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J.M. Adell, Architecte depuis 1979, a développé son enseignement et sa recherche dans l'UAP depuis 1980. Il obtient son doctorat en 1984 sous le thème "l'architecture du XIXe siècle en brique: Technique et forme», il a été jugé professeur exceptionnel "cum laude", a publié dans plusieurs revues et journaux internationaux et a gagné des récompenses de l'entreprise Fondation de l'Université, l'Ordre des Architectes de Madrid et l'Association des fabricants de briques, Hispalyt. Il est actuellement professeur des systèmes de construction de l'université de Madrid et directeur de "S.XXI AIA Architecture" qui développe des techniques brevetés qui sont commercialisés sous le nom de «système de maçonnerie intégré (UPS). En 2000, il a présidé la 12e Conférence internationale des briques et blocs (12 IBMAC) au Palais des Congrès de la Castellana à Madrid.

New PV Self-Orientating Roof Based on a Balanced Movement

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***Abstract*— The purpose of the project is to develop a new PV solar roof which is capable of orienting itself towards the Sun in each moment of the day, without projecting over the foundations of the building. This is achieved by a balanced movement over its centre of gravity along with controlled motorized cable technologies. The approach of the design is focused on adapting the structure and movement of industrial solar trackers to integrate them in construction projects. Consequently, the scientific invention is the internationally registered patent presented by the Polytechnic University of Madrid as part of its Solar Decathlon 2009 Competition R&D Programme. The results of these innovations will be integrated for the first time with the housing prototype, The B&W House, competing in Washington in October of this year. However, the eventual commercial development is considered a priority. The practical implementation of this PV roof system in the global market will set a milestone for sustainable prefabricated residences and other buildings.**

***Keywords*— B&W House, Solar roof, PV Orientation**

I. THE B&W HOUSE

The purpose of this article is to graphically present the profit potential of a balanced, auto orienting rooftop and its benefits in relation to a fixed roof.

First of all, we'll introduce you to some of the more important aspects of the house:

"THE B&W HOUSE" is a single-story, square-shaped house with a lightly inclined rooftop, which can be subdivided into three parts in order to simplify transport and assembly on location. On top of these three cubic-shaped modules with optimized energy usage, lies an inverted pyramid which holds up a solar panel capable of following the orientation of the Sun at every moment up until it returns to a horizontal position at night, focusing its attention on the stars.

The latest solar panel technologies have been implemented in the roof and the facades of "THE B&W HOUSE," developed in Madrid, and presented in Washington in 2009. These panels represent a technological leap with their ability to optimize solar architecture, on a global scale, not just in the context of the American Solar Decathlon. Its energy control systems, directly related to solar capture, as well as their special energy control characteristics have been adapted to this particular building, and allow you to create an interior setting of your choice, regardless of the time of day or the situation in the external environment.

The prototype works to unify the rationality of a design based around bioclimatic criteria, while playing with elements of its environment and technological innovations that are accessible to us in the modern age. The goal of this house is to create a design that minimizes environmental impact while optimizing the comfort and hospitality of its interior.

To gain the maximum solar energy output from the PVsys, we have the additional advantage of a balancing and moveable roof, and this particular innovative installation allows us to gain an additional 11% of energy production at the minimal cost of maintaining the mechanical system. This auto-orienting rooftop can produce up to 35% more energy than a traditional, fixed rooftop facing East or West

For the following study, we have simulated the different orientation positions of the roof and its relation to the solar facades, which will be explained further in this article.

These simulation techniques allow us to not only obtain results specific to the various configurations in real time, but also to differentiate between the production levels of solar energy by the auto-orienting rooftop on clear days, partially cloudy days, and cloudy days.

Fig. 1 : Solar roof in an exhibition.

First, it is important to say that the simulation performed using the new solar roof. It has been deduced that the southwest orientation of the house in the Mall in Washington is the most usable energetically speaking to carry out the contest in the month of October with the “Team Spain” House.

