMRV124EH		SAP-FTRV184EH		SAP-FTRV244EH	
Función		Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor
Capacidad	kW	2,65	3,6	3,5	4,2	5,15	6,0	7,1	8,5
Circulación de aire (A)	m³/h	425		700		720		900	
Nivel de presión de sonido (B/M/A)	dB-A	31/37/40		35/40/44		36/41/45		41/44/47	
Diam. de Tubos Estr./Ancho	mm	6.35(1/4)/9.52(3/8)		6.35(1/4)/9.52(3/8)		6.35(1/4)/12.7(1/2)		6.35(1/4)/15.88(5/8)	
Dimensiones AlxAxP	m	700x560x200		680x900x190		680x900x190		680x900x190	
Peso neto	kg	18.6		23.5		23.5		23.5	
Fuente de alimentación	V, F, Hz	230, 1+N, 50							

Unidad Tipo Cassette de 4 vías		SAP-XMRV94EH		SAP-XMRV124EH		SAP-XRV186EH	
Función		Frío	Calor	Frío	Calor	Frío	Calor
Capacidad	kW	2,65	3,6	3,5	4,2	5,15	6,0
Circulación de aire (A)	m³/h	700		700		790	
Nivel de presión de sonido (B/M/A)	dB-A	37/40/44		37/40/44		35/38/43	
Diam. de Tubos Estr./Ancho	mm	6.35(1/4)/9.52(3/8)		6.35(1/4)/9.52(3/8)		6.35(1/4)/12.7(1/2)	
Dimensiones AlxAxP - Panel	m	64x730x730		64x730x730		64x730x730	
Dimensiones AlxAxP - Unidad	m	296x575x575		296x575x575		296x575x575	
Peso neto - Panel	kg	16.5		16.5		16.5	
Peso neto - Unidad	kg	2.5		2.5		2.5	
Fuente de alimentación	V, F, Hz	230, 1+N, 50					

Unidad de Conductos ocultos		SAP-URV96EH		SAP-URV126EH		SAP-URV186EH		SAP-URV246EH	
Función		Frío	Calor	Frío	Calor	Frío	Calor	Frío	Calor
Capacidad	kW	2,65	3,6	3,5	4,2	5,15	6,0	7,1	8,5
Circulación de aire (A)	m³/h	620		620		865		985	
Presión estática ext. (estándar/impulsor)	Pa	49/69		49/69		49/69		49/69	
Nivel de presión de sonido (B/M/A)	dB-A	38/41/43		33/41/43		35/42/46		39/43/46	
Diam. de Tubos Estr./Ancho	mm	6.35(1/4)/9.52(3/8)		6.35(1/4)/9.52(3/8)		6.35(1/4)/12.7(1/2)		6.35(1/4)/15.88(5/8)	
Dimensiones AlxAxP	m	266x852x571		266x852x571		266x1058x571		266x1058x571	
Peso neto	kg	30		30		35		35	
Fuente de alimentación	V, F, Hz	230, 1+N, 50							

Condiciones nominales
Refrigeración: Temperatura aire interior 27°C DB/19°C WB; Temperatura aire exterior 35°C DB / 24°C WB
Calefacción: Temperatura aire interior 20°C DB; Temperatura aire exterior 7°C DB / 6°C WB

Especificaciones sujetas a cambios sin previo aviso

(1) - (2)
SAP-KMRV..EH

(3)
SAP-FTRV..EH

(4)
SAP-XMRV..EH

(5)
SAP-UMRV..EH

(6)
SAP-KRV..EHDS

1-2-3-4-5-6 DC Inverter
1-2-3-4-5-6 Microprocesador
1-2-3-4-5-6 DRY Deshumidificación
1-2-3-4-5-6 AUTO F. Aire Automatico
1-2-3-4-5-6 AUTO Ventilador Auto
1-2-3-4-5-6 C. Deflector
1-2-3-4-5-6 Reinicio Automático
1-2-3-4-5-6 NIGHT SET BACK Función Nocturna
1-2-3-4-5-6 WIDE OPERATION Amplio Rango Operación
1-2-3-4-5-6 Menor Espacio
1-2-3-4-5-6 $ Ahorro Energía
1-2-3-4-5-6 24H PROGRAM Programador 24 h.
1-2-3-4-5-6 12 ON/OFF Programador 12 h.
1-2-3-4-5-6 Sensor en Mando
1-2-3-4-5-6 F. Antiolores y Antibacterias
1-2-3-4-5-6 COOLING HEATING Cambio Aut. Rer-cal.
1-2-3-4-5-6 Rápida Calefacción
1-2-3-4-5-6 1H TIMER Programador 1/2/3/5 h.
1-2-3-4-5-6 Alta Potencia
1-3-6 ION Ionizador
1-2-3-4-5-6 M. Multifunción
1-2-3-4-5-6 P.Lavable
1-2-3-4-5-6 DEFROST NON REVERSE Defrost con Bypass
1-2-3-4-5-6 APATITA F.Apatita
4-5 B. Condensados
6 Panel Retráctil
6 Panel Multicolor

Dimensiones

* Datos dimensionales en páginas 28 y 29.

Precios

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-KMRV76EH	2,2	2,5	400 €
SAP-KMRV96EH	2,65	3,6	415 €
SAP-KMRV126EH	3,5	4,2	450 €
SAP-KRV186EH	5,15	6,0	500 €
SAP-KRV246EH	7,1	8,5	900 €

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-KRV184EH	5,15	6,0	350 €
SAP-KRV224EH	7,1	8,5	400 €

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-FMRV94EH	2,65	3,6	850 €
SAP-FMRV124EH	3,5	4,2	890 €
SAP-FTRV184EH	5,15	6,0	940 €
SAP-FTRV244EH	7,1	8,5	1.060 €

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-XMRV94EH	2,65	3,6	1.000 €
SAP-XMRV124EH	3,5	4,2	1.050 €
SAP-XRV186EH	5,15	6,0	1.070 €

* En el precio se incluye el panel decorativo modelo PNR-XMRV93EHAA (185)

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-URV96EH	2,65	3,6	800 €
SAP-URV126EH	3,5	4,2	810 €
SAP-URV186EH	5,15	6,0	820 €
SAP-URV246EH	7,1	8,5	950 €

Modelo	Frío(kW)	Calor(kW)	Precio (€)
SAP-KRV96EHDS	2,65	3,6	420 €
SAP-KRV126EHDS	3,5	4,8	460 €
SPN (Panel decorativo)			150 €

* La serie 6 de unidades multi irá sustituyendo durante 2009 a la serie 4.
* La unidad KRV...EHDS incorpora de serie el panel en color plata.
* Los precios arriba indicados no incluyen IVA.

Inversor senoidal SOLÉNER

Manual del usuario

Versión 1.5
Septiembre de 2008

Soluciones Energéticas S.A.

Avenida Real de Pinto, 146
28021 Villaverde alto, Madrid
Teléfono: 91-5050062
Fax: 91-5050079

www.solener.com
solener@solener.com

12.- CARACTERÍSTICAS TÉCNICAS

Tipo de onda ..... **Senoidal pura**
Voltaje nominal de salida..... 230 Vca
Frecuencia nominal de salida..... 50 Hz
Variaciones en la frecuencia de salida..... <0,1%
Variaciones en la tensión de salida..... <5%
Voltaje mínimo de entrada..... 5/6 Vnom
Voltaje máximo de entrada..... 4/3 Vnom
Rendimiento 85-97%
Rendimiento con carga nominal..... >85%
Autoconsumo (en búsqueda) ..... <70 mA
Distorsión armónica ..... <5%

Potencia nominal (W)	**800**	**1000**	**1500**	**1800**	**2000**	**3600**	**4000**	**7000**
Tensión nominal (V)	12	24/36	12	24/36/48	12	24	36/48	48
Sobrecarga 3'' (W)	1500	2000	2800	3300	3600	7000	7000	12000
Sobrecarga 50'' (W)	1200	1500	2250	2700	3000	5400	6000	10500
Sobrecarga 6' (W)	960	1200	1800	2160	2400	4320	4320	8400
Longitud (mm)	315	315	460	460	535	535	535	647
Altura (mm)	118	118	157	157	178	178	178	210
Anchura (mm)	192	192	255	255	285	285	285	344
Peso neto (kg)	9	12	20	22	24	36	36	68

Caja de aluminio protegida con pintura epoxy.

PROTECCIONES

- Contra inversión de polaridad (con diodo inteligente)
- Contra sobretensión y baja tensión
- Contra cortocircuito y sobrecarga
- Contra exceso de temperatura

DATOS SUJETOS A VARIACIÓN SIN PREVIO AVISO

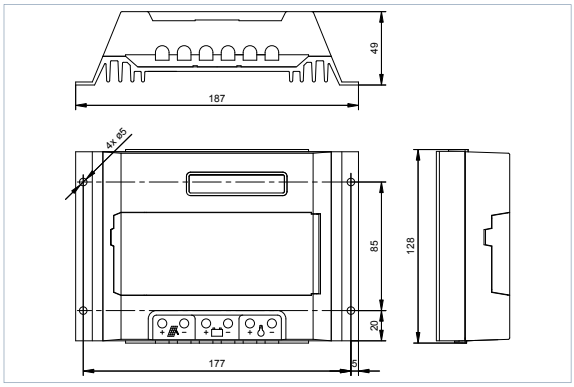
SOLENER

Steca Tarom

235, 245, 440

El Steca Tarom es un regulador de carga solar especialmente indicado para ser aplicado en telecomunicaciones o en sistemas fotovoltaicos híbridos.
Un gran número de funciones interesantes permiten al usuario adaptar el regulador a las condiciones especiales de su sistema. Mediante la determinación del estado de carga de la batería, que ha sido de nuevo claramente mejorada, el sistema se regula de forma óptima y las baterías están protegidas.
El regulador de carga Steca Tarom es la mejor selección para dimensiones de sistema hasta 2.400 Wp en tres niveles de tensión (12 V, 24 V, 48 V).
Opcionalmente cabe la posibilidad de conectar otros dispositivos como un sensor de temperatura, un registrador de datos y un control remoto para configurar y monitorizar el sistema. Un contador de energía integrado (Ah) informa al usuario sobre el presupuesto energético de la aplicación.

[35 A ... 45 A]
3 5 10 20 40 80 160



Características del producto

- Regulador híbrido
- Determinación del estado de carga con Steca AtonIC (SOC)
- Selección automática de tensión
- Regulación MAP
- Tecnología de carga escalonada
- Desconexión de carga en función de SOC
- Reconexión automática del consumidor
- Compensación de temperatura
- Toma de tierra en uno o varios terminales positivos o sólo en uno de los terminales negativos
- Registrador de datos integrado
- Función de luz nocturna con Steca PA 15
- Función de autocontrol
- Carga mensual de mantenimiento
- Contador de energía integrado

Funciones de protección electrónica

- Protección contra sobrecarga
- Protección contra descarga total
- Protección contra polaridad inversa de los módulos solares y de la carga
- Proteccion contra polaridad inversa por medio de fusible interno
- Fusible electrónico automático
- Protección contra cortocircuito de la carga y los módulos solares
- Protección contra sobretensión en la entrada del módulo
- Protección contra circuito abierto sin batería
- Protección contra corriente inversa por la noche
- Protección contra sobretemperatura y sobrecarga
- Desconexión por sobretensión en la batería

Indicaciones

- Display LCD para textos
  — para parámetros de funcionamiento, avisos de fallo, autocontrol

Manejo

- Fácil manejo con menús
- Programación por medio de botones
- Conmutación manual de carga

Interfaces

- Interfaz RJ45

Opciones

- Sensor de temperatura externo
- Contacto de alarma

Certificaciones

- Aprobado por el Banco Mundial para Nepal
- Conforme a los estándares europeos (CE)
- Fabricado en Alemania
- Desarrollado en Alemania
- Fabricado conforme a ISO 9001 e ISO 14001

	235	245	440
Funcionamiento			
Tensión del sistema	12 V (24 V)		48 V
Consumo propio	14 mA		
Datos de entrada CC			
Corriente del módulo	35 A	45 A	40 A
Datos de salida CC			
Corriente de consumo	35 A	45 A	40 A
programable: Tensión final de carga	13,7 V (27,4 V)		54,8 V
programable: Tensión de carga reforzada	14,4 V (28,8 V)		57,6 V
programable: Carga de compensación	14,7 V (29,4 V)		58,8 V
programable: Tension de reconexión (SOC / LVR)	> 50 % / 12,6 V (25,2 V)		> 50 % / 50,4 V
programable: Protección contra descarga profunda (SOC / LVD)	< 30 % / 11,1 V (22,2 V)		< 30 % / 44,4 V
Condiciones de uso			
Temperatura ambiente	-10 °C ... +60 °C		
Equipamiento y diseño			
Terminal (cable fino / único)	16 mm² / 25 mm² - AWG 6 / 4		
Grado de protección	IP 32		
Dimensiones (X x Y x Z)	187 x 128 x 49 mm		
Peso	550 g		

Datos técnicos a 25 °C / 77 °F

Steca PA TSK10
Sensor de temperatura externo

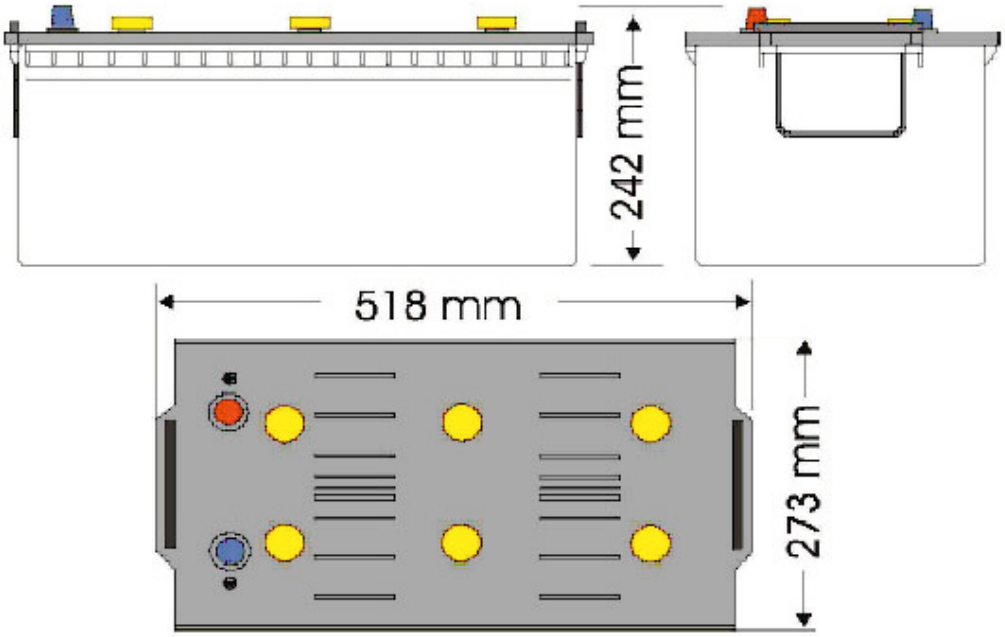
Steca PA Tarcom
Registrador de datos

Steca PA HS200
Shunt

Steca PA 15
Control remoto

[áreas de aplicación]

BATERIA MONOBLOC 12 V 250 Ah



BATERIA CICLICA PARA ENERGIA SOLAR.

La nueva batería Lite Energy Power ofrece una inmejorable combinación de rendimiento en ciclado acompañado de un alto pico de potencia.
Específicamente diseñada para aplicaciones que requieren una demanda de larga duración y de suministro de energía eléctrica
• Apto para aplicaciones cíclicas.
• Homologada en el Departamento de Defensa según EN50342 estándar (1997 Eurobat)
• Alta resistencia a descargas profundas y repetidos ciclos de descarga
• Larga vida útil

Principales características técnicas

• Gruesas placas con geometría radial para aumentar la vida y proporcionar mayor CCA.
• Soldaduras reforzadas en las placas prueba de choque y vibración. También proporciona una vida útil más larga.
• Material activo con composición concreta para reducir al mínimo el estrés cíclico.
• Pb/Sb/Sn/As/Se rejillas de aleación para asegurar la resistencia contra la corrosión y realizar el óptimo contacto con los materiales activos. Diseñado para ciclo profundo.
• Separador especial tipo industrial PE junto con separador de cristal mat - aumenta la vida

Medidas: largo: 518, ancho: 273, alto: 242 mm
Peso: 62 kg.
Capacidad: 250 Ah a C-100

REF: 277725

ELEKTR-ON®
ENERGÍAS RENOVABLES - MEDICIÓN AMBIENTAL

Farigola, 20 local 08023 Barcelona
Tel. 93 210 83 09 fax: 93 219 01 07
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www.tiendaelektron.com

Appendix E: Handbook of software

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1. INTRODUCTION

This text is a handbook of the code implemented with the software MATLAB in order to solve the equations set in the Thesis. The origin and meaning of used equations and variables are explained with detail in the Thesis, and there is constant references to that text. The nomenclature used in the software is the same as in the Thesis as far as possible.
A basic knowledge of the software MATLAB is required for a better understanding of the code and the present explanations.

The main structure of the software is the following:
There is five functions '.m' ('Walls','sprung3','PowerPhoto','PowerCollector6' and 'adsorption6'). 'Walls.m' is the first one which must be run. The simulation takes around 30 minutes and therefore the results are saved in the file 'simulation_Walls'. It is possible to load this file, and run the other four functions independently.
The other functions can be run independently. Each function calls automatically the sub-functions needed in each case.

