

Photovoltaic solar installation

Hospital del Mar

Barcelona

presented by

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1. General information

This inform presents the project for the installation of a photovoltaic solar system in the Hospital del Mar in Barcelona (Spain). The roof of the hospital offers a large space for installing photovoltaic panels with the optimum orientation and very little shading problems. The front façade of the building is made of glass, which can be replaced by glass-glass modules which will provide the hospital with a distinctive feature.

The Hospital del Mar is located by the sea front to the north of the city center, where The Health House opened in the XVI century to treat people coming from overseas. In 1973 an agreement was signed with the Universitat Autònoma de Barcelona, and the Hospital del Mar became a health-university center. It was refurbished for the Olympics in 1992, and nowadays offers all medical and operating services, giving service to 260,000 people from the districts of Ciutat Vella and Poble Nou.

1.1. Client profile

The Hospital del Mar is run by the Institut Municipal d'Assistència Sanitària (IMAS, Health Assistance Local Institute of Barcelona), a public institution of the City Council which also runs other sanitary facilities in Barcelona. The Hospital del Mar is integrated in the Parc de Recerca Biomedica de Barcelona (Biomedical Research Center of Barcelona) together with other research centers as IMIM (Institut Municipal d'Investigació Mèdica), Fundació UPF (Department of Experimental and Health Science of the Universitat Pompeu Fabra), and CRG (Center for Genomic Regulation), which is currently under construction.

Barcelona City Council is very proactive in the development of Renewable Energy, launching programs for the installation of Solar-Thermal and Solar-Photovoltaic Systems in public and private buildings. In this line the IMAS has considered the possibility of installing a photovoltaic system in such an emblematic hospital as the Hospital del Mar. Visited by many people along the year, and located by the sea front, that many people use for a stroll, it can act as an educational example for spreading the concerns about energy consumption and generation among the general public. Not major construction works should be carried out since the building was completely refurbished a decade ago.

1.2. BIPV overview

Building Integrated Photovoltaic (BIPV) systems offer many advantages. As any other photovoltaic system generates electricity, which contributes to the reduction of demand and to meet peak-loads without extending the grid. PV solar generation is very reliable and offers security and independence of supply. In particular, building integrated systems do not require extra space for the installation, as they are installed on façades, roofs, glass roofs, canopies, etc. Moreover, photovoltaic solar panels replace construction elements and insulation materials, reducing the cost of the initial investment, and definitively reduces running costs for the building. Architecturally attractive modules are being designed for the BIPV industry, which makes it easier for customers to appeal the system. In the case of companies or public institutions it also

offers an image of green identity for the general public, very valuable from the point of view of public relations.

1.3. Climatic information

Barcelona with a latitude of $41^{\circ} 18' N$ and a longitude of $2^{\circ} 5' E$ is located on the north Mediterranean coast of Spain. As extracted from the data sheet in the end, the average temperature along the year do not go below $9^{\circ}C$, and the minimum temperature is $4.4^{\circ}C$. The number of days with thunderstorms is low ($DT = 22$), and days with fog (DF) are 10. There is an average of 73 clear days (DD) per year and 2524 hours of sun (I) per year. These data is encouraging for starting the design project.

2. Building information

The Hospital del Mar is located by the sea front, and its front façade with the main entrance is oriented $65^{\circ}E$, while the rest of the building, with a rib structure, has an orientation of $52^{\circ}E$ (see figs. 1 and 2). This is a large building of about $14,000m^2$. Most of the surface is covered by facilities in a two stories construction, and to the north there is a tower building of 11 stories which allocates operating rooms and some other hospital facilities. The hospital offers any major health service, emergency rooms, operating rooms, or specialized treatments. This kind of specialized treatments attracts many patients along the year.

As explained before the Hospital del Mar is integrated in a Research Center, and the surrounding buildings do not produce any shading. The only shading comes from the own north tower of the hospital, which would partially shade the north rib structure of the building during summer time until well entered the morning. To the south there is a park with an old lighthouse tower, which could shade the building at the end of the day.



Fig. 1: Simulation of the Biomedical Research Center of Barcelona. The Hospital del Mar is the building located in the foreground with rib structure.

3. System characteristics

We will install a grid-connected PV system of 385.4 kWp. Mounted on the large roof area of the hospital 10 arrays of 32 kWp each will be installed, with a south orientation and a tilt angle of 30°. Two more arrays of 32.7 kWp will be mounted on the façade made of custom glass-glass modules. Each array will feed an inverter of 30kW, adding to 12 inverters.

