A Prototype from the Solar Decathlon Competition becomes an Educational Building in Sustainable Architecture

M. Carolina HERNÁNDEZ-MARTÍNEZ[1], César BEDOYA[2], Alfonso GARCÍA-SANTOS[1], Javier NEILA[1], Estefanía CAAMAÑO[2]

[1]Department of Construction and Technology in Architecture, School of Architecture, Universidad Politécnica de Madrid, Madrid, Spain
[2]Instituto de Energía Solar, Universidad Politécnica de Madrid, Madrid, Spain

ABSTRACT: In 2008, the City Council of Rivas-Vaciamadrid (Spain) decided to promote the construction of "Rivasecopolis", a complex of sustainable buildings in which a new prototype of a zero-energy house would become the office of the Energy Agency. According to the initiative of the City Council, it was decided to recreate the dwelling prototype "Magic-box" which entered the 2005 Solar Decathlon Competition. The original project has been adapted to a new necessities programme, by adding the necessary spaces that allows it to work as an office. A team from university has designed and carried out the direction of the construction site. The new Solar House is conceived as a "testing building". It is going to become the space for attending citizens in all questions about saving energy, energy efficiency and sustainable construction, having a permanent small exhibition space additional to the working places for the information purpose. At the same time, the building includes the use of experimental passive architecture systems and a monitoring and control system. Collected data will be sent to University to allow developing research work about the experimental strategies included in the building. This paper will describe and analyze the experience of transforming a prototype into a real durable building and the benefits for both university and citizens in learning about sustainability with the building.

Keywords: sustainable architecture, solar energy, education, professional training

1. INTRODUCTION

The Solar House-Energy Office building is based and inspired in the Project "Magic –Box", developed by the Universidad Politécnica de Madrid (UPM) to enter the international competition Solar Decathlon 2005 in Washington, D.C. [1] This competition was promoted by the Department of Energy of the United States of America, with the main aim of promoting possibilities of combining good practice with a reasonable use of energy by means of passive and active use of solar energy and efficient technologies.

The proposal of the UPM team consisted of the design, construction and operation of a single house of around 70m2. The participation of the UPM was an extraordinary multidisciplinarian experience on research and education. Teachers and students from different disciplines collaborated together in order to achieve sustainability by means of combining bioclimatic architecture, use of solar technologies and domotics.

The principal objective of the proposal was developing a small electrical self-sufficient dwelling. It was immediately evident that it represented a very broad and ambitious goal; even so the UPM Solar Decathlon team understood the proposal as a global challenge in terms of habitability, pollution, energy, natural resources, materials and sustainability. The project, called Magic-Box, desired not only being electrically self-sufficient but also bioclimatic, and full of European, Mediterranean and pure Spanish spirit. The team understood the local regionalism as a different way of aesthetically experiencing the architectural space, physical construction and life inside the house.

The dwelling was open to surprise, movement, continuous exploration and enjoyment. A great many layouts were possible, since a number of movable walls allowed the occupants to unify or compartmentalize its interior space. Façades followed a modular scheme yet each was designed according to direction and time of solar radiation. The roof was independent of the livable volume yet preserved a compositional role, extending its appealing wavy shape to the remainder of the lot and the external pieces of furniture.

Figure 1: Original Magic-box prototype

The main features of the MAGIC BOX were: passive design; the application of traditional strategies for winter and summertime, day and night, commonly used in Spanish vernacular architecture, although they were implemented by means of new technologies, materials and systems; and the rational use of architectonical elements, such as porches, greenhouses, green roofs, vegetation, eaves, louvers, sliding panels, and even a “folding” patio. All of these were employed to manage comfort conditions, light and air quality, to control solar penetration, ventilation and thermal storage, as well as to define formal composition and to treat light and color. Electricity came from photovoltaics and heat storage was made possible through passive or active solar heating from evacuated tube solar collectors and free cooling at night in the summer. All indoor devices were operated through an integrated domotic system.

The building was set out to be bioclimatic to the highest degree. In this instance, the term “bioclimatic” refers to the relation of climate and life, both in the natural and man-made environment. Consequently, great importance was given to air quality and ventilation, to necessary levels of thermal comfort and humidity and to an adequate distribution of temperature in the rooms.

The house was characterized by simplicity, versatility, layout consistency, easy use in both the inside and the outside. Such relation with the environment not only highlights its visual and spatial aspects, but also fosters efficient consumption of materials, resources and energy, together with the minimizing of the production of waste.