2. SIMULATION OF ENERGY REQUIREMENTS

Function Walls

2.1. BEFORE RUNNING THE PROGRAM

First of all it is set the variable nd 'number of days'. It is useful to make shorter simulations (10 days long for example) in order to check the first results of the software without waiting for a complete simulation 365 days long (it takes around a half hour with the current computers)

2.2. CLIMATIC DATA

The climatic data are saved in file Soller_M. Variables are given each hour and the group of values of each variable during one year makes a vector with 8760 elements.
Names of variables are shown in table H.1

Symbol	**Description**	**Units**		**Symbol**	**Description**	**Units**
Az_M	Solar Azimuth	[º]		p_M	Atmospheric pressure	[mbar]
DD_M	Direction of wind	[º]		RH_M	Relative Humidity	[%]
FF_M	Speed of wind	[m/s]		dm_M	Day of the month	
G_Bh_M	Direct solar radiation	[W/m^2]		dy_M	day of the year	
G_Dh_M	Diffuse solar radiation	[W/m^2]		h_M	Hour of the day	
G_Gh_M	Global solar radiation	[W/m^2]		hy_M	Hour of the year	
Ta_M	Air temperature	[ºC]		m_M	Month of the year	
hs_M	Solar altitude	[º]		y	year	

Table H.1 – Climatic variables

Interpolation

The convergence criterion of finite difference method used to calculate the temperatures profile imposes an increment of time, Δt <=360 seconds, but the gap of time between a value and the next one for each variable

is 1 hour. Therefore it is needed to interpolate the values of each variable until 10 times. With that in mind is created the variable 'inter'.

inter = 10

New variables vectors with 87600 elements are created from the old ones. The name of the new vectors is the same as the old vectors without the suffix _M with exceptions: speed of wind is called v_wind, because the name 'FF' is used for the form factor of photovoltaic panels; Ta becomes T_amb and p becames p_amb.

2.3. DESIGN CONDITIONS

Parameters set in this section are an extract from the current Spanish law. Values of air density and air specific heat are taken from reference [25].

2.4. MATERIALS

This section describes the geometry of the building and the materials in which the building envelop (external walls and the roof) is made. The walls are differentiated according to its orientation by using the subscripts S (south), N (north), E (east), W (west), roof (roof).

Functions *FourierWall* & *FourierRoof*

These functions describe the composition and thermal characteristic of external walls and roof.
Each surface composing external walls and roof is divided in small layers each one with the same length Δx. Each layer is characterized of their number of Fourier (Fo_i), and each layer corresponds with a node. The subscript i makes reference to the number of node.
The thickness of walls is divided in 'n_wall' nodes. The thickness of roof is divided in 'n_roof' nodes.

With all the number of Fourier of all the layers of the external walls or of the roof, the vectors Fo_wall and Fo_roof are made each one with 'n_wall' and 'n_roof' number of elements respectively.

Just one vector Fo_wall and one Fo_roof is needed to describe the composition and thermal characteristics of all the building since the composition of external walls is supposed the same in all the house.
There is a particularity. The first and the last layer (in external walls or in roof), have a half thickness than the rest. They are also affected by the convection heat transfer phenomenons whereas in internal layers there is only conduction. For the layer in contact with the air inside the building (the first node), it is defined the number of Biot (Bi_walls, Bi_roof), which takes into consideration the convection heat transfer with the air. That is not necessary in external layers (last node) because its temperature is given by another relation which takes also into consideration the solar radiation, as explained in the next point.

2.5. TEMPERATURE ON EXTERNAL WALLS

Function *Temp_equival*

The function *Temp_equival* calculates the temperature on the last layer (external surface of walls and roof), according to the air temperature, the solar irradiance, the color of the surface, and the speed and direction of the wind.
Solar irradiance over the walls and roof is calculated by means of the function *radiation1.* Once the temperature is calculated, *Temp_equival* returns a vector called T_eq_(S,N,E,W,roof), different for each external wall and for the roof, with 87600 elements. Each one is the equivalent temperature on external walls each Δt according the equation 3.5.

Function *radiation1*

In this function are defined the tilt and the orientation of each surface according to explained in chapter 1.4.3. For this, '*radiation1*' takes the values of angles defining the position of the sun.

This function returns the solar irradiance which arrives perpendicular at any surface by means of the equation 3.4.

2.6. INITIAL CONDITIONS

Function *Tempsurf*
The purpose of this function is to set an start point for the simulation at t = 0. The function takes as start point the external equivalent temperature, T_eq_S (calculated in function *Temp_equival*), and the design temperature inside the building, T_design, at t = 1.
The function returns the temperatures profile inside the walls and the roof and allocates a first value of temperature for each node in which the walls and roof were divided (see *FourierWall* and *FourierRoof*).

2.7. PREALLOCATING OF VARIABLES

In this section are set the variables involved in the simulation and their lengths, in order to make the simulation more rapid.

2.8. ITERATIONS

This section is the core of the function '*Walls*'.
Every Δt (360 seconds), the temperature of the air inside the building is calculated until complete one year (87600 times).
It is possible to calculate the temperatures in the node j at t + Δt with the temperature in a node j and the temperature of adjacent nodes (j-1 and j+1) at time t

The start point are the temperatures at time t = 0 calculated in section 'INITIAL CONDITIONS'

Temperature of internal nodes is calculated by using the algorithm for internal nodes.
Temperature of external nodes is calculated by using the algorithm for external nodes.
The deduction of algorithms is explained in chapter 3.
In figure H.1 is made a representation of explained until here.

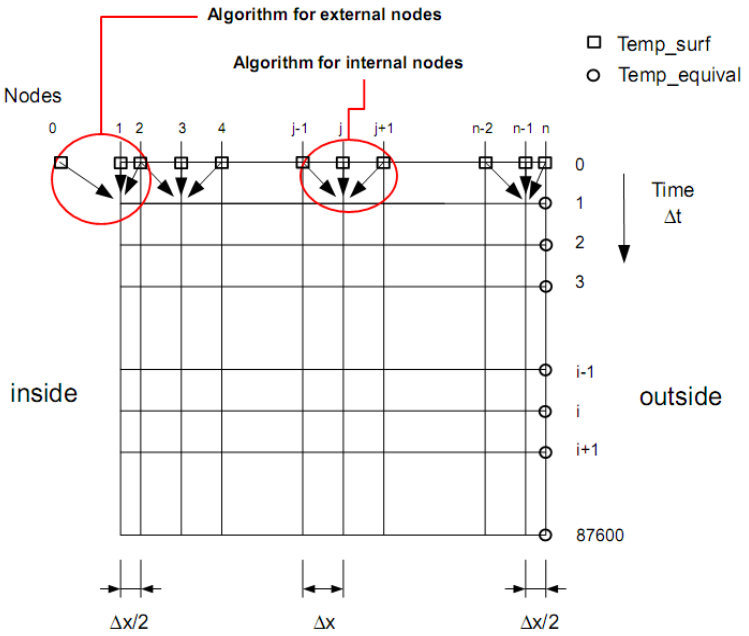

Figure H.1 – Description of Finite Difference Method

The used nomenclature is:

T_node_S,N,W,E,roof (i,j) = T_j^t = Temperature in node j at time t

T_node_S,N,W,E,roof (i,j+1) = T_{j+1}^t = Temperature in node j+1 at time t

T_node_S,N,W,E,roof (i,j-1) = T_{j-1}^t = Temperature in node j-1 at time t

T_node_S,N,W,E,roof (i+1,j) = $T_j^{t+\Delta t}$ = Temperature in node j at time t + Δt

T_0 (i) = T_0^t = Temperature inside the building at time t

T_0 (i+1) = $T_0^{t+\Delta t}$ = Temperature inside the building at time t + Δt

The letters S,N,W,E,roof make reference to walls South, North, West, East or roof, respectively.

2.8.1. Thermal Loads

Until here, it is only possible to calculate the temperature of nodes from t = 0 to t = 1. Now it is necessary to calculate the air temperature inside the building at t = 1 [T_0 (1)]. In calculation of air temperature are involved thermal loads like solar gains or external air flows, for example.

Solar Heat Gain Through Windows

Function *SolarFactor*

In this function are defined the size and orientation of windows as well as thermal and optical properties of materials in which they are made according to explained in chapter 3.2.
Then, this function calls '*radiation1'*, in order to know the perpendicular irradiance over each window. The windows are numbered from 1 to 5.

'SolarFactor' returns the solar radiation, q_sun, that goes through the windows inside the building.
On the other hand, it is also calculated the conduction heat transfer through the glasses, q_window, by accepting that windows have not thermal inertia.

These two loads are added giving q_solar for each Δt of the simulation.

q_solar = q_sun + q_window

Convection Heat Transfer

Once calculated the temperature of nodes at time t + Δt , the next step is to calculate the heat transfer from the internal surface of the building to the air inside it.
An energy balance is made between the nodes temperature at time t + Δt and the air temperature T_0 at time t (in previous instant of time). Note that the temperature T_0 at time t + Δt is not yet calculated. The description of equations is made in chapter 3.3.

Air filtration and ventilation flow loads

Air filtration and ventilation flow loads are calculated for each iteration in the simulation according to explained in chapter 3.4.
They are produced due to the difference of temperature and relative humidity between the internal and the external air.
Latent heat loads are only considered in summer according to the recommendations given in reference [4].

The equations that govern the psychrometry of the process have been obtained from reference [4].

2.8.2. Energy Balance Without Heating

The temperature inside the building at time $t + \Delta t$ [T_0(i+1)] is in this part of the loop finally calculated considering the temperature in the internal surface of the building at time $t + \Delta t$ [T_node(1,i+1)] and the different gains at time $t + \Delta t$. Only the solar heat gain through the windows is considered at time t because it is calculated as a function of the temperature inside the room at time t [T_0(i)].

The used algorithms are a result of the analysis made in chapter 3.6

2.8.3.Energy Balance With Heating

Controller

In this section are set the values of the regulator constants. The regulator must calculate every Δt the value of energy, Q_dot_H, needed to maintain the design conditions.
The method to get this values is explained in chapter 3.7 of this project and calculated by using the function *sprung3*

Function *sprung3*

This function is a copy of *Walls* in which all the climatic variables are eliminated. Its only purpose is to get a graphic which will help to set the controller parameters.
sprung3 can be run independently of *Walls* despite the name of used variables are the same.

sprung3 creates a new state in which the air temperature is 0º inside and outside the building, and also in each node of external walls and roof.
The external air temperature increases suddenly from 0 to 1 ºC and the answer of temperature of air inside the building is represented in a graphic. It is possible to get the value of parameters of the controller from this graphic by using the theory explained in chapter 3.7.
This value is not definitive but it is used as a reference in order to find a better value by means of several simulations.

PI controller

A Proportional-Integral controller is chosen among the other two possibilities, a proportional controller (K) and a Proportional-Integral-Derivative controller (PID). Proportional controller is not able to satisfy the requirements and the obtained results with the PID-controller are quite similar to obtained with the PI.

PI-controller returns the value of Q_dot_H (i+1), that is the energy that the installation has to provide in the next instant of time ($t + \Delta t$) in order to maintain the internal design temperature.

Energy balance

Once all the variables at time $t + \Delta t$ are calculated an energy balance is made according to the equation 3.27. It returns the value of the internal air temperature of the building at time $t + \Delta t$ [T_0H(i+1)], when the heating (or air conditioning) installation is working.

Note the difference in notation.
The air temperature without heating is called T_0 whereas the air temperature with heating is called T_0H.
A complete diagram of software operation is shown in figure H.2

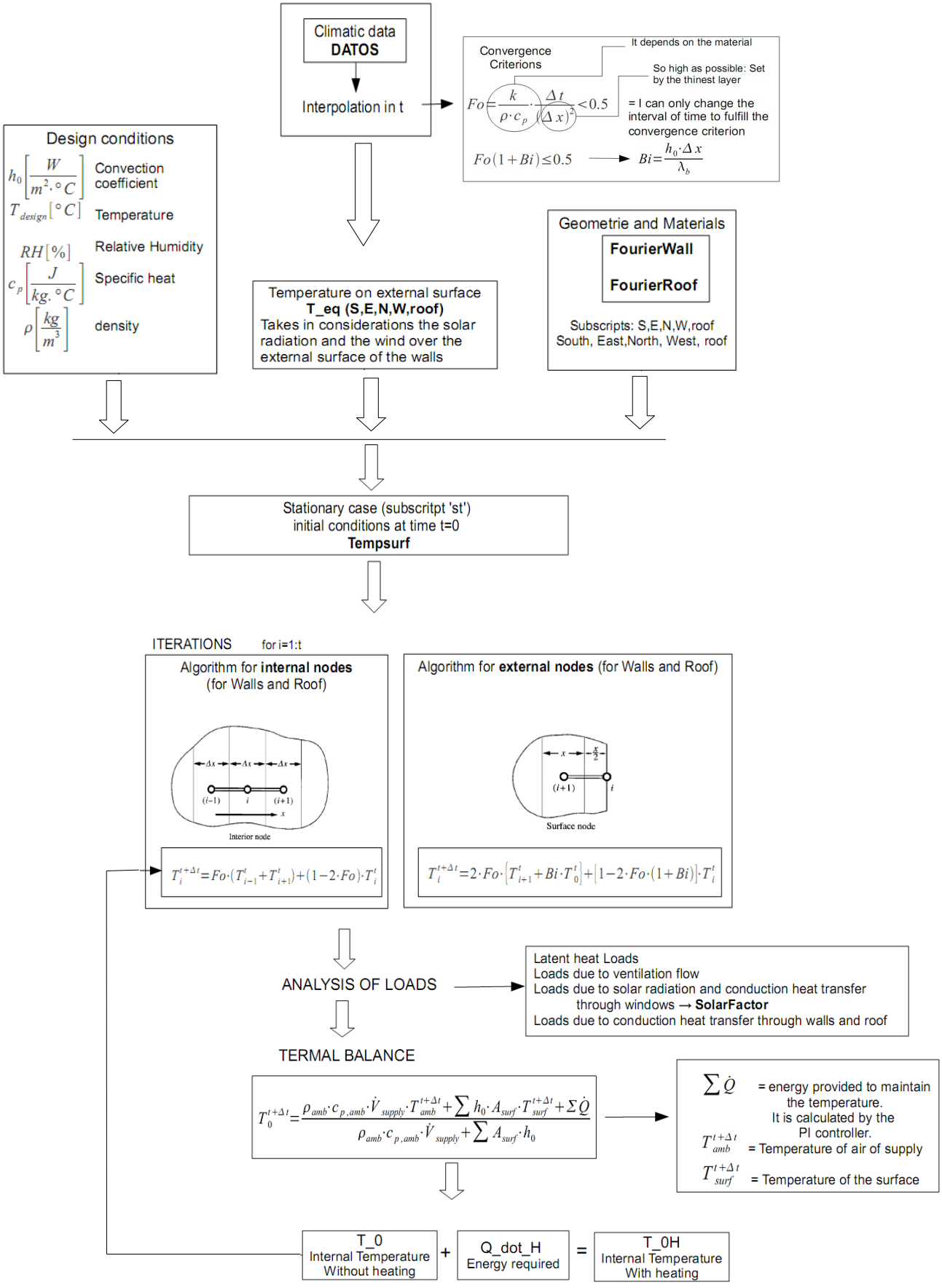

Figure H.1 – Operating software diagram

2.9. AFTER RUNNING THE PROGRAM

The simulation of '*Walls*' gives as result the need of energy of the building for air conditioning and heating during one year. The values of variables are given per Δt (= 360 seconds). Since Δt is a very small interval of time, the use of the function '*hour_1'* is recommended in order to get the values of variables in different formats (hourly, daily or monthly).

Function *hour_1*

The function *'hour_1'* must be run after the simulation of '*Walls*' is completed.
It will take the values of most important variables in '*Walls*' and will return the same variables for longer intervals of time. It can return the highest value, the lowest, the median or the addition of all values of the interval.
There is three possible intervals: one hour, one day and one month.

simulation_Walls

The result of all the variables of the simulation are saved in file the '*simulation_Walls.mat*'.
This file can be loaded and used for subsequently calculations. In the present study, the variables saved in '*simulation_Walls*' are the base for sizing the different solar installations, as explained in following chapters.

3. PHOTOVOLTAIC INSTALLATION

Function *PowerPhoto*

In this function are calculated the main parameters of the photovoltaic installation. The main variables – consumed energy, produced energy and auxiliary energy – are characterized of the subscript '*panel*'.
Before run it, it is needed to load the file '*simulation_Walls*'. The function '*PowerPhoto*' can be run independently of '*PowerCollector6*' and '*adsorption6*' (see chapters 4 and 5 of this section).

3.1. SET THE PARAMETERS

In this section are chosen the number and surface of photovoltaic panels as well as the orientation and the tilt of them. The software will returns later the rate of energy covered with this installation.
The voltage of the batteries is needed to calculate the storage capacity in a posterior step.

3.2. RADIATION ON THE SURFACE OF THE PANEL

This equation calculates the irradiance (W/m^2) and the energy (J) on one panel. The equation is the same as the function *'radiation1'*.

3.3. ENERGY FROM ONE PANEL

Calculation of energy generated for one panel is made according to explained in reference [10].
The used nomenclature is also the same and is explained in the software.
First of all, the characteristic parameters of the chosen panel are set. It is possible with them to calculate the form factor FF of the panel, which can be considered as the relation between the highest theoretical and the really produced energy by the panel.
Then, the variation in open circuit voltage $V_{el,OC}$ due to external air temperature is calculated. For the other hand, it is also calculated the variation in short circuit current I_{SC} due to the variation in solar irradiance.
With these parameters is possible to calculate the power produced by one panel, E_Ppanel as shown in the software.