The patent development is intended for the creation of a new PV solar roof which is capable of orienting itself towards the Sun in each moment of the day, without projecting over the foundation of the building. This is achieved by a balanced movement over its centre of gravity along with a set of controlled motorized cables. The design approach is focused on adapting the structure and movement of industrial solar trackers in order to integrate them into building construction.

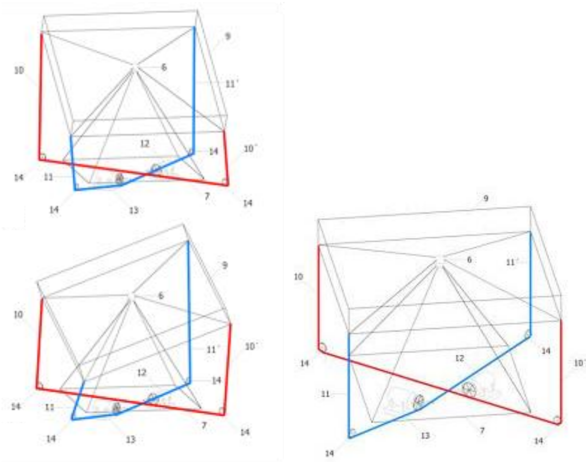

Fig. 2. Patent movements.

II. THE PV DESIGN

The first input in our project was the Meteornorm climatic base from the United States, and more specifically the figures from the City of Washington, the place where the Solar Decathlon 2009 will be held. We’ve done an analysis of the various configuration options of a 8x8m rooftop, and have opted for the modules made by SunPower, a leader in the market for its energy efficiency, at 17% efficiency levels in every cell.

These modules were chosen in black, so that they could provide the house with a darker colour, not only to absorb more energy by attracting the Sun, but also by giving the house an added design detail that goes with the Black&White theme of the house.

After reviewing different module configurations, we’ve chosen a 6 series installation. Given the system requirements for a monophasic installation, we chose three SunPower 3300 nominal power inverters, but in order to obtain even better energy use, one could change the installation to a 3800 Wnominal inverter. This allows you to set up two series per inverter for the 3300 inverters: two parallel series in 8 modules per series. For the 3800, you have two series in parallel with 9 modules.

The total power potentials are (3520+3960+3520) 11,000 Wp with the black SunPower 220 modules.

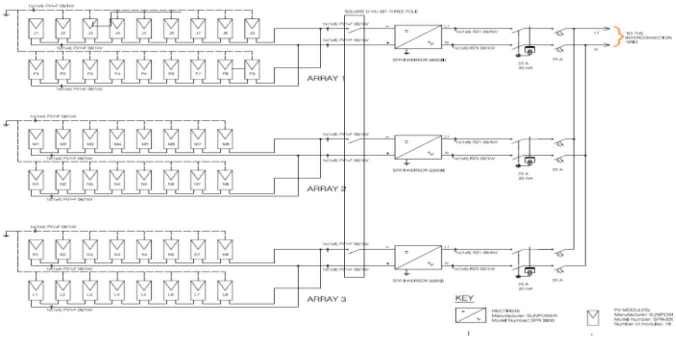

Fig. 3 Rooftop three-line diagram.

III. CONSTRUCTIONS

For the solar panels to adjust into a position best suited for solar capture, and to secure themselves into place during strong winds, it is important to have an automation system and small, resistant and powerful converters.

This system has an adequate automated movement system thanks to the PLC AC500, based on the modular concept included in a CPU, modules of communication and an Entrance/Exit bus. It increases the automation capacities and helps move the facades. The high resolution solar algorithms implemented directly, into the software guarantee that the solar panels will be aligned properly. This particular function allows for the easy adjustment of the panels and facilitates the balancing movements.

This installation has a modern system of remote controls, which allows one to follow changes from afar (by MODEM, telephone) and gain detailed information about the solar production occurring in the installations in real time, allowing one to significantly increase solar capture capabilities.