One of the aims of the Solar Decathlon competition is to raise societies´ awareness of the need to use energy responsibly which is coincident with the City Council of Rivas-Vaciamadrid general aim in sustainability.

The idea of reproducing the Magic-Box house as a new building is an initiative of the City Council of Rivas-Vaciamadrid, adapting to a new necessities program to house the Energy Agency office. It is intended to be a space for attending citizens for everything related to saving energy, energy efficiency and sustainable construction. The house will be visited by people, fully accessible to fulfill a didactic objective, holding also a permanent exhibition space and workstations for the information office.

The Solar House-Energy Agency building is integrated in the Plaza Ecópolis project. It is a new space for the city which houses a park and playground surrounded by a kindergarten, an exhibition hall focused on energy and the Solar House-Energy Agency office.

2. DEVELOPMENT OF THE PROJECT

2.1. The educational and training experience

In 2005, the Solar Decathlon UPM Team was a real example of multidisciplinary content, with institutions having proven experience in Education, R&D within the fields of Photovoltaics, Architecture and Domotics. A total of 40 students and 8 faculty members was coordinated by the Institute of Solar Energy of the UPM.[2]

The common aim was to involve the university community as much as possible. Three different groups were created specializing in the main areas: architecture, energy systems and domotics. Besides these, other small sub-groups were created for specific purposes such as communications, logistics and sponsor funding. Project planning was structured according to five subsequent phases running for 25 months:

1) Conceptual design, market & regulations analysis and, web-site setup.
2) Architectural design & schematic energy analysis.
3) House construction & equipment.
4) Final house preparation & tests.
5) Solar Decathlon event & evaluation.

After the competition, the “Magic Box” was shipped back to Spain, where it was rebuilt and fully equipped in its final site at the UPM premises. The 2005 prototype was installed in the University Campus and became a laboratory for the University.

For information, there is a further copy of the house reproduced in Beijing, representing Spain in the Future House exhibition.

The UPM team maintained R&D activities on the concepts addressed by “Magic Box” until 2007, within a project co-financed by the Spanish National R&D Plan. The aim of this project was 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 backup).

Since then, the house has been periodically shown to students, scientists and the general public with great success: overall, more than500 people see the house every year.

The authors can also say with pride that this experience inspired later participations of UPM in the Solar Decathlon competition in 2007 and 2009 [3], as well as profiting from the previous practice and achieving a deep experience that allowed the University to be part of the organization of the first edition of the Solar Decathlon Europe, held in Madrid in June 2010.

In 2009 a new team was created to face the new challenge of rebuilding the Magic Box. It was formed by people from ABIO Research Group (Bioclimatic Architecture in a Sustainable Environment), researchers from the IES (Institute of Solar Energy) and members of the TISE Research Group (Innovative and Sustainable Technologies in Building), and all three of them from the UPM. The group was made up of architects, urban planners, engineers and industrial designers – a very broad range of practitioners.[4] In essence people from different backgrounds were obliged to work together cooperatively, and in this respect the project mirrors real life.

The ABIO office became a professional architecture office without disrupting the normal research and teaching activities. The Project Planning had at this time a single phase: to start and to finish in only two intensive months.

There has been again a multidisciplinary group of architects and engineers collaborating in a small but very special project. The team integrated undergraduate, master and PhD students as well as faculty members. Only approximately 10% of the team was part of the 2005 original team.

Difficulties presented when adapting the prototype to comply with building regulations without compromising the original style and appearance. Hence, some of the materials used in 2005 were not manufactured or sold any more. The biggest difficulty was that the budget available was insufficient for affording some parts of the original design as expensive pieces of furniture had been funded or donated for the original Solar Decathlon competition. At this point, workers from the Energy Agency and Technology Department of the City Council of Rivas-Vaciamadrid were involved as part of the design team, working together to convince companies to donate material and appliances to the project. The Telecommunications Department of the City Council was also involved in decision making and design for the way citizens were going to be informed about the building performance when it would be finished.

2.2. Taking up again the original prototype

When the opportunity to rebuild the house occurred, it was necessary for a full revision of the 2005 project, mainly designed and built according to the American Building Code. It was also necessary to adapt it to the Spanish Building Technical Code, published in 2007, after the initial design.

First decisions taken that essentially changed the original project:

In terms of construction:

- Deep foundation by pilots according to new characteristic of the ground that do not allow supporting big loads.
- Steel structure instead of light-weight steel and timber structure.
- Concrete cellular insulating blocks instead of steel and timber enclosures.