3.4. CONSUMED AND PRODUCED ENERGY

An specific heat pump must be chosen for this application according to the values of Q_dot_H, calculated in function '*Walls*'. The heat pump is characterized of the maximal power for heating (or air conditioning) that it is able to produce, and the COP (coefficient of performance). These values are given by the manufacturer.
It is supposed that the spin of the heat pump can be regulated in order to produce always the required energy until this maximal value. If required energy is higher, the heat pump will operate at its highest power.

In this situation, the electrical consumption of the heat pump will be the required power for heating (or air conditioning) divided by the COP.

$$P_{heatpump} = \frac{E_{heating}}{COP} \quad \text{(W)} \quad \text{and} \quad E_{heatpump} = P_{heatpump} \cdot \Delta t \quad \text{(J)}$$

On the other hand, it is needed to know the value of the electrical consumption of appliances, $E_{appliances}$. This value is given in chapter 3 of this project.

The addition of heat pump and appliances consumption is the theoretical consumption of the building, called $E_{T,photo}$:

$E_{T,photo} = E_{heatpump} + E_{appliances}$ (J)

The energy consumption of appliances is only daily knew. Therefore is this value interpolate to get the consumption per Δt.

The produced energy from one panel was below calculated. We must multiply this value by the number of panels to get the total production.
The produced energy is affected of the efficiency of the installation (η_{photo}), which is calculated in the software . The energy demanded by the building will be

$$E_{photo} = \frac{E_{T,photo}}{\eta_{photo}}$$

where, according the nomenclature used in the software, will be

E_photo=E_T_photo/eta_photo

The auxiliary energy is in this section also calculated, like the difference between the consumed and the produced energy.

$$E_{aux,photo} = E_{photo} - E_{P,panel} \quad \text{(J)}$$

The values of produced, consumed and auxiliary energy are also calculated hourly, daily and monthly by following the same structure as in function '*hour_1*'.

3.5. SOLAR FRACTION.

The parameter solar fraction, F_panel, shows the relation as a percentage between the produced and the consumed energy for one day, one month and the complete year. There is one variant of this parameter called F_panel_real. This one takes into account that the storage capacity of the batteries is limited and in some periods in summer a part of the energy can not be stored and is therefore wasted.

3.6. BATTERIES

These equations are an extract from [10] and show the method to calculated the storage capacity of the batteries.
These method is used in the calculation of installations isolated from the electric grid in which the batteries installation must provide all the energy needed by the building in cloudy days. The parameter N_d 'number of days' set the number of autonomy days of the installation without solar irradiance.
The installation of this project is connected to the grid. Therefore, the accumulated energy will be calculated as the highest difference between the produced and the consumed energy in one day (normally in summer), represented with the variable 'capacity'.

4. HOT SANITARY WATER INSTALLATION

Function *PowerCollector6*

In this function are calculated the main parameters of the hot sanitary water installation of the case 1 in this Thesis. The main variables – consumed energy, produced energy and auxiliary energy – are characterized of the subscript '*collector*'.
Before run it, it is needed to load the file '*simulation_Walls*'. The function '*PowerCollector6*' can be run independently of '*PowerPhoto'* and '*adsorption6*' (see chapter 5 of this handbook).

4.1. SET THE PARAMETERS

In this section are chosen the number (N_collector) and surface (A_collector) of thermal collectors as well as the orientation (theta_collector) and the tilt (delta_collector) of them. The software will returns later the rate of covered energy with this installation.
The software is planned according an schema in which the thermal collectors are connected in parallel. It is needed to see chapter 5 if N_collector > 1 and the collectors must be connected in series.
rho_water and cp_water are the density and the specific heat of the heat transfer fluid respectively.

The value of flow through the collectors, m_kg_h, is recommended by the manufacturer. But it can be changed if necessary.
It is also needed to set the accumulator volume. In section 4.2.5. of the Thesis are given the relations for a good choice of accumulator volume.

4.2. DESIGN CONDITIONS

This section sets the hot sanitary water flow needed to satisfy the requirements. This value is converted into energy by making an energy balance between the water inside the the accumulator at the design temperature, and the water coming from public net.
The values of cold water temperature in the public net are given in the bibliography.

4.3. RADIATION ON THE SURFACE OF THE COLLECTOR

This equation calculates the irradiance (W/m^2) and the energy (J) over one collector. The equation is the same as function *'radiation1'*.

4.4. PRODUCED ENERGY

One specific thermal collector must be chosen to know the characteristic parameters given by the manufacturer: *eta_0*, *a1* and *a2.*
It is supposed that the input temperature in the collector, Tin, will be 30 ºC as median value. This supposition is acceptable in absence of a model of the accumulator and by accepting that the system will be provided of an automatic control system.
The efficiency in heat transfer is set as 0.8. And it is also supposed that the highest power of auxiliary heater placed inside the accumulator, P_heater_HSW, will be 700 W, as recommended in [10].

The instantaneous energy produced by a thermal collector is given by three equations (they correspond with equations (4.15), (4.16) and (4.17) from the Thesis).

All the parameters of these equations are defined in chapter 4.2.3. of the Thesis.

$$\eta_{collector} = \eta_0 - a_1 \cdot \frac{(T_{m,collector} - T_{amb})}{G_{collector}} - a_2 \cdot \frac{(T_{m,collector} - T_{amb})^2}{G_{collector}} \quad (4.15)$$

$$T_{m,collector} = \frac{T_{out,collector} + T_{in,collector}}{2} \quad (4.16)$$

$$\dot{m}_w \cdot c_{p,w} \cdot (T_{out} - T_{in}) = \eta_{collector} \cdot G_{collector} \cdot N_{collector} \cdot A_{collector} \quad (4.17)$$

The three equations are solved simultaneously for Tout resulting in a second degree polynomial with the form

A.Tout^2 + B.Tout + C = 0

The coefficients A, B and C are calculated in the function PowerCollector6.m
There is two solutions for Tout. The only one valid is given like

$$T_{out,collector} = \frac{-B - \sqrt{(B^2 - 4 \cdot A \cdot C)}}{2 \cdot A}$$

It is important to note that the coefficients A, B and C are different each instant of time.

Once knew the output temperature, we can calculate the produced energy in the collector with equation 4.17 and the energy stored in the accumulator. The difference between the needed energy, Q_HSW, and the stored energy, Q_acc, gives the value of the required auxiliary energy, E_aux_HSW. This value can be positive, if there is a lack of energy; or negative. That means that the energy will be stored in the accumulator.

Finally, the thermal collector efficiency is calculated.

The calculation of these parameters is made for each Δt. After are they calculated hourly, daily and monthly.
The stored energy in one day, according to the characteristics of the accumulator, is supposed to be consumed at the end of that day. Because of that it can't be used the next day.

4.5. SOLAR FRACTION

As made in section 3.5 of this handbook, the parameter solar fraction, F_HSW, for the hot sanitary water installation, shows the relation as a percentage between the produced and the consumed energy for one day, one month and the complete year.

5. ADORPTION MACHINE INSTALLATION

Function *adsorption6*

Fundamentals of an adsorption machine are not implemented in this function. However, the adsorption machine works by means of a hot water flow supply. Therefore, here is only described the performance of an installation producing Hot Water (and Hot Sanitary Water, as well), similar as explained in chapter 4. This function is called '*adsorption6*' in order to make a difference with function '*PowerCollector6*', but the contents of them are very similar.

In this function are calculated the main parameters of the installation described in case 2 of the Thesis. The main variables – consumed energy, produced energy and auxiliary energy – are here characterized of the subscript '*ads*'.
Before run it, it is needed to load the file '*simulation_Walls*'.
This function can be run independently of '*PowerCollector6*' and '*PowerPhoto'*.

5.1. SET THE PARAMETERS

This section is the same as the chapter 4.1 with only one difference: The function '*PowerCollector6*' is planned for thermal collectors connected in parallel.
In case 2, the collectors are going to be connected in series of two, in order to obtain a higher temperature. Therefore there is the variable N_serie, which set the number of collectors connected in series.

5.2. DESIGN CONDITIONS

This section sets values of energy needed to obtain the hot water flow satisfying the requirements for heating (Q_heating), air conditioning (Q_cooling) and Hot Sanitary Water (Q_HSW).
The energy for appliances is also considered in order to calculate the global efficiency of the installation.

Like in chapter 4.2, the values of cold water temperature are given in the bibliography.

5.3. RADIATION ON THE SURFACE OF THE COLLECTOR

This equation calculates the irradiance (W/m^2) and the energy (J) over one collector. The equation is the same as function *'radiation1'*.

5.4. PRODUCED ENERGY

One specific thermal collector must be chosen to know the characteristic parameters given by the manufacturer: *eta_0*, *a1* and *a2.*
It is supposed that the input temperature in the first collector collector of the serie, Tin1, will be 20 ºC as median value. This supposition is acceptable in absence of a model of the accumulator and by accepting that the system will be provided of an automatic control system.
The efficiency in heat transfer is set as 0.8. And it is also supposed that the highest power of auxiliary heater placed inside the accumulator, P_heater_ads, will be 8000 W.

As explained in chapter 4.4 of this handbook, the instantaneous energy produced by a thermal collector is given by three equations (they correspond with equations (4.15), (4.16) and (4.17) from the Thesis).

All the parameters of these equations are defined in chapter 4.2.3. of the Thesis.

There is a difference in relation with the calculation of a single Hot Sanitary Water installation (chapter 4.4 of this handbook), since two collectors are going to be placed in series. In this case, the output temperature of the first one, Tout1, will be the input temperature of the second one, Tin2.

From here on, the calculation of the parameters is the same as explained in chapter 4.4. of this handbook. Note the subscripts 1 and 2, making the difference between the first collector of the series and the second one.

Finally is made the calculation of the available cooling power from the adsorption machine. This one is affected of the external air temperature. The power supply for air conditioning decreases if the external temperature increases; and the power supply increase until 11 kW (highest power for cooling, according the manufacturer). The variations follow the equation of a straight line as shown in the simulation. This equation has been deduced from the graphics provided by the manufacturer, and shown in chapter 5.4.2 of the Thesis.

The calculation of these parameters is made for each Δt. After that are they calculated hourly, daily and monthly.
The stored energy in one day, according to the characteristics of the accumulator, is supposed to be consumed at the end of that day. Because of that it can't be used the next day.

5.5. SOLAR FRACTION

As made in sections 3.5 and 4.5 of this handbook, the parameter solar fraction, F_ads, for the installation described in case 2, shows the relation as a percentage between the produced and the consumed energy for one day, one month and the complete year.

This comparative is made for thermal energy only, F_Q_ads, and including also the energy for electrical appliances which must be taken from the electric grid, F_E_ads.

6. OPERATING COST

Function *tarif2*

In this function are calculated the operating costs of both installations, according to current energy prices. Variables 'total_cost_1(365)' and 'total_cost_2(365)' give the total operating cost at the end of the year, for case 1 and case 2 respectively.
This function must be run when the other functions below have been run (except 'sprung3', which is independent from the rest)