With regard to the necessary maintenance of the whole mechanical installation system, we've noticed that there is an occasional need for the maintenance of two motors (0.25 kW), which balance the rooftop, and one motor of 0.75 kW, which moves the security joints in case of severe winds.

IV. THE KEY

In this project is very important to maxime the solar production. For this we have to order the modules. This ordering categorizes the modules by series and speed of their inverters that can be found in the gooseneck (see placement of inverters). The slowest ones with the lowest peak power potential are shown in the following diagram.

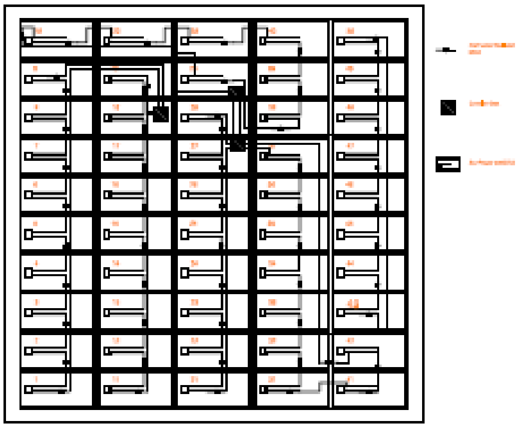

Fig. 4. Roof Series

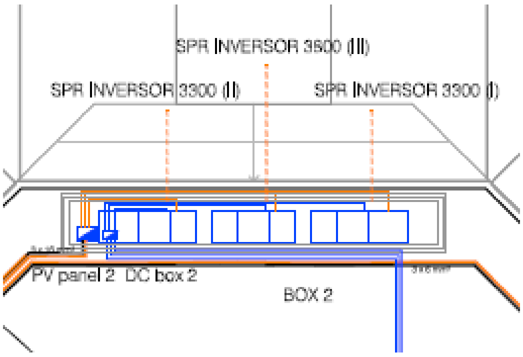

Fig. 5: Roof inverter location.

V. EFFICIENCIES

These modules have been analyzed using test-data measuring their intensity, voltage and energy potential. Analyzing the small voltage and intensity dispersion of the 50 modules, we've chosen to classify them by energy potential (Wp). The following table shows some of the figures from the analyses of these panels, put in order.

TABLE I
CLASSIFIED SUNPOWER MODULES.

Serial_Number	Power	Voc	Imp	Isc
F10P01176315	221.4	48.9	5.4	5.8
F10P01176396	221.7	49	5.4	5.8
F10P01176404	221.8	48.9	5.4	5.8
F10P01176303	221.9	48.9	5.4	5.8
F10P01175769	222	48.8	5.4	5.8
F10P01176401	222	48.9	5.3	5.8
F10P01176087	222	48.9	5.4	5.8
F10P01176302	222.2	48.8	5.4	5.8
F10P01175720	222.2	48.9	5.4	5.8
F10P01175772	222.3	48.8	5.4	5.8
F10P01176301	222.4	48.8	5.3	5.8

For the purposes of the competition and the requirements of its organizer, NREL, we are unable to use simple fuses like the ones used in Spain for the continuous running water circuit; we've exchanged them with continuous running water sections, Square D HU361, which allow a manual disconnection from the module series.

VI. Solar Production

In this section, we will show you the calculations of monthly production to illustrate estimates for this current Solar Installation.

One must keep in mind the solar irradiation affecting the panels, the climate of the United States, as well as the exterior temperature during the installation setup. The analysis has been done at a 15º angle, with a fixed simulation, and another with the moveable rooftop.