Building services:

- Ground source heat pump and fan coil system. The house must be fully efficient all the year round and in extreme winter and summer conditions of continental climate passive strategies may not cover all necessities.
- To improve the design and performance of the passive energy storage system PCM based.

Solar energy:

- The new building is not a stand-alone PC system but a grid connected system.

Architectural design:

- The new office spaces would be connected to the house on the north side, with 3 work stations.
- The “hinge” piece would be a wide corridor holding a building services room for solar inverters and office storage use, and a handicapped accessible bathroom. The new façade rain screen of this module would be a green wall.
- The disappearance of the living-movable room to avoid safety problems in a public building

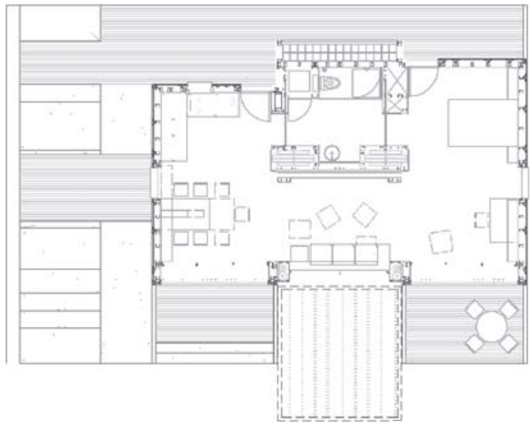

Figure 2: Floor plan of the Magic-Box original prototype

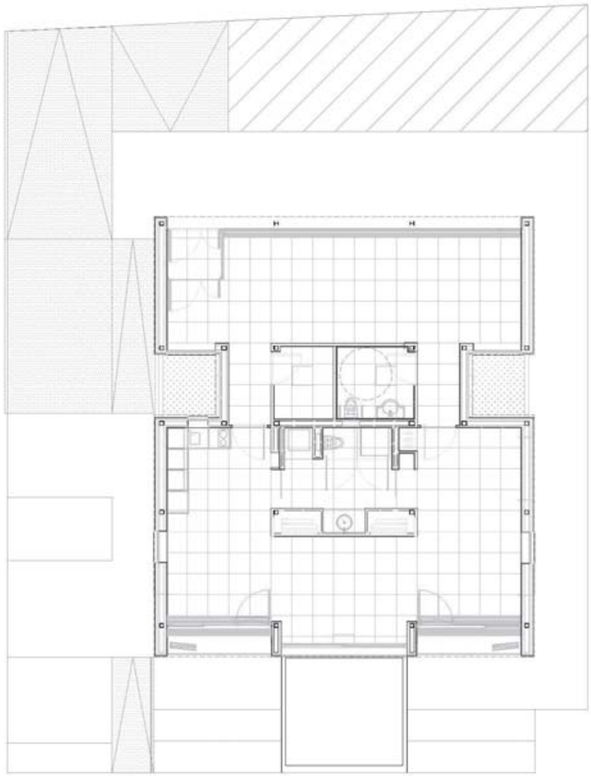

Figure 3: Floor plan of the Solar House-Energy Agency office building in Rivas-Vaciamadrid

Since agreement was established, the architecture office tasks have been completed in record time to allow the City Council to arrive, before the deadline, to participate in the benefits granted in the Plan E for the Incentive of Economy and Employment. This Spanish Government plan established the possibility of funding a large quantity of local projects in order to promote employment in the construction sector hardly damaged during the present day’s global economical crisis.

The construction site has been developed during 2009 and 2010. The Solar House-Energy Office building, together with the other two buildings of the Plaza Ecopolis was inaugurated in September 24th.

3. THE BUILDING AND ITS BIOCLIMATIC DESIGN

The building seeks to illustrate an example of sustainable construction according to the objectives promoted by the City Council and the Energy Office. It is a building that demonstrates that sustainability and self-sufficiency are possible, showing with clarity and simplicity how to achieve it.

The renewable energy produced by the building is more than its energy consumption. It is not only a zero energy building but a building that introduces renewable energy to the electrical grid. In the same way, it can be considered a non carbon emission building because the surplus of produced energy allows compensating the emissions produced during the manufacturing process of materials used in the building construction. Besides, most of those materials have been selected according to the Life Cycle Assessment methodology, choosing materials with a low electrical energy consumption during manufacturing process or recycled materials, as the outside external spaces and windows framing. Renewable materials have been also considered as wood fiber insulation. In addition, the use of green roof as a drain of CO_2 and two green walls panes allows us to reduce the global balance of the building, already converted in a zero emissions building.