7. GRAPHICAL PRESENTATION OF RESULTS

Function *graphics*

In function '*graphics*' are registered the formulation to get all graphics of chapters 3, 5 and 6 of the Thesis.
This function must be run when the other functions below (include 'tarif2') have been run (except 'sprung3', which is independent from the rest)

```
%%%% Walls  %%%%% ____________________________________________________________

%_________________________________1. BEFORE RUNNING THE PROGRAM

nd=365;               %number of the days of the simulation

inter=10;           %number of interpolation points
t=nd*24*inter;      %index for time. if inter=10 --> Each valor of t = 1/10 hour
= 360 sec.

%_________________________________2. CLIMATIC DATAS
tic

DATOS=load('Soller_M');

Az_M=struct(DATOS);
hs_M=struct(DATOS);
DD_M=struct(DATOS);
FF_M=struct(DATOS);
G_Bh_M=struct(DATOS);
G_Dh_M=struct(DATOS);
G_Gh_M=struct(DATOS);
RH_M=struct(DATOS);
Ta_M=struct(DATOS);
p_M=struct(DATOS);


dy_M=struct(DATOS);
hy_M=struct(DATOS);
m_M=struct(DATOS);


r=(t/inter);

Az=interp(DATOS.Az_M(1:r),inter);        %Azimuth [ï¿½]
hs=interp(DATOS.hs_M(1:r),inter);        %solar altitude [ï¿½]
DD=interp(DATOS.DD_M(1:r),inter);        %direction of the wind [ï¿½]
v_wind=interp(DATOS.FF_M(1:r),inter);        %speed of wind [m/s]
G_Bh=interp(DATOS.G_Bh_M(1:r),inter);    %global solar radiation [W/m2 of
horizontal surface]
G_Dh=interp(DATOS.G_Dh_M(1:r),inter);    %Diffuse solar radiation [W/m2 of
horizontal surface]
G_Gh=interp(DATOS.G_Gh_M(1:r),inter);    %Direct solar radiation [W/m2 of
horizontal surface]
RH=interp(DATOS.RH_M(1:r),inter);        %Relative Humidity [%]
T_amb=interp(DATOS.Ta_M(1:r),inter);       %Temperature of the air [ï¿½C]
p_amb=interp(DATOS.p_M(1:r),inter);         %pressure of the air [hPa]


%The objective of the next algoritms is to get vectors of hours (hy), days (dy)
and
%months (my) like this (1,1,...1,2,2,2...2,3,3,...3,3,4....) instead of like
%this (1,1.01,1.025,...1.987,2,2.05...)
hy=floor(interp(DATOS.hy_M(1:r),inter));

dyy=interp(DATOS.dy_M(1:r),inter);
myy=interp(DATOS.m_M(1:r),inter);

dy=ones(1,t);
m=ones(1,t);
for i=1:t
```

```
    dy(i)=max(floor(dyy(i)),round(dyy(i)));     %day of the year
    m(i)=max(floor(myy(i)),round(myy(i)));          %month of the year
end


%_____________________________________3. DESIGN CONDITIONS


% design conditions

h_0_wall=10;            % convection heat transfer coeficient on walls inside
the building [W/m2.ï¿½C]
h_0_roof=8;             % convection heat transfer coeficient on the roof inside
the building [W/m2.ï¿½C]
DELTAt=3600/inter ;     % time between each calculation [s]
DELTAx=0.03;            % width of the element in each calculation [m]

rho_air=1.2;            % density of the air [kg/m3] supossed constant
cp_air=1000;            % specific heat [J/kg.ï¿½C]   supossed constant

% DESIGN TEMPERATURE

T_design=ones(1,t);

for i=1:t

    if m(i)<3||m(i)>=12
        T_design(i)=21;             %January, February or December

    elseif m(i)>=6&&m(i)<9
        T_design(i)=24;             %Juny, July or August

    else
        T_design(i)=23;             %mars,avril, mai, september, october,
november

    end

end
T_design_st=23;         %design temperature in stationary case

%RELATIV HUMIDITY

RH_design=50;

%_____________________________________4. MATERIALS

%Description of the house, the walls, the materials, width and nodes


%surfaces [m2]

%SUBSCRIPTS
%S=South wall, N=North wall, E=East wall and W=West wall

A_S=2.28*8.30-2*1*1.2-1*1.6*2;
A_N=3.38*8.3-0.4*0.4*1.2;
A_E=(3.38+2.28)*4.3/2-0.4*0.4*1.2;
A_W=(3.38+2.28)*4.3/2-0.3*0.3*1.2;
A_roof=(4.3*8.3)/cos(atan(1.1/5));
```

```
A_total=A_S+A_E+A_N+A_W+A_roof;

V_house=A_E*8.3;        %Volume of the House [m3]   NOTE: That's not a flow!!
V_dot_supply=1*V_house/3600;     %flow of external air = 1 renovations/hour
[m3/s]


[Bi_wall,Fo_wall,R_wall,n_wall]=FourierWall(DELTAt,DELTAx,h_0_wall);
[Bi_roof,Fo_roof,R_roof,n_roof]=FourierRoof(DELTAt,DELTAx,h_0_roof);



%_____________________________________5. TEMPERATURE ON EXTERNAL WALLS

%Equivalent temperature on the wall, by modifying the temperature of air with
the solar radiation and
%the convection heat transfer from the wind


[T_eq_S,T_eq_E,T_eq_N,T_eq_W,T_eq_roof]=Temp_equival(DD,v_wind,Az,hs,G_Bh,G_Dh,T
_amb,t);



%_____________________________________6. INITIAL CONDITIONS


%STATIONARY STATE (subscript 'st')

%an STATIONARY STATE is created just before the dynamic simulation, to get the
%initial conditions at time t=0
%in this function is considered that the temperatures profile inside the
%wall is the same for the walls and for the roof. The purpose of this
%function is to get the initial conditions

T_inicial=T_eq_S(1);
[T_node_st_wall,T_node_st_roof,Q_dot_stationary_wall]=Tempsurf(R_wall,R_roof,T_d
esign_st,T_inicial,A_S,A_roof,h_0_wall,h_0_roof,n_wall,n_roof);


%_____________________________________7. PREALLOCATING OF VARIABLES


T_node_S(1,:)=T_node_st_wall;            % temperatures inside each element
T_node_E(1,:)=T_node_st_wall;            % temperatures inside each element
T_node_N(1,:)=T_node_st_wall;            % temperatures inside each element
T_node_W(1,:)=T_node_st_wall;            % temperatures inside each element
T_node_roof(1,:)=T_node_st_roof;         % temperatures inside each element

hAT_S=zeros(1,t);
hAT_E=zeros(1,t);
hAT_N=zeros(1,t);
hAT_W=zeros(1,t);
hAT_roof=zeros(1,t);

hAT_wall=zeros(1,t);

Q_dot_S=T_node_S(1,1)*ones(1,t);
Q_dot_E=T_node_E(1,1)*ones(1,t);
Q_dot_N=T_node_N(1,1)*ones(1,t);
Q_dot_W=T_node_W(1,1)*ones(1,t);
```

```
Q_dot_roof=T_node_roof(1,1)*ones(1,t);

%Loads
Q_dot_H=0*ones(1,t);
Q_dot_latent=zeros(1,t);
Q_dot_flow=zeros(1,t);
Q_dot_sun=zeros(1,t);
Q_dot_window=zeros(1,t);
Q_dot_solar=zeros(1,t);
Q_dot_wall=Q_dot_stationary_wall*ones(1,t);

p_sat_0=ones(1,t);      %[Pa]
p_steam_0=ones(1,t);         %[Pa]
w_0=ones(1,t);          %[kg water/kg dry air]
p_sat_amb=ones(1,t);      %[Pa]
p_steam_amb=ones(1,t);          %[Pa]
w_amb=ones(1,t);          %[kg water/kg dry air]


%temperture inside the building 'without' heating installation
T_0=T_design(1)*ones(1,t);
%T_0(1)=T_design(1);

%temperature inside the building 'with' heating installation on
T_0H=T_design(1)*ones(1,t);
%T_0H(1)=T_design(1);

%variables for the controller
e=zeros(1,t-1);
I=ones(1,t-1);
D=zeros(1,t-1);




%_____________________________________8. ITERATIONS


%   i=index of time
%   j=index of position on the wall : j=1      ---> internal surface of the wall
%                                     j=n_wall ---> external surface of the wall


for i=1:t-1

    % TEMPERATURE IN NODES

    %internal nodes
    for j=2:n_wall-1

        T_node_S(i+1,j)=Fo_wall(j)*(T_node_S(i,j-1)+T_node_S(i,j+1))+(1-
2*Fo_wall(j))*T_node_S(i,j);
        T_node_E(i+1,j)=Fo_wall(j)*(T_node_E(i,j-1)+T_node_E(i,j+1))+(1-
2*Fo_wall(j))*T_node_E(i,j);
        T_node_N(i+1,j)=Fo_wall(j)*(T_node_N(i,j-1)+T_node_N(i,j+1))+(1-
2*Fo_wall(j))*T_node_N(i,j);
        T_node_W(i+1,j)=Fo_wall(j)*(T_node_W(i,j-1)+T_node_W(i,j+1))+(1-
2*Fo_wall(j))*T_node_W(i,j);

    end
```

```
    for j=2:n_roof-1

        T_node_roof(i+1,j)=Fo_roof(j)*(T_node_roof(i,j-1)+T_node_roof(i,j+1))
+(1-2*Fo_roof(j))*T_node_roof(i,j);

    end

    % external nodes
    % temperatures on the first node = internal surface of the walls

    T_node_S(i+1,1)=2*Fo_wall(1)*(T_node_S(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_S(i,1);
    T_node_E(i+1,1)=2*Fo_wall(1)*(T_node_E(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_E(i,1);
    T_node_N(i+1,1)=2*Fo_wall(1)*(T_node_N(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_N(i,1);
    T_node_W(i+1,1)=2*Fo_wall(1)*(T_node_W(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_W(i,1);
    T_node_roof(i+1,1)=2*Fo_roof(1)*(T_node_roof(i,1)+Bi_roof*T_0(i))+(1-
2*Fo_roof(1)*(1+Bi_roof))*T_node_roof(i,1);


    % Temperatures on the last node = external surface of the wall

    T_node_S(i+1,n_wall)=T_eq_S(i+1);
    T_node_E(i+1,n_wall)=T_eq_E(i+1);
    T_node_N(i+1,n_wall)=T_eq_N(i+1);
    T_node_W(i+1,n_wall)=T_eq_W(i+1);
    T_node_roof(i+1,n_roof)=T_eq_roof(i+1);


    %_____________________________________________ 8.1 THERMAL LOADS

    % SOLAR HEAT GAIN THROUGH WINDOWS
    [Q_dot_sun(i),Q_dot_window(i)]=SolarFactor(Az(i),hs(i),G_Bh(i),G_Dh(i),T_amb
(i),T_0(i),t);

    Q_dot_solar(i)=Q_dot_sun(i)+Q_dot_window(i);


    % CONVECTION HEAT TRANSFER LOADS

    Q_dot_S(i+1)=h_0_wall*A_S*(T_node_S(i+1,1)-T_0(i));
    Q_dot_N(i+1)=h_0_wall*A_N*(T_node_N(i+1,1)-T_0(i));
    Q_dot_E(i+1)=h_0_wall*A_E*(T_node_E(i+1,1)-T_0(i));
    Q_dot_W(i+1)=h_0_wall*A_W*(T_node_W(i+1,1)-T_0(i));
    Q_dot_roof(i+1)=h_0_roof*A_roof*(T_node_roof(i+1,1)-T_0(i));

    Q_dot_wall=Q_dot_S(i+1)+Q_dot_E(i+1)+Q_dot_N(i+1)+Q_dot_W(i+1)+Q_dot_roof(i+
1);


    %Temperature of the air inside the building

    hAT_S(i+1)=h_0_wall*A_S*(T_node_S(i+1,1));
    hAT_N(i+1)=h_0_wall*A_N*(T_node_N(i+1,1));
    hAT_E(i+1)=h_0_wall*A_E*(T_node_E(i+1,1));
    hAT_W(i+1)=h_0_wall*A_W*(T_node_W(i+1,1));
    hAT_roof(i+1)=h_0_roof*A_roof*(T_node_roof(i+1,1));

    hAT_wall(i+1)=hAT_S(i+1)+hAT_E(i+1)+hAT_N(i+1)+hAT_W(i+1)+hAT_roof(i+1);
```

```
    % AIR FILTRATION AND VENTILATION FLOW LOADS
    % Latent heat loads

    % It is considered that the pressure, p_amb [hPa] is the same in and outdoor

    p_sat_0(i)=610.5*exp(17.269*T_0(i)/(237.3+T_0(i)));       %[Pa]
    p_steam_0(i)=p_sat_0(i)*RH_design/100;                        %[Pa]
    w_0(i)=0.62198*p_steam_0(i)/(p_amb(i)*100-p_steam_0(i));                %[kg
water/kg dry air]

    p_sat_amb(i)=610.5*exp(17.269*T_amb(i)/(237.3+T_amb(i)));         %[Pa]
    p_steam_amb(i)=p_sat_amb(i)*RH(i)/100;                             %[Pa]
    w_amb(i)=0.62198*p_steam_amb(i)/(p_amb(i)*100-p_steam_amb(i));
%[kg water/kg dry air]


    h_fg=2442000;               %[J/kg]        enthalpy of vaporization at
25ï¿½C (design temperature in Summer)
    Q_dot_latent(i+1)=max(rho_air*V_dot_supply*h_fg*(w_amb(i)-w_0(i)),0);      %
[W]


    % ventilation flow loads

%     Q_dot_flow(i)=V_dot_supply*rho_air*cp_air*(T_amb(i)-T_0(i));          %
[W]
    Q_dot_flow(i+1)=V_dot_supply*rho_air*cp_air*T_amb(i+1);                 %
[W]



    %_____________________________________ 8.2. THERMAL BALANCE without heating

    T_0(i+1)=(Q_dot_flow(i+1)+hAT_wall(i+1)+Q_dot_solar(i)
+Q_dot_latent(i+1))/...
        (V_dot_supply*rho_air*cp_air+h_0_wall*(A_S+A_N+A_W+A_E)
+h_0_roof*A_roof);


    %_____________________________________ 8.3. Thermal Balance with heating


   % CONTROLLER

    %parameters for the controller

    K_system=1;
    tau_I=20;
    T_d=1;

    e(i+1)=T_design(i)-T_0H(i);
    E=cumsum(e);
    I(i+1)=1/tau_I*cumsum(E(i));
    D(i+1)=T_d*(e(i+1)-e(i))/DELTAt;

%__ proportional controller
    %Q_dot_H(i+1)=V_house/DELTAt*cp_air*rho_air*(T_design(i)-T_0H(i))*K_system;

%__ PI controller
```

```
    Q_dot_H(i+1)=V_house/DELTAt*cp_air*rho_air*K_system*( (T_design(i+1)-
T_0H(i)) + I(i+1));

%__ PID controller
    %Q_dot_H(i+1)=V_house/DELTAt*cp_air*rho_air*K_system*( (T_design(i+1)-
T_0H(i)) +I(i+1)+D(i+1));


    % THERMAL BALANCE

    T_0H(i+1)=(Q_dot_flow(i+1)+hAT_wall(i+1)+Q_dot_solar(i+1)+Q_dot_latent(i+1)+
Q_dot_H(i+1))/...                       %numerador
        (V_dot_supply*cp_air*rho_air+h_0_wall*(A_S+A_N+A_W+A_E)
+h_0_roof*A_roof);    %denominador



end
```

%%%% FourierWall %%%%%

```
function [Bi_wall,Fo_wall,R_th_wall,n_wall]=FourierWall(DELTAt,DELTAx,h_0_wall)


%The convergence criterion is Fo<=0.5 and Fo_wall*(1+Bi_roof) < 0.5

%Layer 1     Plaster

rho_1=1000 ;            %density of the material of this layer
[kg/m3]
cp_1= 1000;             %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
lambda_1=0.54;               %thermal condcutivity of the material of this layer
[J/m.ï¿½C]

n_1=1;                  %number of nodes on this layer
x_1=DELTAx/2;              %width of this layer                         [m]

R_th_1=DELTAx/2/lambda_1;           %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_wall_1=ones(1,n_1)*R_th_1;       %thermal resistance of all the elements of
the layer together   [m2.ï¿½C/J]
Fo_1=lambda_1*DELTAt/((DELTAx)*(DELTAx)*rho_1*cp_1);     %number of Fourier for
this layer
F_1=ones(1,n_1)*Fo_1;


%Layer 2     Hollow Block

rho_2=1200 ;        %density of the material of this layer (hollow block)
[kg/m3]
cp_2= 1000;         %specific heat of the mataerial of this layer (hollow block)
[J/kg.ï¿½C]
lambda_2=0.4 ;           %thermal condcutivity of the material of this layer
(hollow block)    [J/m.ï¿½C]

n_2=4;              %number of nodes on this layer
x_2=0.12;            %width of this layer (hollow block)       [m]
```

```
R_th_2=DELTAx/lambda_2;             %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_wall_2=ones(1,n_2)*R_th_2;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_2=lambda_2*DELTAt/((DELTAx)*(DELTAx)*rho_2*cp_2);     %number of Fourier for
this layer
F_2=ones(1,n_2)*Fo_2;

%Layer 3      Concrete Block

rho_3=1500 ;        %density of the material of this layer (concrete block)
[kg/m3]
cp_3=1000 ;         %specific heat of the mataerial of this layer (concrete
block)   [J/kg.ï¿½C]
lambda_3=0.5 ;           %thermal condcutivity of the material of this layer
(concrete block)    [J/m.ï¿½C]

n_3=8;              %number of nodes on this layer
x_3=0.24 ;          %width of this layer (hollow block)       [m]


R_th_3=DELTAx/lambda_3;        %thermal resistance of one element of this layer
[m2.ï¿½C/J]

R_th_wall_3=ones(1,n_3)*R_th_3;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_3=lambda_3*DELTAt/((DELTAx)*(DELTAx)*rho_3*cp_3);     %number of Fourier for
this layer
F_3=ones(1,n_3)*Fo_3;


%Layer 4    Last node of layer 3 Concrete Block

rho_4=1500 ;        %density of the material of this layer (concrete block)
[kg/m3]
cp_4=1000 ;         %specific heat of the mataerial of this layer (concrete
block)   [J/kg.ï¿½C]
lambda_4=0.5 ;           %thermal condcutivity of the material of this layer
(concrete block)    [J/m.ï¿½C]

n_4=1;              %number of nodes on this layer
x_4=DELTAx/2 ;          %width of this layer (hollow block)       [m]


R_th_4=DELTAx/2/lambda_3;        %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_wall_4=ones(1,n_4)*R_th_4;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_4=lambda_4*DELTAt/((DELTAx)*(DELTAx)*rho_4*cp_4);     %number of Fourier for
this layer
F_4=ones(1,n_4)*Fo_4;



%output arguments

n_wall=n_1+n_2+n_3+n_4;                              %number of nodes or
calculation elements
```

```
R_th_wall=[R_th_wall_1, R_th_wall_2, R_th_wall_3, R_th_wall_4];
Fo_wall=[F_1,F_2, F_3, F_4];                          %number of fourier for each
layer, together in one vector
Bi_wall=h_0_wall*DELTAx/lambda_2;                          %number of Biot, for
the inside surface of the wall

wall=[Fo_1,Fo_2,Fo_3,Fo_4];

Criterion=Fo_wall*(1+Bi_wall);

return
```

%%%% FourierRoof %%%%%

```
function [Bi_roof,Fo_roof,R_th_roof,n_roof]=FourierRoof(DELTAt,DELTAx,h_0_roof)


%The convergence criterion is Fo<=0.5 and Fo_roof*(1+Bi_roof) < 0.5

%Layer 1     Plaster

rho_1=1000 ;            %density of the material of this layer
[kg/m3]
cp_1= 1000;             %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
lambda_1=0.54;               %thermal condcutivity of the material of this layer
[J/m.ï¿½C]

n_1=1;                  %number of nodes on this layer
x_1=DELTAx/2;              %width of this layer                        [m]

R_th_1=DELTAx/2/lambda_1;            %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_roof_1=ones(1,n_1)*R_th_1;       %thermal resistance of all the elements of
the layer together   [m2.ï¿½C/J]
Fo_1=lambda_1*DELTAt/((DELTAx)*(DELTAx)*rho_1*cp_1);     %number of Fourier for
this layer
F_1=ones(1,n_1)*Fo_1;


%Layer 2     Hollow Block

rho_2=1200 ;            %density of the material of this layer          [kg/m3]
cp_2= 1000;             %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
lambda_2=0.4 ;               %thermal condcutivity of the material of this layer
[J/m.ï¿½C]
```

```
n_2=2;              %number of nodes on this layer
x_2=0.6;            %width of this layer (hollow block)       [m]

R_th_2=DELTAx/lambda_2;             %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_roof_2=ones(1,n_2)*R_th_2;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_2=lambda_2*DELTAt/((DELTAx)*(DELTAx)*rho_2*cp_2);     %number of Fourier for
this layer
F_2=ones(1,n_2)*Fo_2;

%Layer 3      Isolation

rho_3=1500 ;            %density of the material of this layer           [kg/m3]
cp_3=1000 ;             %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
lambda_3=0.02 ;              %thermal condcutivity of the material of this layer
[J/m.ï¿½C]

n_3=1;              %number of nodes on this layer
x_3=0.03 ;          %width of this layer (hollow block)       [m]


R_th_3=DELTAx/lambda_3;        %thermal resistance of one element of this layer
[m2.ï¿½C/J]

R_th_roof_3=ones(1,n_3)*R_th_3;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_3=lambda_3*DELTAt/((DELTAx)*(DELTAx)*rho_3*cp_3);     %number of Fourier for
this layer
F_3=ones(1,n_3)*Fo_3;


%Layer 4      Concrete

rho_4=1950 ;            %density of the material of this layer           [kg/m3]
cp_4=1050 ;             %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
lambda_4=1.10 ;              %thermal condcutivity of the material of this layer
[J/m.ï¿½C]

n_4=2;              %number of nodes on this layer
x_4=0.06 ;          %width of this layer (hollow block)       [m]

R_th_4=DELTAx/lambda_4;        %thermal resistance of one element of this layer
[m2.ï¿½C/J]

R_th_roof_4=ones(1,n_4)*R_th_4;           %thermal resistance of all the
elements of the layer together   [m2.ï¿½C/J]
Fo_4=lambda_4*DELTAt/((DELTAx)*(DELTAx)*rho_4*cp_4);     %number of Fourier for
this layer
F_4=ones(1,n_4)*Fo_4;


%Layer 5     Tiles

rho_5=2200 ;            %density of the material of this layer           [kg/m3]
cp_5=800 ;              %specific heat of the mataerial of this layer
[J/kg.ï¿½C]
```

```
lambda_5=0.95 ;                  %thermal condcutivity of the material of this
layer    [J/m.ï¿½C]

n_5=1;                    %number of nodes on this layer
x_5=DELTAx/2;               %width of this layer                          [m]

R_th_5=DELTAx/2/lambda_5;            %thermal resistance of one element of this
layer          [m2.ï¿½C/J]

R_th_roof_5=ones(1,n_5)*R_th_5;       %thermal resistance of all the elements of
the layer together   [m2.ï¿½C/J]
Fo_5=lambda_5*DELTAt/((DELTAx)*(DELTAx)*rho_5*cp_5);     %number of Fourier for
this layer
F_5=ones(1,n_5)*Fo_5;


n_roof=n_1+n_2+n_3+n_4+n_5;        %number of nodes or calculation elements
R_th_roof=[R_th_roof_1, R_th_roof_2, R_th_roof_3, R_th_roof_4, R_th_roof_5];
Fo_roof=[F_1, F_2, F_3, F_4, F_5];          %number of fourier for each layer,
together in one vector
Bi_roof=h_0_roof*DELTAx/lambda_1;                %number of Biot, for the inside
surface of the wall

roof=[Fo_1,Fo_2,Fo_3,Fo_4,Fo_5];

Criterion=Fo_roof*(1+Bi_roof);

return
```