3.1. Location of the modules

Fig. 2 shows the proposed layout for the roof array and also a view of the front façade is given. We divide the hospital in three blocks:

- 1) The front block (180m x 24m), where the entrance is located,
- 2) the following parallel structure (80m x 30m), and
- 3) the rib structure, with six parallel sections (92m x 10m).

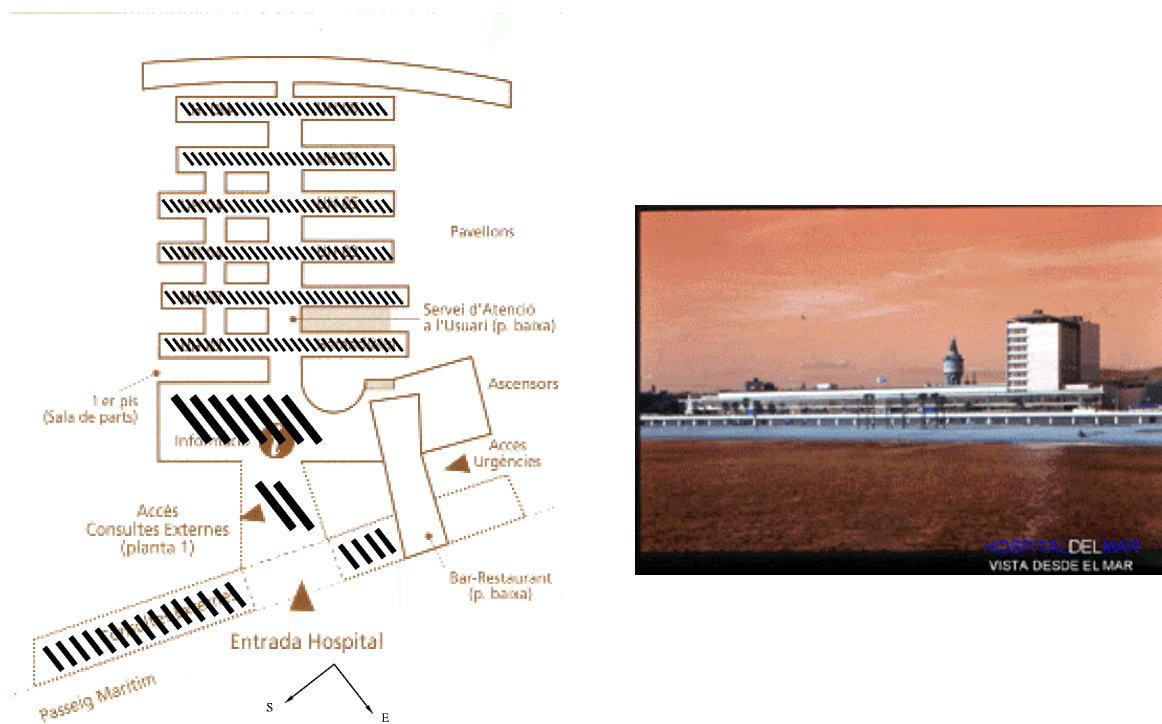


Fig. 2: Layout of the arrays mounted on the roof. The south and east orientations are indicated at the bottom of the picture. On the right there is a view of the glass front façade.

The modules mounted on the roof are supposed not to be seen by the peasants. To this purpose we will install the modules (1.6m x 0.8m) in a landscape orientation at a tilt angle of 30°, such that the whole structure is shorter than half a meter. Behind the main block of the hospital there is a garden, with distances to the main block of about 80m. This was also taken into account for determining the location and size of the array.

We should allow a distance between rows of modules of at least half a meter to avoid shading from one row of modules to the next. In addition to this minimum inter-space requirement, on the roof there are some roof-windows to light the building. With all this we can propose the installation of 2000 modules (1.6m x 0.8m) with the following distribution on the different blocks:

- 1) 50 rows x 10 modules = 500 modules,
- 2) 20 rows x 14 modules + 20 modules = 300 modules, and
- 3) 6 sections x 40 rows x 5 modules = 1200 modules.

The main façade has a length of 180m and it is two stories high, about 3m each. We will install 160 glass-glass custom modules (3m x 1.8m) which will cover 144m of the façade. The 36m of allowance is used for the front door, and some original distribution of the modules which could confer a particular characteristic to the façade.