The building produces electrical energy by means of photovoltaic generators, hot water by evacuated tube solar collectors and energy for conditioning mainly by means of a passive system. The passive system incorporated in the building should cover most of comfort necessities during summer, and a major percentage during many hours in winter time. When it is not covered by the passive system, the thermal source pump with high energy efficiency will contribute to supplement the shortfall in energy.

The passive system is mainly a collecting and storing energy system to allow using it for 24 hours a day and to be a mechanism of distribution to the different parts of the building. A storage system is essential in any building that collects energy during very short hours during the day time and that should distribute it during the remaining parts of the day. The system installed is a collection of devices that contain phase changing material (PCM) settled at 23ºC. The PCMs store or release energy during the phase changing, when solidify by storing cold, and storage heat while becomes liquid. The PCM used is paraffin based [5].

These substances are located in the raised technical floor and this is the place where energy is going to be stored. A part of the PCMs are inside cylindrical recipients settled in EPS moulds located under every piece of the raised floor. Every metallic cylinder facilitates the exchange of energy with the air forced to circulate between them. The flooring tile is on a metallic mould also filled with PCM. [6]

Winter conditioning system is based on solar radiation and internal loads (the heat generated by occupants, lighting and any electric equipment working inside the house.) In order to collect solar radiation two big window panes forming small greenhouses occupy 2/3 of the south façade. Every single green house has a double skin: the first single glass pane to facilitate solar radiation collection and the second one to isolate and avoid heat loss. A great quantity of radiation passes through the greenhouses and directly heats the floor. A part of this heat is retained in the green house that, in case of necessity, may pass into the house by the tilt bottom hung motorized opening of a single window pane.

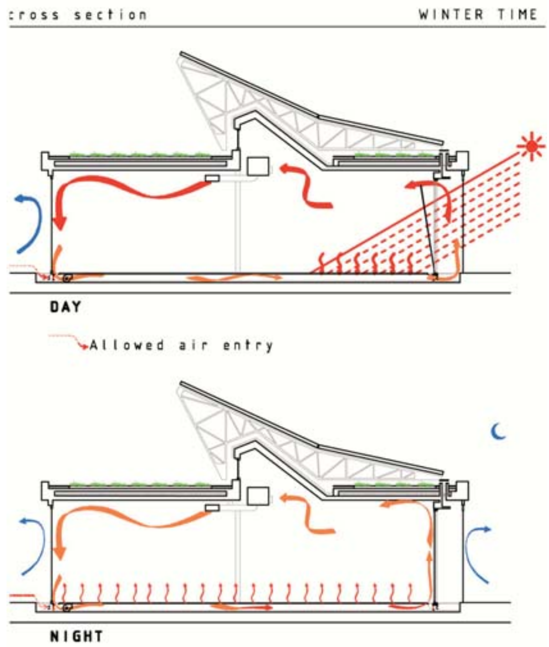

Figure 4: Winter time: bioclimatic performance.

Summer time conditioning system is based on taking advantage of the night cool that in Madrid's climate is under the comfort temperature established as 25ºC in this period of the year. Cool air is collected in the north façade passing through a garden zone to allow an evaporative cooling and conducted under the external flooring. It is forced to circulate through the raised technical floor as far as the south façade. Once it has given its energy to the PCMs located there, goes out through the grates located in the greenhouse floor whose external glass skin should be folded and acting only as vertical shading.

There is a conventional supporting system that allows re-circulating air inside the building. It is made up of the ground source heat pump mentioned before, that works when the passive system does not cover all conditioning necessities and a fan coil that transfers the energy produced by the pump to the rest of the building.

Once the air is pumped to the office area, it goes through the grates located on the floor and some fans facilitate it to circulate through the technical floor passing between the recipients with the PCM. During this journey, the air is charged with the energy accumulated in the paraffins, i.e. heat in winter and cool in summer. This air goes out through the south facade grates, on the internal side of the glass enclosure in winter and on its external side in summer.