Table 2
Roof Production

	P, kWh	
Month	**Fixed Roof,**	**Roof**
January	838	848
Febrary	892	1003
March	1325	1377
April	1492	1599
May	1665	1849
June	1683	1881
July	1666	1842
August	1557	1689
September	1372	1456
October	1171	1212
November	794	802
December	690	689
Year	15145	16247

A. *Grid-Connected System: Simulation parameters*

- Project : SD09
- Geographical Site Washington Country USA
- Situation Latitude 39.1°N and Longitude 76.5°W
- Time defined as Legal Time
- Time zone UT+5 Altitude 5 m
- Albedo 0.20
- Meteo data : Washington D.C. US, Meteonorm SYN File

B. *Simulation parameters*

- Collector Plane Orientation Tilt = 15° and Azimuth = 0°
- Horizon Free Horizon
- Near Shadings No Shadings
- PV Array Characteristics
- PV module Si-mono Model SPR-220-WHT
- Manufacturer SunPower
- Number of PV modules In series 8 and 9 modules In parallel 6 strings
- Total number of PV modules Nb. modules 50 Unit Nom. Power 220 Wp
- Array global power Nominal (STC) 11 kWp At operating cond. 10 kWp (50°C)
- Array operating characteristics (50°C) U mpp 363 V I m pp 28 A
- Total area Module area 62.2 m²

C. *PV Array Loss Factors*

- Heat Loss Factor ko (const) 29.0 W/m²K
- kv (wind) 0.0 W/m²K for 0 m/s
- Nominal Oper. Coll. Temp. (800 W/m², Tamb=20°C, wind 1 m/s) NOCT 45 °C
- Wiring Ohmic Loss Global array res. 422.3 mOhm Loss Fraction 3.0 % at STC
- Serie Diode Loss Voltage Drop 0.7 V
- Loss Fraction 0.2 % at STC
- Module Quality Loss Loss Fraction 3.0 %
- Module Mismatch Losses Loss Fraction 2.0 % at MPP
- Incidence effect, ASHRAE

D. *System Parameter*

- System type Grid-Connected System
- Inverter Model: 2SPR3300 and SPR33800
- Manufacturer Power One
- Inverter Characteristics Operating Voltage 200-850 V Unit Nom. Power 10 kW AC
- User's needs : Unlimited load (grid)

We have calculated the solar production of the panels most adequate for this kind of sustainable building and the design of The B&W House. Given the importance of installation quality, we've found that the panels give us an 11% advantage over conventional fixed installation systems. The results are the following:

1. *Main system parameters System type Grid-Connected*
   PV Field Orientation tilt 15° azimuth -120° to 120º
   PV modules Model SPR-220-WHT Pnom 220 Wp
   PV Array Nb. of modules 50 Pnom total 11 kWp
   Inverter Model PVI-10.0-OUTD-S-IT Pnom 10 kW ac
   User's needs unlimited load (grid)

1. *Main simulation results*
   System Production : Produced Energy 16.24 MWh/year Specific 1345 kWh/kWp/year
   Performance Ratio PR 79.8 %

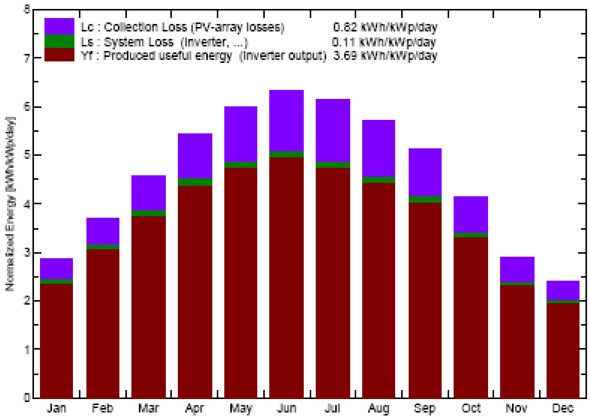

Fig. 6. Normalized production (per installed kWp : Nominal 11kWp

Figure 6 shows the monthly energy production of our auto-orienting rooftop. Here you can see the total production and total losses due to temperature, inverters, and other electric losses.

