

**SPANISH PARTICIPATION IN THE “SOLAR DECATHLON 2005” COMPETITION:
NEW PROPOSALS FOR ZERO-ENERGY HOUSES**

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ABSTRACT: The Polytechnical University of Madrid will be representing Europe in the “Solar Decathlon 2005” competition, a solar challenge that will bring together 18 universities and colleges worldwide for the design, construction and demonstration of the most livable and energy efficient solar powered homes. UPM’s proposal, called “magic BOX”, is an example of “active bioclimatic architecture” where tradition and modern technologies (especially Photovoltaics) merge towards meeting the objectives of quality of life, exploitation of natural resources and responsible energy use.

Keywords: Building Integration, Education and Training, Stand-alone PV Systems

1 INTRODUCTION

In the fall of 2005 the Universidad Politécnica de Madrid (UPM) will be representing Europe in the “Solar Decathlon” competition, promoted by the U.S. Department of Energy and its National Renewable Energy Laboratory [1,2]. The event is a truly “solar adventure” for today’s students —tomorrow’s engineers, architects, homeowners...— on the design, construction and demonstration of energy sufficient solar-powered houses. After almost two years of intense work, 18 teams representing universities and colleges will test their prototypes during one week (7-15 October) in Washington D.C., in 10 contests encompassing all the ways we use energy in our daily lives: architecture, livability, comfort, energy performance and management, transportation, communications.

This paper describes the main features of “magic BOX”, UPM’s zero-energy solar house proposal that represents, as the well-known toy, a dwelling open to surprise, movement, continuous exploration and enjoyment. Full of Mediterranean and purely Spanish spirit, the house is set out to be bioclimatic to the highest degree in the relation between climate and life, both in the natural and man-made environment. To this purpose, versatility, layout consistency, and easy use have been emphasized, as well as a particular relation between the house and its environment. The paper also describes the educational experience of multidisciplinary content that has made possible “magic BOX”.

2 “MAGIC BOX” DESCRIPTION

2.1 Design philosophy

The UPM Team has understood the “Solar Decathlon” competition as a comprehensive challenge in terms of choice of materials, use of resources, energy consumption and production of waste. Main design premises of UPM’s proposal are:

- “Active” Bioclimatic architecture: application of traditional strategies for winter and summertime, day and night, commonly used in Spanish vernacular architecture, implemented by means of new materials and systems [3].
- Attractive integration of solar technologies

(Photovoltaics and solar thermal) and maximum exploitation of their multifunctional possibilities, as energy production and construction elements.

- Rational use of elements such as porches, greenhouses, green roofs, eaves, louvers, sliding panels, and even a “folding” patio.

Quality of life is the main goal of “magic BOX” proposal. Far beyond the conditions imposed by the competition, the efficient use and the true enjoyment of the house and its surroundings have been the essential principles underlying the project. The building has been designed to establish a dialogue between interior and exterior, to the point that these fuse thanks to daylighting. Movement and usability are the house’s leading themes, with spaces that merge into each other or unfold, opening up a broad range of perceptual and functional possibilities. Rooms are conceived to avoid restricted and closed-off areas which could foster the occupant’s feeling of loneliness, yet, at the same time, they give the chance to perform individual tasks without bothering other users.

Figure 1 shows the house ground plan; footprint (horizontal projection of the house) is around 72 m² and maximum height 5.5 m.; the enclosed conditioned space is 55 m². Two sliding panels enable different house configurations, from fully open (with the panels completely folded inside their closets) to divisions in the east-west or north-south directions (see dotted lines showing the sliding panels possibilities). Figure 2 shows two pictures of the first “magic BOX” prototype: a general view with the living room in the unfolded position (left), and a view of the east façade with its roof framing and semitransparent PV-cover on top (right).

The house is equipped with the most common appliances on U.S. homes kitchen appliances (dishwasher, refrigerator-freezer, oven, cooktop), laundry facilities (washing machine, dryer), lighting and electronics (PC, TV/video). An electric car is also another load to power, reflecting the importance of transportation in energy use. Overall, the estimated average daily electrical consumption during the contest week is 20 kWh (65% for the house needs and the remaining for a complete car batteries charge).