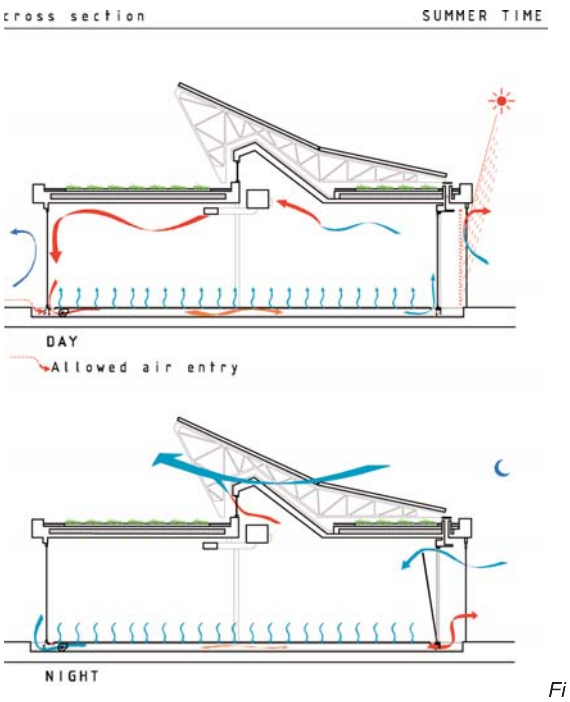

Figure 5: Summer time: bioclimatic performance.

Not any single one of these conditioning systems would be efficient enough if the building would not perfectly conserve its energy by means of reducing its necessities. Insulation levels of façades, floor and roof have been raised beyond those minimums established in building regulations. All possible thermal bridging has been carefully studied and solved.

All the design has been refined to create a quasi adiabatic envelope, reducing to the minimum the exchange of energy between the building and the environment.

The air recirculating in the house has been taken from the outside in the south green houses in winter and at night directly to the raised floor plenum in summer. Thus, before entering the house, the air has been favorably modified between 5 and 10ºC. The expenses on ventilation have been also minimized.

4. SOLAR HOUSE + ENERGY AGENCY OFFICE BUILDING

4.1. Visiting the Energy Agency office

The Energy Agency is a city public service depending on the Urban Planning, Sustainable Development and Maintenance Department of the City Council. It was created in July 2008 with the aim of converting the city to an example of efficiency, saving energy and citizens' commitment to the present crisis of the energy model. The Energy Agency promotes a new way of looking at energy, of using natural resources and responsible consumption.

The main objective is assessing citizens and companies based on Rivas-Vaciamadrid in all issues related to saving energy and energy efficiency, clean and renewable energies, sustainable transport, ecological footprint, etc.

The Energy Agency will also manage the project Rivas Solar that works to extend the generation of thermal and photovoltaic solar energy throughout the city.

The Energy Agency coordinates and promotes the project RIVAS ECÓPOLIS [7] whose target is to transform all the city of Rivas Vaciamadrid to become more sustainable. Rivasecopolis has been conceived as a "city project", absolutely integrated in the City Council structure

All citizens who go to the Energy Office will be able to visit the house according to an educational and didactic aim. Posters and explicative panels will allow then to obtain detailed information about every single system working in the building as well as explanations from the people working in the Agency.

Figure 6: The Energy Agency office building. External and internal views

The house is completely furnished and working (fully equipped kitchen, appliances, bathroom, etc) as an ordinary house.

Two screen displays located in the living room will illustrate and explain the performance of the building. Simultaneously, there is the possibility of observing the energy produced by other public buildings also controlled by the City Council. In the same way, the values from the Solar House-Energy office can be remotely checked by visitors to those other public city buildings.

4.2. Collected data for research

In order to obtain data to develop research, all the Energy Office building is being monitored.

The control system is registering data available for 3 different targets:

1. The property (the City Council) is obtaining data on consumption and energy saving,
2. The citizens can observe and learn about the building performance. There is a net established between some public buildings in the city and it is possible to check the energy production of all them from every single building.
3. The University is receiving the data lists to compare with the results considered in hypothesis and with the data obtained in the laboratory tests with the results while the real system is working.

A weather station and a PV calibrated cell have been installed in the roof. Thermostat and different temperature and humidity sensors and located in every single space of the building as well as under the raised technical floor.

All the instant values obtained are shown in the displays located in the living room area of the house.

Table 1: Parameters being controlled and monitored in the building

BUILDING SYSTEM	PARAMETER
PV System	Instantaneous production
	Cumulated production per day
	Cumulated production per month
	Cumulated production per year
	Electrical consumption per day
	Electrical consumption per month
	Electrical consumption per year
Conditioning	Outside temperature
	Inside temperature in every space of the building
	Fan-coil. In-take air temperature
	Fan-coil. Egress air temperature
Ground source heat pump	Instant energy production
	Energy production per year
	Instant energy consumption
	Energy consumption per year
Energy storing raised floor	Temperature of entering air
	Air temperature inside the technical floor
	Temperature of egress air
	PCM material temperature
	Hatch´s position open / close
	Air fans on / off
Green walls	Water consumption
Green roof	Water consumption

Data will be regularly sent to University to allow to quantify and to characterize the results. For instance, simultaneously a sample of the prototype of the passive energy storing system integrated in the technical floor is already being monitored in University laboratories.