%%%% Temp_equival %%%%

```
function
[T_eq_S,T_eq_E,T_eq_N,T_eq_W,T_eq_roof]=Temp_equival(DD,v_wind,Az,hs,G_Bh,G_Dh,T
_amb,t)

%rad=pi/180;
alpha_0=0.5;  %absortance, according its color
alpha_0_roof=0.8;

[G_S,G_E,G_N,G_W,G_roof]=radiation1(Az,hs,G_Bh,G_Dh,t);



T_eq_S=sparse(t,1);     %equivalent temperature on the wall, corrected with air
and solar radiation
T_eq_E=sparse(t,1);
T_eq_N=sparse(t,1);
T_eq_W=sparse(t,1);
T_eq_roof=sparse(t,1);


%heat convective transfer coeficient on the walls

h_S=sparse(t,1);
h_E=sparse(t,1);
h_N=sparse(t,1);
h_W=sparse(t,1);


for i=1:t
```

```
    if DD(i)>=0&&DD(i)<90
        h_N(i)=10.218294+4.469945*v_wind(i)*sin(DD(i)*pi/180);
        h_E(i)=10.218294+4.469945*v_wind(i)*cos(DD(i)*pi/180);
        h_S(i)=10.218294;
        h_W(i)=h_S(i);

    elseif DD(i)>=90&&DD(i)<180
        h_N(i)=10.218294;
        h_E(i)=10.218294-4.469945*v_wind(i)*cos(DD(i)*pi/180);
        h_S(i)=10.218294+4.469945*v_wind(i).*sin(DD(i)*pi/180);
        h_W(i)=h_N(i);

    elseif DD(i)>=180&&DD(i)<270
        h_N(i)=10.218294;
        h_E(i)=h_N(i);
        h_S(i)=10.218294-4.469945*v_wind(i)*sin(DD(i)*pi/180);
        h_W(i)=10.218294-4.469945*v_wind(i)*cos(DD(i)*pi/180);

    else
        h_N(i)=10.218294+4.469945*v_wind(i)*sin(DD(i)*pi/180);
        h_E(i)=10.218294;
        h_S(i)=h_E(i);
        h_W(i)=10.218294+4.469945*v_wind(i)*cos(DD(i)*pi/180);
    end

    h_roof=10.218294+4.469945*v_wind(i);

    %Modified temperature on the wall,because of the solar radiation and
    %the wind
    T_eq_S(i)=T_amb(i)+alpha_0*G_S(i)./h_S(i);
    T_eq_E(i)=T_amb(i)+alpha_0*G_E(i)./h_E(i);
    T_eq_N(i)=T_amb(i)+alpha_0*G_N(i)./h_N(i);
    T_eq_W(i)=T_amb(i)+alpha_0*G_W(i)./h_W(i);
    T_eq_roof(i)=T_amb(i)+alpha_0_roof*G_roof(i)./h_roof;


end

return
```

%%%%% Tempsurf %%%%%

```
function
[T_node_st_wall,T_node_st_roof,Q_dot_stationary_wall]=Tempsurf(R_th_wall,R_th_ro
of,T_design_st,T_inicial,A_S,A_roof,h_0_wall,h_0_roof,n_wall,n_roof)


%Since the compositions of the walls is the same,the profil of temperatures
%on this wall will taked the same for each wall, in the stationary case

R_th_cum_wall=cumsum(R_th_wall);
R_th_cum_roof=cumsum(R_th_roof);

Q_dot_stationary_wall=(T_design_st-T_inicial)*A_S/
(1/h_0_wall+R_th_cum_wall(n_wall));
```

```
Q_dot_stationary_roof=(T_design_st-T_inicial)*A_roof/
(1/h_0_roof+R_th_cum_roof(n_roof));


%temperatures on the interface of elements, in stationary case

T_node_st_wall=zeros(1,n_wall);
T_node_st_wall(1)=T_design_st-Q_dot_stationary_wall/h_0_wall/A_S;
T_node_st_wall(n_wall)=T_inicial;

T_node_st_roof=zeros(1,n_roof);
T_node_st_roof(1)=T_design_st-Q_dot_stationary_roof/h_0_roof/A_roof;
T_node_st_roof(n_roof)=T_inicial;


T_surf_st_wall=zeros(1,n_wall+1);
T_surf_st_wall(1)=T_node_st_wall(1);
T_surf_st_wall(n_wall+1)=T_node_st_wall(n_wall);

T_surf_st_roof=zeros(1,n_roof+1);
T_surf_st_roof(1)=T_node_st_roof(1);
T_surf_st_roof(n_roof+1)=T_node_st_roof(n_roof);


%In stationary case, the temperature on the interface of each element is
%calculated. Then, the initial temperatures on nodes are the media of the
%temperatures on interfaces

for k=2:n_wall
    T_surf_st_wall(k)=T_surf_st_wall(k-1)-Q_dot_stationary_wall*R_th_wall(k-
1)/A_S;
end


for k=2:n_wall-1
    T_node_st_wall(k)=(T_surf_st_wall(k)+T_surf_st_wall(k+1))/2;
end


for k=2:n_roof
    T_surf_st_roof(k)=T_surf_st_roof(k-1)-Q_dot_stationary_roof*R_th_roof(k-
1)/A_roof;
end


for k=2:n_roof-1
    T_node_st_roof(k)=(T_surf_st_roof(k)+T_surf_st_roof(k+1))/2;
end


return
```

%%%% radiation1 %%%%

```
function [G_S,G_E,G_N,G_W,G_roof]=radiation1(Az,hs,G_Bh,G_Dh,t)

rad=pi/180;
```

```
%radiacion on the plane perpendicular to the radiation

%theta = angle of orientation. The reference is South=0Â°, positives angles at
West
%and negatives at East, like Azimuth angle
theta_S=0;
theta_E=-90;
theta_N=180;
theta_W=90;
theta_roof=0;


%delta = inclincation respect the horizontal

delta_S=90;
delta_E=90;
delta_N=90;
delta_W=90;
delta_roof=atan(1.1/5);


G_S=abs( max ( G_Bh.*(cos(hs*rad)*sin(delta_S*rad).*cos((Az-theta_S)*rad)
+sin(hs.*rad)*cos(delta_S*rad))+G_Dh , G_Dh ) );
G_E=abs ( max ( G_Bh.*(cos(hs*rad)*sin(delta_E*rad).*cos((Az-theta_E)*rad)
+sin(hs.*rad)*cos(delta_E*rad))+G_Dh , G_Dh ) );
G_N=abs ( max ( G_Bh.*(cos(hs*rad)*sin(delta_N*rad).*cos((Az-theta_N)*rad)
+sin(hs.*rad)*cos(delta_N*rad))+G_Dh , G_Dh ) );
G_W=abs ( max ( G_Bh.*(cos(hs*rad)*sin(delta_W*rad).*cos((Az-theta_W)*rad)
+sin(hs.*rad)*cos(delta_W*rad))+G_Dh , G_Dh ) );
G_roof=abs ( max ( G_Bh.*(cos(hs*rad)*sin(delta_roof*rad).*cos((Az-
theta_roof)*rad)+sin(hs.*rad)*cos(delta_roof*rad))+G_Dh , G_Dh ));

return
```