Fig. 3: View of the glass façade from the interior of the hospital at ground and first level. This pictures show the areas the patients attending specialized treatments are visited by doctors.

3.2. Stringing of the system

3.2.1. Roof arrays

For the roof arrays we use modules manufactured by Shell Solar of 160Wp (SQ-160-C, with 72 mono-crystalline silicon cells in series). From the product information sheet at the end we can take the main parameters (temperature coefficients are used to obtain the range of voltages):

Shell SQ-160-C	$P_{mpp} = 160 \text{ Wp}$
$I_{mpp} = 4.58 \text{ A}$	
$V_{mpp} = 35 \text{ V}$	$V_{mpp} (60^\circ\text{C}) = 29.2 \text{ V}$
$V_{oc} = 43.5 \text{ V}$	$V_{oc} (-10^\circ\text{C}) = 49.1 \text{ V}$
$I_{sc} = 4.9 \text{ A}$	$I_{sc} (60^\circ\text{C}) = 4.95 \text{ A}$

We install 10 arrays with 200 modules. Each array will have 20 strings in parallel with 10 modules in series per string, namely,

- 10 arrays x 20 parallel strings x 10 series modules,

which yields the following parameters for the array:

$$P_{mpp} = 32 \text{ kWp}$$

$$V_{range} = 292\text{-}491 \text{ V}$$

$$I_{max} = 99 \text{ A}$$

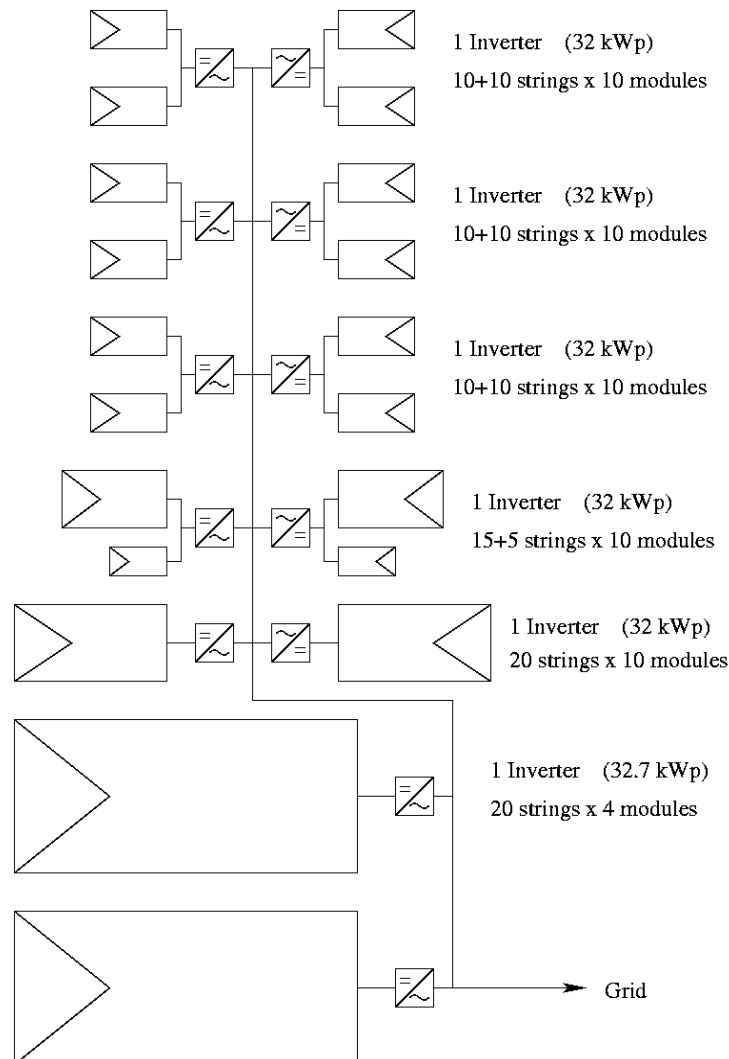


Fig. 4: Stringing of the PV system. Every string feeds an inverter of 30 kW. To obtain the required rating in the block 1 and 2, 5 strings of the block 1 are connected with the strings in block 2. The two large strings at the bottom correspond to the glass-glass modules.

Stringing the modules on the roof with different inverters on the right and on the left we try to minimize the effect that the shading of the north tower of the hospital will produce in the mornings.