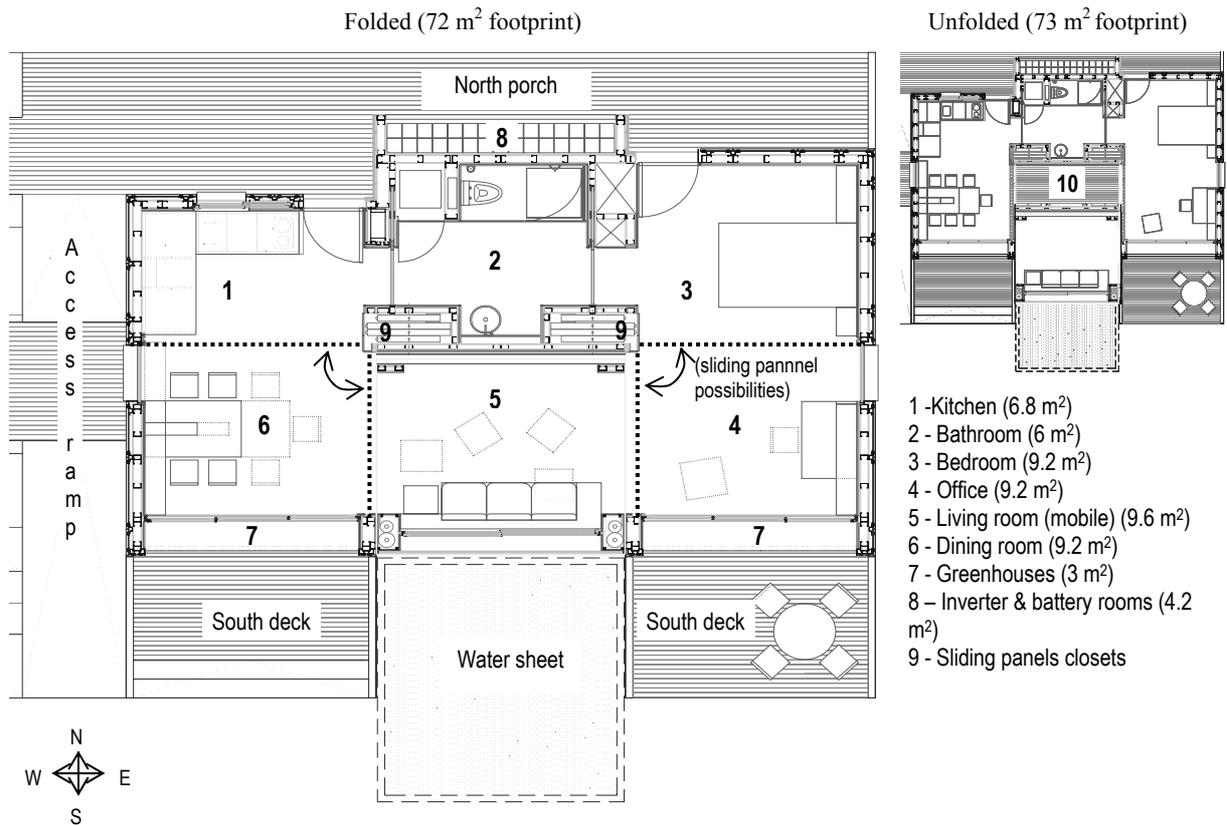


Figure 1: Plan of UPM's "magic BOX" Zero-energy house in its folded and unfolded positions



(a) General view

(b) West side



Figure 2: Pictures of "magic BOX" first prototype

2.2 Materials selection

From the very beginning, the approach selected by the team has been to address the concepts of sustainability and integration of architecture with renewable technologies. The requirements established by the competition (the houses must be built in one week) have conditioned, however, the selection of certain materials, specially those structural ones. In that sense, a galvanized-steel floor structure has been designed to make assembly and transportation easier. To this aim, the floor has been fragmented into 12 segments; oriented Strand Boards (OSBs) cover the whole floor surface, with wood-fiber insulating boards resting on the OSBs. The house structure is made up of a steel-framing system, which turns walls into load-bearing ones with OSBs fixed on each side and insulation layers between them.