%%%% SolarFactor %%%%

```
function [Q_dot_sun,Q_dot_window]=SolarFactor(Az,hs,G_Bh,G_Dh,T_amb,T_0,t)

alpha_0=0.5;  %absortance of frames, according its color = blue dark

F_shadow_1=1;     %There is not any shadow on the windows [dimensionlees]
F_shadow_2=1;
F_shadow_3=1;
F_shadow_4=1;
F_shadow_5=1;
g=0.75;       %For the chosen glass of windows, the transmitance is this value
[dimensionlees]
U_frame=4;      %heat transferm coeffient of the frame of the window [W/m2.Â°C]
U_glass=3.3;    %heat transferm coeffient of the glass of the window [W/m2.Â°C]



%percentage of the hollow (window) covered by the frame
A_window_1=1*1.2;
FM_1=0.37;
F_solar_1=F_shadow_1*( (1-FM_1)*g+FM_1*0.04*U_frame*alpha_0 );
```

```
U_hollow_1=(1-FM_1)*U_glass+U_frame*FM_1;       %[W/m2.Â°C]

A_window_2=1*1.2;
FM_2=0.37;
F_solar_2=F_shadow_2*((1-FM_2)*g+FM_2*0.04*U_frame*alpha_0);
U_hollow_2=(1-FM_2)*U_glass+U_frame*FM_2;       %[W/m2.Â°C]

A_window_3=0.4*0.4*1.2;
FM_3=0.5;
F_solar_3=F_shadow_3*((1-FM_3)*g+FM_3*0.04*U_frame*alpha_0 );
U_hollow_3=(1-FM_3)*U_glass+U_frame*FM_3;       %[W/m2.Â°C]

A_window_4=0.4*0.4*1.2;
FM_4=0.5;
F_solar_4=F_shadow_4*( (1-FM_4)*g+FM_4*0.04*U_frame*alpha_0  );
U_hollow_4=(1-FM_4)*U_glass+U_frame*FM_4;       %[W/m2.Â°C]

A_window_5=0.3*0.3*1.2;
FM_5=0.6;
F_solar_5=F_shadow_5*( (1-FM_5)*g+FM_5*0.04*U_frame*alpha_0 );
U_hollow_5=(1-FM_5)*U_glass+U_frame*FM_5;       %[W/m2.Â°C]


%raidation on the walls

[G_S,G_E,G_N,G_W]=radiation1(Az,hs,G_Bh,G_Dh,t);



  Q_dot_sun_1=A_window_1*G_S*F_solar_1;
  Q_dot_sun_2=A_window_2*G_S*F_solar_2;
  Q_dot_sun_3=A_window_3*G_E*F_solar_3;
  Q_dot_sun_4=A_window_4*G_N*F_solar_4;
  Q_dot_sun_5=A_window_5*G_W*F_solar_5;


  Q_dot_window_1=A_window_1*U_hollow_1*(T_amb-T_0);       %[W]
  Q_dot_window_2=A_window_2*U_hollow_2*(T_amb-T_0);       %[W]
  Q_dot_window_3=A_window_3*U_hollow_3*(T_amb-T_0);       %[W]
  Q_dot_window_4=A_window_4*U_hollow_4*(T_amb-T_0);       %[W]
  Q_dot_window_5=A_window_5*U_hollow_5*(T_amb-T_0);       %[W]



Q_dot_sun=Q_dot_sun_1+Q_dot_sun_2+Q_dot_sun_3+Q_dot_sun_4+Q_dot_sun_5;     %[W]
Q_dot_window=Q_dot_window_1+Q_dot_window_2+Q_dot_window_3+Q_dot_window_4+Q_dot_w
indow_5;  %[W]


return




%%%%    hour_1    %%%%


% _____________________ steps
hour=inter;
```

```
day=24*inter;
month=(365/12)*24*inter;        % I suposse that the during of days of each
month is the same

% _____________________ vectors of time
t_hour=(1:hour:t);           % vector of time for hourly daten
t_day=(1:day:t);             % vector of time for dayly daten
t_month=(1:month:t);         % vector of time for monthly daten



%_____________________________values each hour

            T_amb_hour=T_amb(1:hour:t);
            T_0_hour=T_0(1:hour:t);
            T_0H_hour=T_0H(1:hour:t);
            T_design_hour=T_design(1:hour:t);

            Q_dot_H_hour=Q_dot_H(1:hour:t);


for i=1:length(t_hour)

    T_amb_hour(i)=median( T_amb( t_hour(i):1:t_hour(i)+hour-1 )  );
    T_0_hour(i)=median( T_0( t_hour(i):1:t_hour(i)+hour-1 )  );
    T_0H_hour(i)=median( T_0H( t_hour(i):1:t_hour(i)+hour-1 )  );
    T_design_hour(i)=median( T_design( t_hour(i):1:t_hour(i)+hour-1 )  );

    Q_dot_H_hour(i)=median( Q_dot_H( t_hour(i):1:t_hour(i)+hour-1 )   );

end

% plot(t,T_amb, 'b'); % plotten alle Werte
% hold on
% plot(t_max, T_amb_max, 'o')
% plot(t_mittel, T_amb_mittel, 'v')
% plot(t_step, T_amb_step, '--r');



%_____________________________values each day

            T_0_max_day=T_0(1:day:t);          % max temperature in the room
without heating each day
            T_0_min_day=T_0(1:day:t);          % min temperature in the room
without heating each day
            T_0_median_day=T_0(1:day:t);        % median temperature in the
room without heating each day

            T_amb_max_day=T_amb(1:day:t);            % max temperature of the
air each day
            T_amb_min_day=T_amb(1:day:t);            % min temperature of the
air each day
            T_amb_median_day=T_amb(1:day:t);         % median temperature of
the air each day

            T_0H_max_day=T_0H(1:day:t);          % max temperature in the room
with heating each day
            T_0H_min_day=T_0H(1:day:t);          % min temperature in the room
with heating each day
```

```
            T_0H_median_day=T_0H(1:day:t);       % median temperature in the
room with heating each day

            T_design_day=T_design(1:day:t);

            Q_dot_H_max_day=Q_dot_H(1:day:t);           % max energy supplied
for heating each day (W)
            Q_dot_H_min_day=Q_dot_H(1:day:t);           % min energy supplied
for heating each day (W)
            Q_dot_H_median_day=Q_dot_H(1:day:t);        % median energy
supplied for heating each day (W)
%


for i=1:length(t_day)

            T_amb_max_day(i)=max( T_amb( t_day(i):1:t_day(i)+day-1 )  );
            T_0_max_day(i)=max( T_0( t_day(i):1:t_day(i)+day-1 )  );
            T_0H_max_day(i)=max( T_0H( t_day(i):1:t_day(i)+day-1 )  );

            T_amb_min_day(i)=min( T_amb( t_day(i):1:t_day(i)+day-1 )  );
            T_0_min_day(i)=min( T_0( t_day(i):1:t_day(i)+day-1 )  );
            T_0H_min_day(i)=min( T_0H( t_day(i):1:t_day(i)+day-1 )  );

            T_amb_median_day(i)=median( T_amb( t_day(i):1:t_day(i)+day-1 )  );
            T_0_median_day(i)=median( T_0( t_day(i):1:t_day(i)+day-1 )  );
            T_0H_median_day(i)=median( T_0H( t_day(i):1:t_day(i)+day-1 )  );

            T_design_day(i)=median( T_design( t_day(i):1:t_day(i)+day-1 )  );

            Q_dot_H_max_day(i)=max( Q_dot_H( t_day(i):1:t_day(i)+day-1 )   );
            Q_dot_H_min_day(i)=min( Q_dot_H( t_day(i):1:t_day(i)+day-1 )   );
            Q_dot_H_median_day(i)=median( Q_dot_H( t_day(i):1:t_day(i)+day-1 )
);

end


%_______________________________values each month

            T_0_max_month=T_0(1:month:t);               % max temperature in
the room without heating each month
            T_0_min_month=T_0(1:month:t);               % min temperature in
the room without heating each month
            T_0_median_month=T_0(1:month:t);            % median temperature
in the room without heatin each month

            T_amb_max_month=T_amb(1:month:t);              % max temperature
of the air each month
            T_amb_min_month=T_amb(1:month:t);             % min temperature
of the air each month
            T_amb_median_month=T_amb(1:month:t);           % median
temperature of the air each month

            T_0H_max_month=T_0H(1:month:t);             % max temperature in
the room with heating each month
            T_0H_min_month=T_0H(1:month:t);             % min temperature in
the room with heating each month
            T_0H_median_month=T_0H(1:month:t);          % median temperature
in the room with heating each month
```

```
            T_design_month=T_design(1:month:t);

            Q_dot_H_max_month=Q_dot_H(1:month:t);
            Q_dot_H_min_month=Q_dot_H(1:month:t);
            Q_dot_H_median_month=Q_dot_H(1:month:t);


for i=1:length(t_month)

        T_amb_max_month(i)=max( T_amb( t_month(i):1:t_month(i)+month-1 )  );
        T_0_max_month(i)=max( T_0( t_month(i):1:t_month(i)+month-1 )  );
        T_0H_max_month(i)=max( T_0H( t_month(i):1:t_month(i)+month-1 )  );

        T_amb_min_month(i)=min( T_amb( t_month(i):1:t_month(i)+month-1 )  );
        T_0_min_month(i)=min( T_0( t_month(i):1:t_month(i)+month-1 )  );
        T_0H_min_month(i)=min( T_0H( t_month(i):1:t_month(i)+month-1 )  );

        T_amb_median_month(i)=median( T_amb( t_month(i):1:t_month(i)+month-1));
        T_0_median_month(i)=median( T_0( t_month(i):1:t_month(i)+month-1)  );
        T_0H_median_month(i)=median( T_0H( t_month(i):1:t_month(i)+month-1 )  );

        T_design_month(i)=median( T_design( t_month(i):1:t_month(i)+month-1));

        Q_dot_H_max_month(i)=max( Q_dot_H( t_month(i):1:t_month(i)+month-1));
        Q_dot_H_min_month(i)=min( Q_dot_H( t_month(i):1:t_month(i)+month-1) );
      Q_dot_H_median_month(i)=median(Q_dot_H(t_month(i):1:t_month(i)+month-1));

end
```

```
%%%%     PowerPhoto     %%%%

%_____________________1. SET THE PARAMETERS


N_panel=24;                 %      number of panels for the installation
A_panel=1.65;               % (m2) surface of the panel
theta_panel=0;          % (ï¿½)  orientation of the axe of the panel respect the
south
                        %      The reference is South=0ï¿½, positives angles at
West
                        %      and negatives at East, like Azimuth angle
```

```
delta_panel=12.41;      % (ï¿½)  inclination of the panel respect the horizontal
= The same of the roof

V_el_batt=12;                 % (V)  working voltage of the batteries


% _____________________________

day=24*inter;
month=365/12*24*inter;

t_day=(1:day:t);
t_month=(1:month:t);

t_month_day=(1:360/12:length(t_day));


%_____________________ 2. RADIATION ON THE SURFACE OF THE PANEL (see
radiation1.m)

rad=pi/180;
G_panel=abs (max ( G_Bh.*(cos(hs*rad)*sin(delta_panel*rad).*cos((Az-
theta_panel)*rad)+...
    sin(hs.*rad)*cos(delta_panel*rad))+G_Dh , G_Dh ));

Q_S_panel=G_panel*A_panel*N_panel*DELTAt;        %(J) Energy which arrives to
the panels field each DELTAt


%_____________________3. Energy from ONE panel (or module - subscript 'mod')

% The dates are from the modules SolvisPico PI-AE/ 210 Wp
% The output of the cell is proportional to the radiation
% The speed of wind is not considered in the calculation of the
    %temperature of the cell

%Subscripts
    % OC=Open Circuit
    % SC=Short Circuit
    % mod=module
    % MPP=max power production


%NOCT = nominal operating cell temperature
NOCT=49.5;

T_cell=(NOCT-20)/800*G_panel+T_amb;      % (ï¿½C)

% N_scell=number of cells put in serie
N_scell=60;

% electric characteristics, whith 25 ï¿½C and 1000 W/m2
I_SCmod1000=8.3;                % (A)
V_OCmod1000=36.1;               % (V)
I_MPPmod=7.6;                   % (A)
V_MPPmod=27.6;                  % (V)

% Preallocating of variables
V_OCmod=ones(1,t);
```

```
% FF=FormFactor
FF=I_MPPmod*V_MPPmod/(I_SCmod1000*V_OCmod1000);


% variation in the output voltage of the module on Open Circuit
T_cell(1)=T_amb(1);                 % (ï¿½C)
V_OCmod(1)=V_OCmod1000;          % (V)


for i=2:t
    V_OCmod(i)=-0.0023*N_scell*(T_cell(i)-T_cell(i-1))+V_OCmod(i-1);
end

% variation in the output current in Short Circuit and power of the module

I_SCmod=I_SCmod1000*G_panel/1000;      % (A)  Not effect of the temperature
P_panel=FF*I_SCmod.*V_OCmod';              % (W)  Power produced by ONE panel

%eta_mod=100*FF*I_SCmod1000*V_OCmod/1000/A_panel;       % [dimensionless]
efficiency
% of the module. There is problems with this equation due to [div(0)]


%power of the module

I_mod=I_MPPmod*G_panel/1000;           % (A)  linear variation.
V_mod=FF*V_OCmod;                        % (V)  It is suppossed that this voltage
is constant


%_____________________4. consumed and produced Energy


P_heatpump=9000;                                    % (W) Max thermal Power produced
by the heat pump
COP=4.4;                                            % (dimensionless) coefficient of
operating of the heat pump
P_appliances=1860*ones(1,t);                        % (W) Max electrical power
demanded by appliances
                                                    % (considering simultaneous
factor)

Q_dot_heatpump=min(abs(Q_dot_H),P_heatpump);     % (W) Max Power given by the
heatpump for heating/cooling
E_heatpump=Q_dot_heatpump*DELTAt/COP;            % (J) Electrical Energy consumed
by the heatpump (per DELTA t)


E_heatpump_day=(1:day:t);                           % (J) Electrical Energy consumed
by the heat pump (per DAY)

for i=1:length(t_day)
    E_heatpump_day(i)=sum(    E_heatpump(t_day(i):1:t_day(i)+day-1)    );
end


E_appliances_day=6200*3600*ones(1,365);          % (J) Theoretic energy consumed
by the electrical appliances in one day
                                                    % I transform the unities from
Wh to J
E_T_photo_day=E_appliances_day+E_heatpump_day;   % (J) Theoretic energy consumed
```

```
by the building (per DAY)
eta_regulator=0.98;                              %    efficiency of the regulator

%_____________________________________

%//////////////////////  IF THERE IS BATTERIES...

N_day=1;                       % number of autonomy days. If there is not
batteries, N_day=0
DOD=0.8;                    % deep of discharge. Tipical valor for this kind of
installation = 0.8
ka=0.005;                   % daily self-discharge coefficient. Tipical valor for
Pb batteries
k_batt=0.05;                     % loss due to the efficiency of the batteries
eta_inverter=0.9;           % efficiency of the inverter
k_convert=1-eta_inverter;      % loss in DC/AC converter. Valor given by the
manufacturer
kv=0.05;                    % other losses (Joule, efficiency of the Net...)

%///////////////////  IF THERE IS NOT BATTERIES...

% N_day=1;                        % number of autonomy days. If there is not
batteries, N_day=0
% DOD=1;                        % deep of discharge. Tipical valor for this kind
of installation = 0.8
% ka=0;                         % daily self-discharge coefficient. Tipical valor
for Pb batteries
% k_batt=0;                        % loss due to the efficiency of the batteries
% eta_inverter=0.9;             % efficiency of the inverter
% k_convert=1-eta_inverter;          % loss in DC/AC converter. Valor given by
the manufacturer
% kv=0.05;                      % other losses (Joule, efficiency of the Net...)

%_____________________________________________

eta_photo=eta_regulator*(1-k_batt-k_convert-kv)*(1-ka*N_day/DOD);          %
General effciency factor of the installation

E_T_photo=interp(E_T_photo_day/240,240);    % (J) Theoretic Electrical Energy
demanded by the building (per DELTAt)
E_photo=E_T_photo/eta_photo;            % (J) Electrical Energy demanded by the
building (per DELTAt)
E_Ppanel=ones(1,t);                     % (J) Energy really produced by the
panel   (per DELTAt )
E_aux_photo=ones(1,t);                  % (J) Auxiliary Energy from the Net
(per DELTA t)
P_aux_photo=ones(1,t);                  % (W) Max aux power demanded by the
building       (per DELTA t)
P_photo=ones(1,t);                      % (W) power consumed by the building
(per DELTA t)

eta_panel=ones(1,t);                    %     Efficiency of the photovoltaic
panel (per DELTA t)

for i=1:t
    E_Ppanel(i)    = N_panel*P_panel(i)*DELTAt;
    % ATTENTION!! E_aux can be negative in small DELTAt. This energy is stored
in the batteries
    E_aux_photo(i)=   ( E_photo(i)-E_Ppanel(i)   );
    P_aux_photo(i)=min( 9000/COP, max(0, E_aux_photo(i)/DELTAt ));
```

```
    P_photo(i)=Q_dot_heatpump(i)+P_appliances(i);
    eta_panel(i) = 100*E_Ppanel(i)/Q_S_panel(i);
end


%_____________________________ Values each day


% Preallocating of variables

E_Ppanel_day     = (1:day:t);                % (J) Energy  produced by  all the
panels in one day (J)
E_photo_day      = (1:day:t);                % (J) Energy consumed by building
in one day (J)
Q_S_panel_day    = (1:day:t);               % (J) Energy who cames to all the
panels in one day (J)
F_photo_day  =(1:day:t);            %     Relation betwenn E_Ppanel (produced)
and E_photo (consumed) (per DAY)
E_aux_photo_day  = (1:day:t);
P_aux_photo_day    = (1:day:t);              % (W) max aux power demanded by the
building          (per DAY)
P_max_photo_day    = (1:day:t);              % (W) max power demanded by the
building       (per DAY)
eta_panel_day =(1:day:t);                %     Efficiency of the photovoltaic
panel       (per DAY)
E_max_Ppanel_day  =(1:day:t);

P_median_panel_day = (1:day:t);                % (W) median power produced by
the panels         (per DAY)
P_max_panel_day    = (1:day:t);                % (W) max power produced by the
panels          (per DAY)
Q_dot_max_heatpump_day = (1:day:t);          % (W) max power consumed by the
heatpump
P_appliances_day = (1:day:t);

for i=1:length(t_day)

    E_Ppanel_day(i)    =  sum (  E_Ppanel( t_day(i):1:t_day(i)+day-1)  );
    E_photo_day(i)     =  sum (  E_photo( t_day(i):1:t_day(i)+day-1)  );
    E_max_Ppanel_day(i)=  max (  E_Ppanel( t_day(i):1:t_day(i)+day-1)  );
    Q_S_panel_day(i)   =  sum (  Q_S_panel( t_day(i):1:t_day(i)+day-1)  );
    % ATTENTION!! At the end of the day, I suppossed that E_aux is not anymore
negative
    E_aux_photo_day(i) = max( 0,  sum (  E_aux_photo( t_day(i):1:t_day(i)+day-1)
) );

    P_aux_photo_day(i) =  max (  P_aux_photo(t_day(i):1:t_day(i)+day-1)  );
    P_max_photo_day(i) =  max (  P_photo(t_day(i):1:t_day(i)+day-1)  );
    P_median_panel_day(i)=   median(  P_panel (t_day(i):1:t_day(i)+day-1)  );
    P_max_panel_day  (i) =   max(  P_panel (t_day(i):1:t_day(i)+day-1)  );
    Q_dot_max_heatpump_day(i) = max(  Q_dot_heatpump (t_day(i):1:t_day(i)+day-1)
);
    P_appliances_day (i) = median (  P_appliances( t_day(i):1:t_day(i)+day-
1)  );

    eta_panel_day(i)=  max (  eta_panel(t_day(i):1:t_day(i)+day-1)  );

    F_photo_day(i)= 100*E_Ppanel_day(i)/E_photo_day(i);
end
```

```
E_aux_photo_day_stationary=max( 0 , E_photo_day-E_Ppanel_day );      % (J)
Auxiliary Energy from the Net (per DAY)

% _____________________ Values each month

E_photo_month=ones(1,12);
E_Ppanel_month = ones(1,12);
E_aux_photo_month=ones(1,12);
F_photo_month=ones(1,12);


for i=1:length(t_month)

    E_photo_month(i)= sum ( E_photo_day( t_month_day(i):1:t_month_day(i)+360/12-
1)  );
    E_Ppanel_month(i) = sum ( E_Ppanel_day( t_month_day(i):1:t_month_day(i)
+360/12-1)  );
    E_aux_photo_month(i) = sum
( E_aux_photo_day( t_month_day(i):1:t_month_day(i)+360/12-1)  );
    F_photo_month(i)=  median ( F_photo_day( t_month_day(i):1:t_month_day(i)
+360/12-1)  );

end

%_____________________ 5. Solar Fraction




E_Ppanel_total=cumsum(E_Ppanel_day);    %(J)
E_photo_total=cumsum(E_photo_day);                                  % (J)
F_photo=E_Ppanel_total(365)/E_photo_total(365)*100

E_Ppanel_total_real=cumsum ( min( E_Ppanel_day , E_photo_day) );
F_photo_real=E_Ppanel_total_real(365)/E_photo_total(365)*100



%_____________________________________6. BATTERIES

%V_el_batt=12;                     % working voltage of the batteries (V). Set
on line 14 of the program
E_acc=E_T_photo_day*N_day/eta_photo/DOD;      % Energy stored in the Batteries
C=E_acc/V_el_batt/3600;             % (Ah) Capacity of storage of the batteries


% capacity shows the maximal difference between the energy produced and
% the energy consumed in the installation.
% The difference is the energy which the batteries haven to store
capacity=ones(1,365);

for i=1:365
    capacity(i)=E_Ppanel_day(i)*N_panel*eta_photo-E_T_photo_day(i);
end
```

```
%%%%    PowerCollector6    %%%%

%_____________________1. SET THE PARAMETERS

N_collector=1;                  % number of collectors for the installation
A_collector=2.378;              % surface of each colector
theta_collector=0;     % orientation of the axe of the collector respect the
south
                        % The reference is South=0Â°, positives angles at West
                        % and negatives at East, like Azimuth angle

delta_collector=12.41;      % inclination of the panel respect the horizontal =
The same of the roof

rho_w=1000;
cp_w=4180;
m_kg_h=50;                          % (kg/h) flow through one collector
m_dot_collector=m_kg_h/3600;        % (kg/s)
V_acc_HSW=150;                  % (liters) total volume of the accumulator


%_____________________ 2. DESIGN CONDITIONS

% Temperature of accumulation = 60 Â°C
% Number of persons = 4
% Consumption/person = 30 liters (w at 60 Â°C)
% Median Valor of temperature of cool water on public net in Baleares
Tjanuar=8;
Tfebruar=9;
Tmarch=11;
Tapril=13;
Tmay=14;
Tjune=15;
Tjule=16;
Tagost=15;
Tsept=14;
Toct=13;
Tnov=11;
Tdec=8;

T_w_net=[ Tjanuar*ones(1,31),Tfebruar*ones(1,28),Tmarch*ones(1,31),Tapril*ones(1
,30),Tmay*ones(1,31),...
    Tjune*ones(1,30),Tjule*ones(1,31),Tagost*ones(1,31),Tsept*ones(1,30),Toct*on
es(1,31),Tnov*ones(1,30),Tdec*ones(1,31) ];

% Energy needed every day

Q_HSW_day=4*30*cp_w*(60-T_w_net);     % (J)
Q_HSW=interp(Q_HSW_day/240,240);


%_____________________3.  RADIATION ON THE SURFACE OF THE COLLECTOR (see
radiation1.m)

%direct radiation, according Fariï¿½a (1990), plus diffuse radiation,
%supossing equal in all directions, on the collector
rad=pi/180;

 G_S_collector=abs ( max(  G_Bh.*(cos(hs*rad)*sin(delta_collector*rad).*cos((Az-
theta_collector)*rad)+...
```

```
     sin(hs.*rad)*cos(delta_collector*rad))+G_Dh ,  G_Dh  ));

Q_S_collector=G_S_collector*DELTAt*A_collector*N_collector;   % (J) Energy which
arrives to ONE the collectors

% _____________________ 4. PRODUCED ENERGY

eta_0=0.798;                % optical factor of the solar collector
a1=-3.42;                   % first coefficient of loses in solar collector
a2=-0.016;                  % second coefficient of loses in solar collector

eta_collector=zeros(1,t);

Tin=30;
Tout=ones(1,t);
Tm=ones(1,t);

eta_inter=0.8;              % efficiency of heat tranfer inside the accumulator

Q_Pcollector=ones(1,t);                              % (J) Energy really produced
by the collector
Q_acc_HSW=ones(1,t);                            % (J) Energy transfered to the
accumulator

P_aux_HSW=700*ones(1,t);                        % (W) Power of auxiliary heater
E_aux_HSW=ones(1,t);                            % (J) Energy given by the auxliary
heater
F_HSW=ones(1,t);

P_heater_HSW=700;             % Power of the auxiliar heater

% parameters for a second degree equation: Tout^2*A + Tout*B + C = 0
A=ones(1,t);
B=ones(1,t);
C=ones(1,t);


for i=1:t

        % Schema for the resolution of a second degree equation
        A(i)=A_collector*a2/4;
        B(i)= A_collector*( a1/2+a2*( Tin/2-T_amb(i) )  ) - m_dot_collector*cp_w
;
        C(i)=eta_0*G_S_collector(i)*A_collector+m_dot_collector*cp_w*Tin+a1*A_co
llector*Tin/2-a1*A_collector*T_amb(i)+A_collector*a2*(Tin/2-T_amb(i))^2;

        Tout(i)=max( 20, ( -B(i)-(B(i)^2-4*A(i)*C(i))^(1/2) )/(2*A(i)) );

        Q_Pcollector(i)= max( 0 ,
cp_w*N_collector*m_dot_collector*DELTAt*(Tout(i)-Tin) );
        Q_acc_HSW(i)=Q_Pcollector(i)*eta_inter;

        %Tin(i+1)=( Q_acc_HSW(i) )/( cp_w*V_acc_HSW/1000*rho_water )+Tin(i);

        E_aux_HSW(i)=Q_HSW(i)-Q_acc_HSW(i);
        P_aux_HSW(i)=min (P_heater_HSW , max (0, E_aux_HSW(i) / DELTAt )  );

        Tm(i)=(Tout(i)+Tin)/2;

        eta_collector(i)=max( 0, (eta_0+a1*(Tm(i)-T_amb(i))/G_S_collector(i)
+a2*(Tm(i)-T_amb(i))^2/G_S_collector(i))*100  );
```

```
        %F_HSW(i)= 100*Q_acc_HSW(i)/Q_HSW(i);

end

%_____________________ values every day

day=24*inter;
month=365/12*24*inter;

t_day=(1:day:t);            % vector of time for dayly daten
t_month=(1:month:t);

t_month_day=(1:360/12:length(t_day));

eta_collector_day=(1:day:t);

Q_S_collector_day=(1:day:t);
Q_Pcollector_day=(1:day:t);
Q_acc_HSW_day=(1:day:t);
E_aux_HSW_day=(1:day:t);          % (J) Energy given by the auxiliary heater
P_aux_HSW_day=(1:day:t);
F_HSW_day=(1:day:t);

Tout_day=(1:day:t);

for i=1:length(t_day)

   Q_S_collector_day(i)=  sum(  Q_S_collector(t_day(i):1:t_day(i)+day-1)   );
   Q_Pcollector_day(i)=    sum(  Q_Pcollector(t_day(i):1:t_day(i)+day-1)   );
   Q_acc_HSW_day(i)= max ( 0 ,sum(  Q_acc_HSW(t_day(i):1:t_day(i)+day-1) ) );

   E_aux_HSW_day(i)= max( 0 , Q_HSW_day(i)-Q_acc_HSW_day(i) );
   P_aux_HSW_day(i)=max(  P_aux_HSW(t_day(i):1:t_day(i)+day-1)   );

   eta_collector_day(i)=Q_Pcollector_day(i)/Q_S_collector_day(i)*100;

   Tout_day(i)=max(  Tout(t_day(i):1:t_day(i)+day-1)   );
   %F_HSW_day(i)= median( F_HSW(t_day(i):1:t_day(i)+day-1)   );

end

   % (W) Max power demanded by the accumulator  (per DAY)
%P_aux_HSW_day = E_aux_HSW_day/(24*inter*DELTAt);

%_____________________ values each month

Q_Pcollector_month=ones(1,length(t_month));
Q_acc_HSW_month=ones(1,length(t_month));
Q_HSW_month=ones(1,length(t_month));
F_HSW_month=ones(1,length(t_month));

for i=1:length(t_month)
    Q_Pcollector_month(i)   = sum(  Q_Pcollector(  t_month(i):1:t_month(i)
+month-1)   );
    Q_acc_HSW_month(i)= sum(  Q_acc_HSW(  t_month(i):1:t_month(i)+month-1)   );
    Q_HSW_month(i)    = sum (  Q_HSW (t_month(i):1:t_month(i)+month-1)  );

   % F_HSW_month(i)= median(  F_HSW(t_month(i):1:t_month(i)+month-1)  );

end
 % _____________________ 5. SOLAR FRACTION
```

```
F_HSW_day=Q_acc_HSW_day./Q_HSW_day*100;
F_HSW_month=Q_acc_HSW_month./Q_HSW_month*100;

Q_HSW_total=cumsum(Q_HSW_day);
Q_acc_HSW_total=cumsum(Q_acc_HSW_day);

F_HSW_year=Q_acc_HSW_total(365)/Q_HSW_total(365)*100
```