5. CONCLUSION

The Solar House- Energy Agency building is an example of sustainable construction because in global quantification it does not consume energy, neither the building itself nor taken from the electrical net. Renewable energy generated by the building itself is greater than the energy consumed. Hence, it is not only a zero-energy building but a building that incorporates energy into the electrical grid. As a shared objective with the Solar Decathlon Competition, the building intends clearly showing that solar houses can be built without sacrificing energy efficiency or comfort, and that they can be both attractive and affordable.

The benefits of the experience of entering the Solar Decathlon Competition are unquestionable for a University. From an educational perspective, the experience initiated with "Magic-Box" has been unique. Students could learn what a real project is and the need to integrate several disciplines in building-related projects. Professors also found the project very stimulating and rewarding

The experience has been reinforced when having the opportunity of reconsider about the proposal, redesign and convert the prototype into an absolute real building. For some of the students involved in the experience, it has been the first approach to professional practice while being undergraduate students. They have had the opportunity of working on design, budget planning, specifications as well as construction management.

The holistic view of the experience reveals a double immediate benefit in education in sustainability: the building itself is a real clear and tangible demonstrator for citizens visiting the office and house and at the same time it allows access to a real scale testing sample for university students.

6. ACKNOWLEDGEMENTS

We are grateful to the “Solar Decathlon UPM 2005 Team” for their generous effort and dedication. The first prototype would never have seen the light of day without their support.

The Energy Agency building has been constructed with the financial support of the city council of Rivas-Vaciamadrid and the Government of Spain, in the framework of the Plan E for the Incentive of Economy and Employment.

Many thanks are given to the City Council of Rivas-Vaciamadrid for being interested in our prototype and for the aim to promote sustainable architecture and encourage their citizens to live in a sustainable attitude.

7. REFERENCES

[1] Caamaño, E. et al. Viviendas solares autosuficientes: participación de la Universidad Politécnica de Madrid en el concurso “Solar Decathlon”. Informes de la Construcción, 2004, Vol. 56, p. 35-46.

[2] Caamaño, E. et al. Spanish participation in the “Solar Decathlon 2005” competition: new proposals for zero-energy houses. Proc. 20th European Photovoltaic Solar Energy Conference, Barcelona – Spain (2005), 2587

[3] www.solardecathlon.upm.es

[4] Derome, D. Pearl, D. and Athienitis, A. Engaging Engineering and Architectural Students in the Integrated Design Process (IDP) for a competition Entry Demonstration House – the Solar Decathlon. Proc. 21st PLEA conference, Eindhoven - The Netherlands (2004)

[5] Hernández-Martínez, M.C. et al. Phase change material capsules for thermal storage purposes in housing. Proc. SEEP 2009, 3rd International conference in Sustainable Energy and Environmental Protection, Dublin – Ireland (2009), 350.

[6] Cerón, I. et al., this conference.

[7] http://www.rivasecopolis.org

The 27th PLEA conference PLEA2011 - Architecture and Sustainable Development marks the 30th anniversary of PLEA. The topics of the conference tackle a broad range well beyond the subject of energy.
Following from the last PLEA conference that was held in Quebec in 2009, we want this celebratory PLEA 2011 in Louvain-la-Neuve to provide a special meeting ground for architects, engineers and researchers to debate the theme of sustainable architecture and the different aspects of sustainable development that range from the scale of the city to those of materials and components.
This book of Proceedings presents the latest thinking and research in the rapidly evolving world of architecture and sustainable development through 255 papers which were selected out of more than 750 abstracts that were proposed by authors coming from over 60 countries.

ARCHITECTURE & SUSTAINABLE DEVELOPMENT

PLEA2011

27th INTERNATIONAL CONFERENCE ON PASSIVE AND LOW ENERGY ARCHITECTURE
LOUVAIN-LA-NEUVE 13 - 15 JULY 2011

Conference Proceedings Volume 1

PLEA

ISBN 978-2-87463-278-5
9 782874 632785

i6doc.com
la librairie des documents scientifiques