3.2.2. Façade arrays

The two arrays on the façade are made of 160 custom glass-glass modules, using 192 Photowatt 5'' PV cells (12.55cm x 12.55cm) class A1 multi-crystalline silicon in series, with an efficiency of 13.5% and an output power of 2.13Wp. Stringing in series limits the current inside the module, avoid wiring losses.

We use a glass-glass laminate of 3 m x 1.8 m, with a distribution of the 192 cells such that there is an inch in between cells (this would eliminate problems with shading from the frame, if any). At half height a cell gap is left to allow the direct sight of the sea (fig. 5). The cells reduce the solar gain of the building. The transparency of the area covered with cells is 30%, and the transparency of the module as a whole is 44%. Figs. 3 and 5 give an idea of the appearance of the façade with PV glass-glass modules. We should eliminate the eaves and the palm trees from the sidewalk in order to eliminate sources of shading.

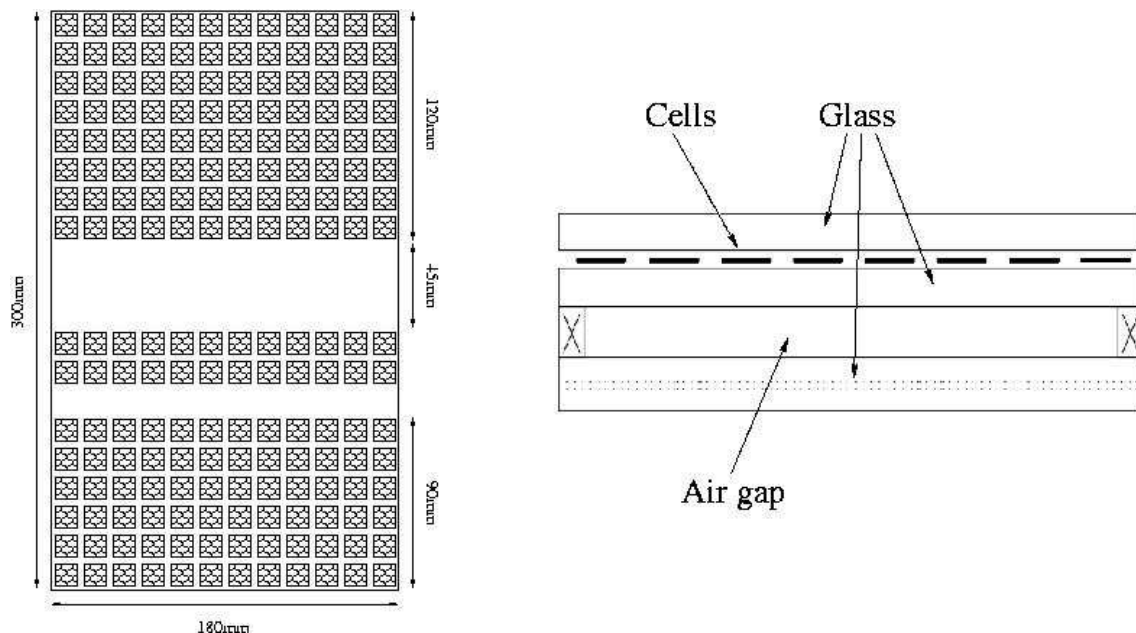


Fig. 5: Glass-glass laminate for the front façade. A transparent gap is left to have a sight of the sea. The glass laminate is done with an air gap to improve the isolation of the building.

Taking into account the information for the individual cells (ratings are given for individual cells, but for its use after lamination; see enclosed information at the end) the parameters for the modules are (temperature coefficients are used to obtain the range of voltage):

Costum Photowatt cells glass-glass module $P_{mpp} = 409 \text{ Wp}$

$I_{mpp} = 4.49 \text{ A}$	
$V_{mpp} = 91.2 \text{ V}$	$V_{mpp} (60^\circ\text{C}) = 76.6 \text{ V}$
$V_{oc} = 115 \text{ V}$	$V_{oc} (-10^\circ\text{C}) = 129,6 \text{ V}$
$I_{sc} = 4.93 \text{ A}$	$I_{sc} (60^\circ\text{C}) = 4.99 \text{ A}$

We install 2 arrays with 80 modules. Each array will have 20 strings in parallel with 4 modules in series per string, namely,