%%%% adsorption6 %%%%

```
% SUBSCRIPTS
% 'ads' = 'adsorption machine installation'
% 'HSW' = 'Hot Sanitary Water'

%_____________________1. SET THE PARAMETERS

N_person_ads=4;
N_collector_ads=16;             % number of collectors for the installation
A_collector=2.378;              % surface of each colector
N_serie=2;              % number of collectors connected in serie

theta_ads=0;     % orientation of the axe of the collector respect the south
                        % The reference is South=0Â°, positives angles at West
                        % and negatives at East, like Azimuth angle

delta_ads=12.4;      % inclination of the panel respect the horizontal = The
same of the roof

rho_w=1000;         % (kg/m3) density of w
cp_w=4180;
m_kg_h=50;              % (kg/h)
m_dot_ads=m_kg_h/3600;      % (kg/s)
V_acc_ads=1500;            % (liters) total volume of the accumulator

% ____________________________________________

day=24*inter;
month=365/12*24*inter;

t_day=(1:day:t);            % vector of time for dayly daten
t_month=(1:month:t);

t_month_day=(1:360/12:length(t_day));

%_____________________2. DESIGN CONDITIONS

% Temperature of accumulation = 60 Â°C
% Number of persons = 4
% Consumption/person = 30 liters (water at 60 Â°C)
% Median Valor of temperature of cool water on public net in Baleares
Tjanuar=8;
Tfebruar=9;
Tmarch=11;
Tapril=13;
Tmay=14;
Tjune=15;
Tjule=16;
```

```
Tagost=15;
Tsept=14;
Toct=13;
Tnov=11;
Tdec=8;

T_w_net=[ Tjanuar*ones(1,31),Tfebruar*ones(1,28),Tmarch*ones(1,31),Tapril*ones(1
,30),Tmay*ones(1,31),...
    Tjune*ones(1,30),Tjule*ones(1,31),Tagost*ones(1,31),Tsept*ones(1,30),Toct*on
es(1,31),Tnov*ones(1,30),Tdec*ones(1,31) ];

V_dot_HSW=23;               % (liters/person.day)


% _____________________________ Energy needed

Q_HSW_day=N_person_ads*V_dot_HSW*cp_w*(75-T_w_net);      % (J) energy needed for
Hot Sanitary Water (per day)


Q_HSW=interp(Q_HSW_day/240,240);                          % (J) Energy needed for
Hot Sanitary Water (per DELTAt)
Q_cooling_ads= - min(0, Q_dot_H*DELTAt);                    % (J) Energy needed
for cooling, in summer (per DELTAt)
Q_heating_ads=   max(0, Q_dot_H*DELTAt);                    % (J) Energy needed
for heating, in winter (per DELTAt)

Q_ads=Q_HSW+Q_heating_ads+Q_cooling_ads;                % (J) energy needed by
the building (per DELTAt)

E_appliances_day=6200*3600*ones(1,365);
E_appliances_month=6200*3600*365*ones(1,12);

P_appliances=1860;                                  % (W) Max electrical power
demanded by appliances (per DELTAt)
                                                    % (considering simultaneous
                                                    % factor)

%____________________3. RADIATION ON THE SURFACE OF THE PANEL (see
radiation1.m)

%direct radiation, according Fariï¿½a (1990), plus diffuse radiation,
%supossing equal in all directions, on the collector
rad=pi/180;

 G_S_ads=abs ( max(  G_Bh.*(cos(hs*rad)*sin(delta_ads*rad).*cos((Az-
theta_ads)*rad)+...
     sin(hs.*rad)*cos(delta_ads*rad))+G_Dh ,  G_Dh  ));

 Q_S_ads=G_S_ads*DELTAt*A_collector*N_collector_ads;      % (J) energy received
in ONE thermal collector (per DELTAt)

 % _____________________________________ 4. PRODUCED ENERGY


eta_0=0.798;
a1=-3.42;
a2=-0.016;

eta_ads1=zeros(1,t);
eta_ads2=zeros(1,t);
```

```
eta_inter_ads=0.8;                          % Efficiency of heat transfer in the
accumulator

Tm1=ones(1,t);
Tm2=ones(1,t);
Tout1=ones(1,t);            % (ï¿½C) output temperature from the FIRST column of
collectors
Tout2=ones(1,t);            % (ï¿½C) output temperature from the SECOND column
of collectors
Tin1=20;          % (ï¿½C) Temperature in the accumulator = intput temperature
to the first collectors
Tin2=ones(1,t);             % (ï¿½C) input temperature to the SECOND column of
collectors

Q_Pads=ones(1,t);                           % (J) energy produced by TWO thermal
collectors (per DELTAt)
Q_Pads1=ones(1,t);                          % (J) energy produced by ONE
collectors on the first column (per DELTAt)
Q_Pads2=ones(1,t);                          % (J) energy produced by ONE
collectors on the second column (per DELTAt)
Q_Acc_ads=ones(1,t);                        % (J) Energy transfered to the
accumulator (per DELTAt)

E_aux_ads=ones(1,t);                        % (J) Energy given by the auxliary
heater
P_heater_ads=8000;                          % Power of the auxiliar heater
P_aux_ads=ones(1,t);                        % (W) design conditions for heating


A1=ones(1,t);
B1=ones(1,t);
C1=ones(1,t);
A2=ones(1,t);
B2=ones(1,t);
C2=ones(1,t);


for i=1:t


        % Schema for the resolution of a second degree equation
        A1(i)=A_collector*a2/4;
        B1(i)=(A_collector/2*(a1+a2*( Tin1/2-T_amb(i) ))-m_dot_ads*cp_w);
        C1(i)=eta_0*G_S_ads(i)*A_collector+m_dot_ads*cp_w*Tin1+a1*A_collector*Ti
n1/2-a1*A_collector*T_amb(i)/2+A_collector*a2*(Tin1/2-T_amb(i))^2;

        Tout1(i)=max( 20, ( -B1(i)-(B1(i)^2-4*A1(i)*C1(i))^(1/2) )/(2*A1(i)) );

        Tin2(i)=Tout1(i);

        % Schema for the resolution of a second degree equation
        A2(i)=A_collector*a2/4;
        B2(i)=(A_collector/2*(a1+a2*( Tin2(i)/2-T_amb(i) ))-m_dot_ads*cp_w);
        C2(i)=eta_0*G_S_ads(i)*A_collector+m_dot_ads*cp_w*Tin2(i)
+a1*A_collector*Tin2(i)/2-a1*A_collector*T_amb(i)/2+A_collector*a2*(Tin2(i)/2-
T_amb(i))^2;

        Tout2(i)=max (20, (-B2(i)-(B2(i)^2-4*A2(i)*C2(i))^(1/2))/(2*A2(i)) );

       Q_Pads(i)= max( 0 , cp_w*m_dot_ads*DELTAt*(Tout2(i)-Tin1) );
```

```
            Q_Pads1(i)=max( 0 , cp_w*m_dot_ads*DELTAt*(Tout1(i)-Tin1) );
            Q_Pads2(i)=max( 0 , cp_w*m_dot_ads*DELTAt*(Tout2(i)-Tin2(i)) );

        Q_Acc_ads(i)= eta_inter_ads*N_collector_ads/N_serie*Q_Pads(i);

        % ATTENTION!! E_aux can be negative in small DELTAt. This energy is
stored in the accumulator
        E_aux_ads(i) =   (  Q_ads(i) - Q_Acc_ads(i)) ;
        P_aux_ads(i) = min(P_heater_ads,  max (0, E_aux_ads(i)/DELTAt) );

        Tm1(i)=(Tout1(i)+Tin1)/2;
        Tm2(i)=(Tout2(i)+Tin2(i))/2;

        eta_ads1(i)=max( 0, (eta_0+a1*(Tm1(i)-T_amb(i))/G_S_ads(i)+a2*(Tm1(i)-
T_amb(i))^2/G_S_ads(i))*100  );
        eta_ads2(i)=max( 0, (eta_0+a1*(Tm2(i)-T_amb(i))/G_S_ads(i)+a2*(Tm2(i)-
T_amb(i))^2/G_S_ads(i))*100  );


end

%_________ Avaible energy for cooling, given by the adsorption machine
P_cooling_ads=ones(1,t);
for i=1:t
    if Q_dot_H(i) < 0
        P_cooling_ads(i)=min ( 11000 ,( 23.2 - 0.53*T_amb(i))*1000  );
% (W) Power for heating each DELTAt
    else
        P_cooling_ads(i)=0;
    end
end


%_____________________ values each day

Q_S_ads_day=(1:day:t);                  % (J) Energy which arrives to ONE thermal
collectors (per DAY)
Q_Pads_day=(1:day:t);                    % (J) Energy produced by TWO thermal
collectors in serie (per DAY)
    Q_Pads1_day=(1:day:t);               % (J) Energy produced by THE FIRST
thermal collectors in serie (per DAY)
    Q_Pads2_day=(1:day:t);               % (J) Energy produced by THE SECOND
thermal collectors in serie (per DAY)
Q_Acc_ads_day=(1:day:t);                 % (J) Energy transfered to the
accumulator (per DAY)

Q_ads_day=(1:day:t);                     % (J) Energy needed by the building (per
DAY)
    Q_cooling_ads_day=(1:day:t);         % (J) Energy needed by the building for
cooling(per DAY)
    Q_heating_ads_day=(1:day:t);         % (J) Energy needed by the building for
heating(per DAY)

E_aux_ads_day=(1:day:t);                 % (J) Energy given by the auxiliary
heater (per DAY)
P_aux_ads_day=(1:day:t);

eta_ads1_day=(1:day:t);                  % (dimensionless) efficieny of
collectors of the first column
eta_ads2_day=(1:day:t);                  % (dimensionless) efficieny of
collectors of the second column
```

```
P_cooling_ads_day=ones(1,length(t_day));  % (W) available power for cooling,
given by the adsorption machine


for i=1:length(t_day)

   Q_S_ads_day(i)  =  sum(  Q_S_ads(t_day(i):1:t_day(i)+day-1)   );
   Q_Pads_day(i)    =  sum (   Q_Pads(t_day(i):1:t_day(i)+day-1)   );
        Q_Pads1_day(i)    =  sum (   Q_Pads1(t_day(i):1:t_day(i)+day-1)   );
        Q_Pads2_day(i)    =  sum (   Q_Pads2(t_day(i):1:t_day(i)+day-1)   );

   Q_Acc_ads_day(i)    =  sum (   Q_Acc_ads(t_day(i):1:t_day(i)+day-1)   );

   Q_ads_day(i)     =   sum (   Q_ads(t_day(i):1:t_day(i)+day-1)   );
        Q_cooling_ads_day(i)= sum (   Q_cooling_ads(t_day(i):1:t_day(i)+day-1)
);
        Q_heating_ads_day(i)= sum (   Q_heating_ads(t_day(i):1:t_day(i)+day-1)
);

   % ATTENTION!! At the end of the day, I suppossed that E_aux is not anymore
negative
   E_aux_ads_day(i)  =  max(0 ,sum ( E_aux_ads(t_day(i):1:t_day(i)+day-1)  ) );
   P_aux_ads_day(i)  =  max( P_aux_ads(t_day(i):1:t_day(i)+day-1)   );

   eta_ads1_day(i)=Q_Pads1_day(i)/(Q_S_ads_day(i)/N_collector_ads)*100;
   eta_ads2_day(i)=Q_Pads2_day(i)/(Q_S_ads_day(i)/N_collector_ads)*100;

   P_cooling_ads_day(i)  =  median (  P_cooling_ads(t_day(i):1:t_day(i)+day-1)
);

end

%E_aux_ads_day=E_aux_ads_day+6200*3600;          % (J) Electrical extra Energy
for heating and for appliances (per DAY)
%E_ads_day=Q_ads_day/COP + 6200*3600;            % (J) Total Electrical Energy
for heating and for appliances (per DAY)


    % (J) Energy provided by the auxiliary heater (per DAY), by using a
stationary equation
E_aux_ads_day_stationary=max(0 , Q_ads_day-Q_Acc_ads_day);


%_____________________ values each month


Q_Acc_ads_month=ones(1,length(t_month));
Q_ads_month=ones(1,length(t_month));


for i=1:length(t_month)

    Q_Acc_ads_month(i)=sum(  Q_Acc_ads(  t_month(i):1:t_month(i)+ month-1)   );
    Q_ads_month(i)=  sum (  Q_ads (  t_month(i):1:t_month(i)+ month-1)  );


end
```

```
F_ads_day=100*Q_Acc_ads_day./Q_ads_day;
F_ads_month=100*Q_Acc_ads_month./Q_ads_month;

F_ads_appliances_day=100*Q_Acc_ads_day./(Q_ads_day+E_appliances_day);
F_ads_appliances_month=100*Q_Acc_ads_month./(Q_ads_month+E_appliances_month);

Q_ads_total=cumsum(Q_ads_day);
E_appliances_total=cumsum(E_appliances_day);
Q_Acc_ads_total=cumsum(Q_Acc_ads_day);

F_Q_ads=Q_Acc_ads_total(365)/Q_ads_total(365)*100
F_Q_E_ads=Q_Acc_ads_total(365)/(Q_ads_total(365)+E_appliances_total(365))*100
```