The following figure shows monthly changes in the Performance Ratio of the installations:

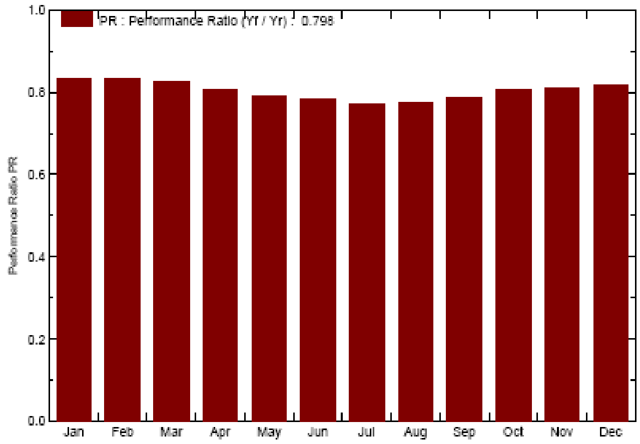

Fig. 7 Performance ration

In the table 3, we are able to see those parameters quantified. Additionally, we've contrasted these figures with those calculated in the Spanish city of Herencia (Royal City) where the house was constructed, to show the preciseness of our simulation.

V. Application

One of the biggest advantages of this type of roof is its excellent quality-to-price ratio in relation to a conventional tracking mechanism.

Not only is there minimal maintenance, but there is also a minimal cost, which makes this roof a bargain with respect to traditional fixed solar roofs present in the market.

TABLE 3

MONTHLY SOLAR PRODUCTION ROOF. DIFERENCE BETWEEN FIXED ROOF AND TILTING SELF-ORIENTATING ROOF.

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
Enero	67.2	2.06	93.4	89.9	887	848	15.28	14.61
Febrero	84.9	4.12	110.2	106.6	1048	1003	15.29	14.63
Marzo	125.3	7.59	152.7	148.0	1439	1377	15.15	14.50
Abril	152.8	13.25	180.9	175.9	1672	1599	14.86	14.21
Mayo	182.9	18.39	212.7	207.1	1934	1849	14.62	13.98
Junio	190.7	22.66	219.4	213.5	1966	1881	14.41	13.78
Julio	189.1	25.43	217.7	212.0	1926	1842	14.22	13.60
Agosto	170.3	25.00	199.1	193.7	1766	1689	14.26	13.64
Septiembre	138.2	20.89	169.5	165.0	1523	1456	14.45	13.81
Octubre	107.1	14.46	137.9	133.6	1266	1212	14.76	14.12
Noviembre	69.0	9.07	90.9	87.6	839	802	14.83	14.18
Diciembre	56.5	4.10	77.4	74.3	721	689	14.98	14.32
Año	1534.0	13.97	1861.7	1807.2	16987	16246	14.67	14.03

Legends:
- GlobHor: Horizontal global irradiation
- T Amb: Ambient Temperature
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- EOutInv: Available Energy at Inverter Output
- EffArrR: Effic. Eout array / rough area
- EffSysR: Effic. Eout system / rough area

This installation provides a 10.5% increase in production when oriented at a 15º angle and in comparison to traditional models, as can be observed in the following table:

TABLE 4
PRODUCTION DIFFERENCE BETWEEN A FIXED AND A MOVED ROOF.

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
Enero	67.2	2.06	93.4	89.9	887	848	15.28	14.61
Febrero	84.9	4.12	110.2	106.6	1048	1003	15.29	14.63
Marzo	125.3	7.59	152.7	148.0	1439	1377	15.15	14.50
Abril	152.8	13.25	180.9	175.9	1672	1599	14.86	14.21
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Julio	189.1	25.43	217.7	212.0	1926	1842	14.22	13.60
Agosto	170.3	25.00	199.1	193.7	1766	1689	14.26	13.64
Septiembre	138.2	20.89	169.5	165.0	1523	1456	14.45	13.81
Octubre	107.1	14.46	137.9	133.6	1266	1212	14.76	14.12
Noviembre	69.0	9.07	90.9	87.6	839	802	14.83	14.18
Diciembre	56.5	4.10	77.4	74.3	721	689	14.98	14.32
Año	1534.0	13.97	1861.7	1807.2	16987	16246	14.67	14.03

If we add the cost of construction to these tables, we've achieved a 30% decrease in cost when compared to the trackers that currently exist in the market (ADES, EXAUNE), and its maintenance is an additional 10-20% less than that of traditional models, which shows that our solar tracking roof provides an excellent service.