- 2 arrays x 20 parallel strings x 4 series modules,

which yields the following parameters for the array:

$$P_{mpp} = 32.7 \text{ kWp}$$

$$V_{range} = 306-518 \text{ V}$$

$$I_{max} = 99.8 \text{ A}$$

3.2.3. Inverters

We have 12 strings of power 32 kWp. A 10-15% derate of the inverter would be desirable for the roof-top mounted modules, while for the façade it would be better a 25-30% derated inverter. Finally we will use 12 inverters manufactured by ARTESA of 30kW (see specification at the end):

ARTESA ALTAIR/SOLEIL 30

$$P = 30 \text{ kW}$$

$$V_{range} = 200-600 \text{ V}$$

$$I_{max} = 100 \text{ A}$$

$$V_{nom} = 400 \text{ V}$$

$$I_{nom} = 43.4 \text{ A}$$

$$\eta = 94\%$$

All the arrays are within the tolerance values for voltage and current. The distribution of the arrays has been chosen symmetrically for the right and left sides (figs. 2 and 4) of the roof to minimize the shading effects that the north tower can have on the north part of the building. The existence of several inverters increases the reliability of the system, since they work independently. The volume of one inverter is 1.15 m^3 , and a total of 14 m^3 , which may be allocated altogether in a room of the block 2 near the tower.

4. Performance and output estimate

An estimate of the annual output is given in table 1. This table contains data for the average irradiation level in the plane of the modules, i.e. south orientation and 30° tilt for the roof-top modules and 65°E and vertical position for the façade.

The efficiency of the panels is 12.1% for the roof mounted and 7.57% for the glass-glass modules (even the transparent area of the module was considered to obtain this efficiency; the efficiency of the cells is 13.5%).

The annual output is 596 MWh/year if we assume an operation under STC, and then this is an upper estimate. The north tower of the hospital will shade the three north wings of the rib structure until 10am in June. We can estimate that a 30% of the array is shaded a 20% of the time, which amounts to a 5% loss of the output. In this case the output is also computed on the right columns of table 1, and it is 570 MWh/year.

We can assume a 5% of losses due to not working at STC. Moreover, losses in the cables can be estimated in a 1%, and the inverter maximum efficiency is 94%, which accumulates to 12% losses. The final estimate for the AC output is about **500MWh/year**. With this value of the annual yield, the **number of equivalent hours** working at the MPP under STC (385.4kWp) would be of the order of **1300 hours/year**.

We do not have values for the energy consumption of the hospital. Taking into account the mission of a hospital, where many critical applications are carried out, the energy consumption is not one of the major concerns. We could try to compare the output of the proposed PV system with the energy used for illumination or air-conditioning in non-critical areas of the hospital. In any case, from the global point of view, the energy production will be negligible compared to the needs of the hospital.

Location	Barcelona Irradiation (kWh/m2)		Energy (kWh)			Energy (kWh)		
Latitude	41,3							
	Façade Roof		Façade	Roof	TOTAL	Façade	Roof	TOTAL
Azimuth	65 E	0						
Tilt Angle	90	30						
						Shading 0,95		
Power (kWp)			65,44	320	385,44	65,44	320	385
Surface (m2)			864	2640,62		864	2640,62	
Efficiency			7,57%	12,10%		7,57%	12,10%	
January	54	85	3531,859	27158,78	30690,64	3531,86	25800,84	29332
February	62	95	4055,098	30353,93	34409,02	4055,10	28836,23	32891
March	89	142	5821,027	45371,13	51192,16	5821,03	43102,58	48923
April	94	154	6148,051	49205,31	55353,36	6148,05	46745,05	52893
May	104	172	6802,099	54956,58	61758,68	6802,10	52208,75	59010
June	107	182	6998,314	58151,73	65150,05	6998,31	55244,15	62242
July	116	197	7586,957	62944,46	70531,42	7586,96	59797,24	67384
August	112	185	7325,338	59110,28	66435,62	7325,34	56154,76	63480
September	96	157	6278,861	50163,86	56442,72	6278,86	47655,67	53934
October	78	125	5101,574	39939,38	45040,95	5101,57	37942,41	43043
November	56	90	3662,669	28756,35	32419,02	3662,67	27318,53	30981
December	46	77	3008,621	24602,66	27611,28	3008,62	23372,52	26381
TOTAL	1014	1659	66320,47	530075,4	596395,9	66320,47	503571,65	569892
Rating (kWh/kWp)	1547,312							

Table 1: Calculation of the DC output of the array considering that it operates at MPP under STC, and (i) there is no shading, or (ii) considering the shading produced by the north tower.