The house is basically a "clay box". East and west sides are mainly covered with clay tiles (see Figure 2b) attached by steel clips to a secondary structure that leaves an air chamber, thus becoming ventilated façades. Small windows with 100% recycled-aluminum frames are strategically located to allow the user to get a beam of the morning/ sunset light, as well as to see the outside while working or having lunch. Glass is externally covered with woven wire cloth.

The north side combines clay with materials such as woven wire cloth and ventilated wooden cladding, made up of a mixture of sawdust and high-density polyethylene. The south side can be divided into 3 parts:

- Two correspond to greenhouses externally covered by glazing that can be fully opened. In the interior, glazing consists of three sliding panes; light wooden blinds hang on the inside of the greenhouses so as to control solar penetration when needed.
- The central part is the mobile volume, with a "PV greenhouse" facing south. A movable grate at the top serves to control air ventilation and warmth by an automated system. The other two sides are insulated by a double enclosure.

The roof is made up of a flat green roof over the mobile volume and house perimeter, and a sloped roof, whose framing consists of steel trusses with different shapes and horizontal joists. The sloped roof is partly covered with PV laminates and partly with evacuated tube solar collectors for hot water supply.

A technical floor consisting of grey granite-looking porcelain ceramic tiles has been selected for paving the indoor surface. Under this floor there are three layers of capsules containing phase-change-materials: they absorb a large amount of energy as latent heat at a constant phase transition temperature and are thus used for passive heat storage and temperature control [4] (here, 22-24 °C).

The principal concept to define the interior layout of "magic BOX" is the movement from darkness to light. For this reason, the main source of daylight is the south side. Diffuse light is provided at the upper area through the lateral surfaces within the roof framing covered by woven wire (see Figure 2b) and skylight glazing placed under the evacuated tube solar collectors.

2.3 Photovoltaic system design

As mentioned before, one of the project's design premises has been to achieve an attractive integration of solar technologies while making best use of their multifunctional possibilities.

In that sense, the UPM team wanted to break away

from the traditional image of a self-sufficient solar house, where the PV generator covers the whole roof and is placed under a single tilt angle. Close collaboration between the Architecture and Energy systems groups (see section 3) has resulted in the following:

- A PV cover with three different tilt angles (see Figure 2a) acting as a chimney to ease ventilation as well as filter solar radiation incident on the waterproofing coating placed beneath, thus protecting the house from undesirable thermal loads. The cover integrates 72 monocrystalline Silicon glass-semi-transparent Tedlar laminates of 2 different sizes (60 commercial 110 Wp of 635×1278 mm², and 12 custom 55 Wp of 635×661 mm² at the lower row; all made up of 4" solar cells). These are distributed in five independent PV arrays, each connected to a string-type inverter feeding an AC bus in an AC-coupled Stand-alone PV system configuration [5]. The laminates glass thickness is 6 mm. in order to comply with the competition structural requirements [6]. They are fixed to the roof structure by means of aluminum frames stuck to the back side with silicone (see Figure 2b), which are screwed to the horizontal joists, creating extremely flat surfaces. Nominal power, according to manufacturer's laminates data sheets, is 7.3 kWp.

- A PV green house, consisting of an 0.8 kWp PV curtain wall (3.4×2.1 m²) made up of five customized glass-glass laminates (6+6 mm. thickness, 5" solar cells) and internal double glazing, also connected to a string-inverter.

The "power rooms" are located in the center of the north side, the coolest part of the house. There are two closets operable from the outside, covered with woven wire cloth and separated by a steel-framing floor: the upper one shelters 8 power inverters (6 string-type and 2 bi-directional feeding the batteries and the AC bus, total nominal power 15 kVA), while batteries are locked in the lower space (stationary lead-acid type, total capacity of 1500 Ah. at 60 V nominal operation voltage).

The remaining electrical installation includes double isolation for DC cabling and protection measures against direct contact, ground fault, overcurrents, lightning and surges). The PV system is grounded at its DC negative conductor, to comply with the electrical regulations applicable (National Electrical Code, 2002).