This installation is specially connected to the electric power grid, a system which provides a bidirectional service for those living in the house, as you can inject energy into the electric power grid and also consume energy from it.
To estimate the energy balance of the installation, we've simulated solar production for clear, cloudy, and partially cloudy days, and have come up with the following analysis, which also includes the Solar Decathlon competition days.
According to this table, the average daily production in the month of October (when the Solar Decathlon 2009 competition is held) can oscillate between 28.06 and 53.18 kWh daily. These figures provide an estimate of daily energy production and consumption and the remaining balance.

TABLE V
DAILY PRODUCTION

Days	kWh Roof	kWh House	Euros*
A day	44.51	53.00	18.02
Day October	39.10	48.13	16.36
Day 8	27.77	34.18	11.62
Day 9	28.24	34.76	11.82
Day 10	38.94	47.93	16.30
Day 11	38.49	47.38	16.11
Day 12	49.49	60.92	20.71
Day 13	48.55	59.76	20.32
Day 14	31.64	38.95	13.24
Day 15	61.49	75.69	25.74
Day 16	28.18	34.69	11.79
Middle day	39.20	48.25	16.41

These estimates can be used to calculate the difference produced in the grid thanks to bigger installations. These daily figures can help one estimate how solar energy production can affect the grid as a whole.
At this point, we've been able to show the excellent versatility of this installation, not only with regard to its use in the housing market, but also in the various other applications in the solar energy market.

Photovoltaics represent an ideal opportunity for towns and cities as they have a high concentration of potential PV sites with heavy energy demands. At the same time, the physical infrastructure can support localized electricity generation. It is estimated that installing PVs on suitable façades and roofs could meet up to 25% of the total energy demands. The biggest potential for PV is as systems embedded in buildings. Whatever the type of PV module, the potential for exploitation of building integrated photovoltaic (BIPV) installations depends primarily on the available solar irradiation. For demonstration projects recently completed, planned or speculative, shading issues were largely avoided by choosing open sites with minimal nearby obstructions.

However, in the medium to long-term, BIPV in dense urban environments will need to be considered since this is where the majority of energy use takes place. The wider adoption of BIPV will depend on the demonstration of its economic viability. Currently, PV devices are based on silicon in various formulations, but new materials and processes of PV fabrication are being investigated to obtain more efficient and accessible products.

9.2 Market

A possible application of these technologies is in solar gardens, which could form a solar ring (a ring with all the transformers and inverters) in an urban housing development.

In this way, you will be building something that is similar to a solar garden, but will be providing additional value to the housing development and making greater use of its outdoor spaces.

Refurbishment is another alternative based on the implementation of the solar tracking roof on existing buildings with adequate conditions for its incorporation. This option upgrades buildings to reach a higher level of sustainability through energy self-sufficiency.

VI. CONCLUSION

In addition to the financial savings that are the by product of using the new PV self-orientating roof, The B&W House produces a total of 16327 kWh, substituting the massive amounts of traditional energy use.
The efficiency of a moveable tracking roof can produce up to 33% more energy production and this allows us to decrease the environmental footprint by cutting greenhouse gas emissions, which cause acid rain, among other things.

One of these installations can create up to 5.9 times the typical energy usage of a Spanish house (3300 kWh annually), which indicates that this housing development could provide energy for neighbouring areas that do not use this solar potential.