%%%% graphics %%%%

```
% Figure 3.1
% See function "sprung3"



% %Figure 3.2
evolution of the power for heating and cooling
figure(32)
bar(Q_dot_H_hour,'LineWidth',1)
xlabel('Hour of the year','FontSize',12)
ylabel('Power (Watt)','FontSize',12)
grid
%
%
% %Figure 3.3
% Evolution of temperatures inside and outside the building
figure(33)
plot(T_0_median_day,'LineWidth',1)
hold on
plot(T_0H_median_day,'r','LineWidth',1)
hold on
plot(T_amb_median_day,'k','LineWidth',1)
hold on
plot(T_design_day,':k','LineWidth',1.5)
xlabel('Day of the year','FontSize',12)
ylabel('Median temperature (°C)','FontSize',12)
legend('T_{m,0,day}','T_{m,0H,day}','T_{m,amb,day}','T_{m,design,day}','location
','SouthOutside')
grid

% %_____________________________________ PowerPhoto
%
%
```

```
% %figure 5.2
% %max power raised (produced) every day
figure(52)
plot(P_max_panel_day*N_panel,'LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Power (Watt)','FontSize',12)
grid


% %figure 5.3
figure(53)
plot(E_acc/1000000,'k','LineWidth',1)
hold on
plot(E_Ppanel_day/1000000,'LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('E_{acc}','E_{P,panel}','location','EastOutside')
grid


%figure 5.4
figure(54)
plot(P_max_photo_day/COP+P_appliances_day+P_aux_HSW_day,'LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Power (Watt)','FontSize',12)
grid



% %figure(5.5)
figure(55)
plot(E_photo_day/1000000,'k','LineWidth',1)
hold on
plot(E_Ppanel_day/1000000,'b','LineWidth',1)
hold on
plot(Q_S_panel_day/1000000,'r','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('E_{photo,day}','E_{P,panel,day}','E_{S,panel,day}','location','EastOutsi
de')
grid


% %figure 5.6
figure(56)
plot(E_Ppanel_day/1000000,'LineWidth',1)
hold on
plot(E_photo_day/1000000,'k','LineWidth',1)
hold on
plot(E_aux_photo_day/1000000,':k','LineWidth',1.5)
axis([0,400,0,300])
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('E_{P,panel,day}','E_{photo,day}','E_{aux,panel,day}','location','EastOut
side')
grid



% %figure 5.7
figure(57)
```

```
plot(t_day,F_photo_day,'k','LineWidth',1)
hold on
stairs(t_month,F_photo_month,'b','LineWidth',1.5)
ylabel('Energy fraction (%)','FontSize',12)
legend('F_{photo,day}','F_{photo,month}','location','EastOutside')
grid


% %efficiency of the photovoltaic panel
% figure()
% plot(eta_panel_max_day,'LineWidth',1)
% axis([0,400,10,15])
% xlabel('Day of the year','FontSize',12)
% ylabel('Energy fraction (%)','FontSize',12)



% %_____________________________________  PowerCollector6

% %figure 5.8
figure(58)
plot(Q_HSW_day/1000000,'k','LineWidth',1)
hold on
plot(Q_acc_HSW_day/1000000,'b','LineWidth',1)
hold on
plot(Q_S_collector_day/1000000,'r','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Q_{HSW,day}','Q_{acc,HSW,day}','Q_{S,day}','location','EastOutside')
grid



% %figure 5.9
figure(59)
plot(Q_HSW_day/1000000,'k','LineWidth',1)
hold on
plot(Q_acc_HSW_day/1000000,'b','LineWidth',1)
hold on
plot(E_aux_HSW_day/1000000,':k','LineWidth',1.5)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Q_{HSW,day}','Q_{acc,HSW,day}','E_{aux,HSW,day}','location','EastOutside
')
grid




% %figure 5.10
% %Solar fraction of energy covered with the installation,
figure(510)
plot(t_day,F_HSW_day,'k','LineWidth',1)
hold on
stairs(t_month,F_HSW_month,'b','LineWidth',1.5)
ylabel('Energy fraction (%)','FontSize',12)
legend('F_{HSW,day}','F_{HSW,month}','location','EastOutside')
grid


% %figure 5.11
```

```
figure(511)
plot(eta_collector_day,'LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Efficiency (%)','FontSize',12)
grid


%  _____ adsorption6

% %figure 5.14
% %energies in MJ
figure(514)
plot(Q_ads_day/1000000,'k','LineWidth',1)
hold on
plot(Q_Acc_ads_day/1000000,'b','LineWidth',1)
hold on
plot(Q_S_ads_day/1000000,'r','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Q_{ads,day}','Q_{acc,ads,day}','Q_{S,ads,day}','location','EastOutside')
grid



% %figure 5.15
% %energies in MJ
figure(515)
plot(Q_ads_day/1000000,'k','LineWidth',1)
hold on
plot(Q_Acc_ads_day/1000000,'b','LineWidth',1)
hold on
plot(E_aux_ads_day/1000000,':k','LineWidth',1.5)
xlabel('day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Q_{ads,day}','Q_{acc,ads,day}','E_{aux,ads,day}','location','SouthOutsid
e')
grid


% %figure 5.16
% %Efficiency of adsorption machine - condenser
figure(516)
plot(Q_cooling_ads_day/86400,'k','LineWidth',1)
hold on
plot(P_cooling_ads_day,'b','LineWidth',1)
xlabel('day of the year','FontSize',12)
ylabel('Power (W)','FontSize',12)
legend('Q_{cooling,ads,day}','Q_{machine,day}','location','SouthOutside')
grid


% %figure 5.17
figure(517)
plot(t_day,F_ads_day,'k','LineWidth',1)
hold on
stairs(t_month,F_ads_month,'b','LineWidth',1.5)
xlabel('day of the year','FontSize',12)
ylabel('Energy fraction (%)','FontSize',12)
legend('F_{ads,day}','F_{ads,month}','location','SouthOutside')
grid
```

```
% %figure 5.18
figure(518)
plot(eta_ads1_day,'LineWidth',1)
hold on
plot(eta_ads2_day,'k','LineWidth',1)
axis([0,400,0,80])
ylabel('Efficiency (%)','FontSize',12)
legend('First Collector of the series','Second collector of the
series','location','SouthOutside')
grid

 % %_____________________________________ COMPARATION OF THE TWO INSTALLATIONS

% %figure 6.1
figure(61)
plot(  (eta_photo*E_Ppanel_day*COP + Q_acc_HSW_day)/(N_collector*A_collector +
N_panel*A_panel) /1000000,'b','LineWidth',1  )
hold on
plot(Q_Acc_ads_day /(N_collector_ads*A_collector)/1000000,'k','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy/surf (MJ/m2)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')



% %figure 6.2
figure (62)
plot(  ( E_photo_day  +  Q_HSW_day   ) /1000000,'b','LineWidth',1)
hold on
plot( ( Q_ads_day + E_appliances_day ) / 1000000,'k','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')



% %figure 6.3
figure(63)
plot( (E_aux_photo_day + E_aux_HSW_day) / 1000000 ,'b','LineWidth',1 )
hold on
plot(  (E_aux_ads_day + E_appliances_day)/ 1000000 ,'k','LineWidth',1   )
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')


% %figure 6.4
figure(64)
plot(  (E_photo_day + Q_HSW_day)/1000000,'b','LineWidth',1)
hold on
plot( (E_aux_photo_day + E_aux_HSW_day) / 1000000 ,':b','LineWidth',1.5 )
hold on
plot( ( Q_ads_day + E_appliances_day ) / 1000000,'k','LineWidth',1)
hold on
plot(  (E_aux_ads_day + E_appliances_day)/ 1000000 ,':k' ,'LineWidth',1.5  )
xlabel('Day of the year','FontSize',12)
ylabel('Energy (MJ)','FontSize',12)
legend('E_{photo,day}+Q_{HSW,day}','E_{aux,photo,day}+E_{aux,HSW,day}',...
    'Q_{ads,day}+E_{appliances,day}','E_{aux,ads,day}
+E_{appliances,day}','location','SouthOutside')
```

```
%

%figure 6.5
figure(65)
plot( 100* (    (eta_panel_day.*E_Ppanel_day*COP + Q_acc_HSW_day) ./
(N_panel*Q_S_panel_day+Q_S_collector_day) ),'b','LineWidth',1)
hold on
plot(100*Q_Acc_ads_day ./(N_collector_ads*Q_S_collector_day),'k','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Efficiency (%)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')
grid


%figure (6.6)
figure(66)
plot(  (P_aux_photo_day+P_aux_HSW_day) / 1000,'b','LineWidth',1  )      % [kW]
max instantaneous power
hold on
plot(  (P_aux_ads_day + P_appliances_day) / 1000 ,'k','LineWidth',1 )
axis([0,400,0,11])
xlabel('Day of the year','FontSize',12)
ylabel('Power (kW)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')



%figure 6.7
figure(67)
plot(price_case1,'b','LineWidth',1  )
hold on
plot(price_case2,'k','LineWidth',1)
xlabel('Day of the year','FontSize',12)
ylabel('Euros (€)','FontSize',12)
legend('Case 1','Case 2','location','SouthOutside')



%%%%    sprung3    %%%%_____________________________________________________


t=3000;
inter=10;       %number of points in the interpolation (see 'Walls.m')

%___________________________________ DESIGN CONDITIONS


%design conditions

T_design=0;
delay_a=500;

Ta=[T_design*ones(1,delay_a),(T_design+1)*ones(1,t-delay_a)];      %Temperature
of the air [ï¿½C]
%Ta=T_design*ones(1,t);


h_0_wall=10;        %convection heat transfer coeficient on walls inside the
building [W/m2.ï¿½C]
h_0_roof=8;         %convection heat transfer coeficient on the roof inside the
```

```
building [W/m2.ï¿½C]
DELTAt=3600/inter ;        %time between each calculation [s]
DELTAx=0.03;        %width of the element in each calculation [m]

rho_air=1.2;            %density of the air [kg/m3] constant
cp_air=1000;            %specific heat [J/kg.ï¿½C]   constant


%RELATIV HUMIDITY

RH_design=50;

%_____________________________________ MATERIALS

%Description of the house, the walls, the materials, width and nodes


%surfaces [m2]

%SUBSCRIPTS
%S=South wall, N=North wall, E=East wall and W=West wall

A_S=2.28*8.30-2*1*1.2-1*1.6*2;
A_N=3.38*8.3-0.4*0.4*1.2;
A_E=(3.38+2.28)*4.3/2-0.4*0.4*1.2;
A_W=(3.38+2.28)*4.3/2-0.3*0.3*1.2;
A_roof=(4.3*8.3)/cos(atan(1.1/5));

A_total=A_S+A_E+A_N+A_W+A_roof;

V_house=A_E*8.3;        %Volume of the House [m3]   NOTE: That's not a flow!!
V_dot=1*V_house/3600;     %flow of external air = 1 renovations/hour [m3/s]


[Bi_wall,Fo_wall,R_wall,n_wall]=FourierWall(DELTAt,DELTAx,h_0_wall);
[Bi_roof,Fo_roof,R_roof,n_roof]=FourierRoof(DELTAt,DELTAx,h_0_roof);



%_____________________________________ TEMP ON EXTERNAL WALLS

%Equivalent temperature on the wall, by modifying the temperature of air with
the solar radiation and
%the convection heat transfer from the wind


T_eq_S=Ta;
T_eq_E=Ta;
T_eq_N=Ta;
T_eq_W=Ta;
T_eq_roof=Ta;


%_____________________________________ INITIAL CONDITIONS


%STATIONARY STATE

%an STATIONARY STATE is created just before the dynamic simulation, to get the
%initial conditions
```

```
T_inicial=T_eq_S(1);
T_design_st=T_design;

%in this function is considered that the temperatures profile inside the
%wall is the same for the walls and for the roof. The purpose of this
%function is to get the initial conditions

[T_node_st_wall,T_node_st_roof,q_stationary_wall]=Tempsurf(R_wall,R_roof,T_desig
n_st,T_inicial,A_S,A_roof,h_0_wall,h_0_roof,n_wall,n_roof);


%_____________________________________PREALLOCATING OF VARIABLES


T_node_S(1,:)=T_node_st_wall;            %temperatures inside each element
T_node_E(1,:)=T_node_st_wall;            %temperatures inside each element
T_node_N(1,:)=T_node_st_wall;            %temperatures inside each element
T_node_W(1,:)=T_node_st_wall;            %temperatures inside each element
T_node_roof(1,:)=T_node_st_roof;         %temperatures inside each element

hAT_S=zeros(1,t);
hAT_E=zeros(1,t);
hAT_N=zeros(1,t);
hAT_W=zeros(1,t);
hAT_roof=zeros(1,t);

hAT_wall=zeros(1,t);

q_S=T_node_S(1,1)*ones(1,t);
q_E=T_node_E(1,1)*ones(1,t);
q_N=T_node_N(1,1)*ones(1,t);
q_W=T_node_W(1,1)*ones(1,t);
q_roof=T_node_roof(1,1)*ones(1,t);

%Loads
q_H=0*ones(1,t);
q_latent=zeros(1,t);
q_flow=zeros(1,t);
q_sun=zeros(1,t);
q_window=zeros(1,t);
q_wall=q_stationary_wall*ones(1,t);

p_sat_0=ones(1,t);      %[Pa]
pv_0=ones(1,t);         %[Pa]
w_0=ones(1,t);          %[kg water/kg dry air]
p_sat_a=ones(1,t);      %[Pa]
pv_a=ones(1,t);         %[Pa]
w_a=ones(1,t);          %[kg water/kg dry air]


%temperture inside the building 'without' heating installation
T_0=T_design*ones(1,t);
%T_0(1)=T_design(1);

%temperature inside the building 'with' heating installation on
T_0H=T_design*ones(1,t);
%T_0H(1)=T_design(1);

%variables for the controller
e=zeros(1,t-1);
I=ones(1,t-1);
```

```
D=zeros(1,t-1);


%_____________________________________ CONTROLLER

%parameters for the controller

K=1;
T_I=20;
T_d=1;

%_____________________________________ ITERATIONS

%   i=index of time
%   j=index of position on the wall : j=1      ---> internal surface of the wall
%                                     j=n_wall ---> external surface of the wall

tic;
for i=1:t-1

    %internal nodes
    for j=2:n_wall-1

        T_node_S(i+1,j)=Fo_wall(j)*(T_node_S(i,j-1)+T_node_S(i,j+1))+(1-
2*Fo_wall(j))*T_node_S(i,j);
        T_node_E(i+1,j)=Fo_wall(j)*(T_node_E(i,j-1)+T_node_E(i,j+1))+(1-
2*Fo_wall(j))*T_node_E(i,j);
        T_node_N(i+1,j)=Fo_wall(j)*(T_node_N(i,j-1)+T_node_N(i,j+1))+(1-
2*Fo_wall(j))*T_node_N(i,j);
        T_node_W(i+1,j)=Fo_wall(j)*(T_node_W(i,j-1)+T_node_W(i,j+1))+(1-
2*Fo_wall(j))*T_node_W(i,j);

    end

    for j=2:n_roof-1

        T_node_roof(i+1,j)=Fo_roof(j)*(T_node_roof(i,j-1)+T_node_roof(i,j+1))
+(1-2*Fo_roof(j))*T_node_roof(i,j);

    end

    %external nodes
    %temperatures on the first node = internal surface of the walls

    T_node_S(i+1,1)=2*Fo_wall(1)*(T_node_S(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_S(i,1);
    T_node_E(i+1,1)=2*Fo_wall(1)*(T_node_E(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_E(i,1);
    T_node_N(i+1,1)=2*Fo_wall(1)*(T_node_N(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_N(i,1);
    T_node_W(i+1,1)=2*Fo_wall(1)*(T_node_W(i,2)+Bi_wall*T_0(i))+(1-
2*Fo_wall(1)*(1+Bi_wall))*T_node_W(i,1);
    T_node_roof(i+1,1)=2*Fo_roof(1)*(T_node_roof(i,1)+Bi_roof*T_0(i))+(1-
2*Fo_roof(1)*(1+Bi_roof))*T_node_roof(i,1);


    %Temperatures on the last node = external surface of the wall

    T_node_S(i+1,n_wall)=T_eq_S(i+1);
    T_node_E(i+1,n_wall)=T_eq_E(i+1);
    T_node_N(i+1,n_wall)=T_eq_N(i+1);
```

```
    T_node_W(i+1,n_wall)=T_eq_W(i+1);
    T_node_roof(i+1,n_roof)=T_eq_roof(i+1);


    %Latent heat loads

     q_latent=zeros(1,t);

    %Loads due ventilation flow

    q_flow=zeros(1,t);

    %Loads due to windows

    q_solar=zeros(1,t);

    %Loads trought walls

    q_S(i+1)=h_0_wall*A_S*(T_node_S(i+1,1)-T_0(i));
    q_N(i+1)=h_0_wall*A_N*(T_node_N(i+1,1)-T_0(i));
    q_E(i+1)=h_0_wall*A_E*(T_node_E(i+1,1)-T_0(i));
    q_W(i+1)=h_0_wall*A_W*(T_node_W(i+1,1)-T_0(i));
    q_roof(i+1)=h_0_roof*A_roof*(T_node_roof(i+1,1)-T_0(i));

    q_wall=q_S(i+1)+q_E(i+1)+q_N(i+1)+q_W(i+1)+q_roof(i+1);



    %Temperature of the air inside the building

    hAT_S(i+1)=h_0_wall*A_S*(T_node_S(i+1,1));
    hAT_N(i+1)=h_0_wall*A_N*(T_node_N(i+1,1));
    hAT_E(i+1)=h_0_wall*A_E*(T_node_E(i+1,1));
    hAT_W(i+1)=h_0_wall*A_W*(T_node_W(i+1,1));
    hAT_roof(i+1)=h_0_roof*A_roof*(T_node_roof(i+1,1));

    hAT_wall(i+1)=hAT_S(i+1)+hAT_E(i+1)+hAT_N(i+1)+hAT_W(i+1)+hAT_roof(i+1);


    %THERMAL BALANCE without heating
    T_0(i+1)=(q_flow(i+1)+hAT_wall(i+1)+q_solar(i+1)+q_latent(i+1))/...
        (V_dot*rho_air*cp_air+h_0_wall*(A_S+A_N+A_W+A_E)+h_0_roof*A_roof);


   %Controller

    e(i+1)=T_design-T_0H(i);
    E=cumsum(e);
    I(i+1)=1/T_I*cumsum(E(i));
    D(i+1)=T_d*(e(i+1)-e(i))/DELTAt;

%__ proportional controller
    %q_H(i+1)=V_house/DELTAt*cp_air*rho_air*(T_design(i)-T_0H(i))*K;

%__ PI controller
    q_H(i+1)=V_house/DELTAt*cp_air*rho_air*K*( (T_design-T_0H(i)) + I(i+1));

%__ PID controller
    %q_H(i+1)=V_house/DELTAt*cp_air*rho_air*K*( (T_design(i+1)-T_0H(i))
+I(i+1)+D(i+1));
```

```
%_____________ Thermal Balance with heating

    %THERMAL BALANCE

    T_0H(i+1)=(q_flow(i+1)+hAT_wall(i+1)+q_solar(i+1)+q_latent(i+1)+q_H(i+1))/..
.                    %numerador
        (V_dot*cp_air*rho_air+h_0_wall*(A_S+A_N+A_W+A_E)+h_0_roof*A_roof);
%denominador

end

%_____________________________________FIGURES


figure(1)

plot(Ta,'k','LineWidth',1.5)
hold on
plot(T_0,':b','LineWidth',1.5)
hold on
plot(T_0H,'k','LineWidth',1)
axis([0,3000,0,1.5])
xlabel('Time (s)','FontSize',12)
ylabel('Temperature (°C)','FontSize',12)
legend('T_{amb}','T_{0}','T_{0H}','location','EastOutside')
```