The adopted configuration has the implicit advantages of modularity (each PV array operates at its maximum power point) and easy adaptability to different operation environments (grid-connection or other back-up generators). Another advantage arises from direct supply to loads by the PV strings, specially when Demand-Side-Management strategies are adopted by the home users. To that aim, the PV system incorporates a monitoring and supervision system consisting of [7]:

- A small meteorological station (irradiance, ambient temperature and relative humidity sensors) and a data acquisition system for the PV arrays and inverters operation data;
- An embedded Control PC where specifically designed software gives information about PV system performance (including performance indexes and failure detection), energy availability (production, storage) and management options for an optimal use of solar energy.

A testing campaign on the described PV system is being carried out in the first house prototype.

3 THE EDUCATIONAL EXPERIENCE

3.1 The team

Coordinated by the Institute of Solar Energy, the UPM team is a real example of multidisciplinary content, with institutions having proven experience in Education, R&D within the fields of Photovoltaics, Architecture and Domotics. At present, it comprises almost 40 students (60% of architecture and 40% of different engineering disciplines) and 8 coordinators. It has been a common wish of the team coordinators to involve the university community as much as possible. In this sense, a participative approach has been adopted, with initiatives such as an Ideas Competition on Bioclimatic zero-energy houses, and the interaction with regular courses given on Bioclimatic Architecture and Photovoltaics by some of the lecturers involved [8]. Of particular interest is the fact that 50% of all architecture students involved in the project had previous knowledge of Photovoltaics.

Three groups have been created, each one specializing in the main areas that define "magic BOX":

- Architecture: Bioclimatic design, materials selection, construction.
- Energy Systems: Electricity supply, monitoring and supervision; hot water supply.
- Domotics: domestic appliances, electrical and mechanical systems.

Besides these, other groups have been created for specific purposes (communications, logistics, sponsorship). All students have followed training courses of technical and non-technical content (such as English language, Safety and First Aid).

3.2 Project planning

Project planning has been structured according to five subsequent phases running for 25 months:

- 1) Conceptual design, market & regulations analysis, web-site setup (December.2003–April.2004). The creative process of the house took place, using a participative approach (Ideas Competition). Market surveys of appliances and components of the energy systems were carried out, as well as compilation and analysis of applicable regulations. The web-site structure of the project (www.solardecathlon.upm.es) was also designed and provided with initial contents.
- 2) Architectural design, schematic energy analysis (May–September.2004). Detailed design of the house, together with energy simulation tools that helped the process of identifying materials, components and systems for optimal energy behaviour.
- 3) House construction & equipment (October.2004–April.2005). Materials and equipment were purchased and stockpiled at UPM's facilities, where the first prototype has been built. Characterization of appliances and energy systems components (Quality control) has been also carried out.
- 4) Final house preparation and tests (May–July.2005). The house prototype was officially inaugurated on the 18 May, one week later a second one was presented at the Madrid Real State Fair, where it has been visited by thousands of visitors. These events

have enabled to identify the most critical issues associated to construction, commissioning & transportation, resulting in adjustments made on the 2nd prototype. Specific Tests are being carried out in both houses since then, mainly conducted by the students as a part of their training program. As a result, the "As-built" plans and documents will be produced, together with specific reports for the Solar Decathlon exhibition.

- 5) Solar Decathlon event and evaluation (August–December.2005). This phase begins with the shipment of the house materials, systems components and all necessary elements (tools, spare materials, components & appliances), followed by transportation of the UPM team to Washington D.C. and participation in the Solar Decathlon 2005 Event. After the competition, "magic BOX" will be shipped back to Spain, where it will be built and fully equipped in its final site at UPM's premises. A comprehensive evaluation and dissemination activities of the Solar Decathlon experience by the UPM are foreseen after this.

3.3 Research and Development prospects

The UPM team will maintain R&D activities on the concepts addressed by "magic BOX" until 2007, within a project co-financed by the Spanish National R&D Plan (reference BIA2004-05234). It is the aim of this project to analyze in detail the house energy behaviour, as well as to propose modifications to adapt its design and systems to different Spanish climate conditions, house typologies and environments (grid-connection with back up).

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