

## 12. A highly sustainable house

**Cordero, Raúl<sup>(1,\*)</sup>**

(\*) Departamento de Investigación de la Facultad de Arquitectura y Urbanismo, Construcción Arquitectónica y eficiencia energética, Universidad de Cuenca, Cuenca, Ecuador, raul.cordero@ucuenca.edu.ec, +5934051000.

**Abstract** A sustainable house is capable of generating and self-sustaining energy by itself to function autonomously, that is to say, without depending on external supply networks. That is possible by supplying the internal energy consumption through renewable energy. This work describes and analyzes the construction of a sustainable house in Paute, Ecuador. The goal of this house was to achieve self-sustainability in several aspects such as construction techniques, creative and functional forms, alternative energy usage, and food production. This papers aims to reveal a unique and innovative housing destined to the enjoyment of its inhabits. As a consequence of the various technologies included in this house, as vegetal coverings, cross ventilation, solar panels, and others, is satisfactory to say that this house is taking a big step to achieve sustainability, especially in our region where the cases that try to reach sustainability are almost null. Finally, sustainability includes environment care, human well-being and emotional satisfaction, and this house has made a major effort in that quest.

**Key words** self-sustainable, sustainability, plant coatings, cross ventilation, renewable energies.

### 1 Introduction

The industrialized world is mainly appalled by the destruction it has caused on the planet. This has led to many reflections and attempts to stop and, if possible, to reverse that damage. In developed countries, "the green movement developed in the 1970s with a special emphasis on energy conservation and energy efficiency. Concerns about the impact of the operation of a building and the manufacture of construction materials on the natural environment grew in the 1980s " (Macías and Navarro 2010)

In these countries arises an ecological conscience to conserve resources and the environment, and the phrase "Sustainable Development that satisfies the needs of the present, without creating environmental problems, and without compromising the demands of future generations " (Lamela, 2005), which refers to energy and

resource consumption, so today is stated, for instance, "energy saving, ... in practically all areas" (Asrar, Hipps, & Kanemasu, 1984).

There are hundreds of initiatives, research and practices in this area. Some of them trying to get the house and architecture self-sustaining. This house in particular employs bioclimatic resources such as cross-ventilation, solar, and other additional alternative resources such as green roofs, thus further reducing the need for energy for its air conditioning.

On the other hand, the habitants of this house also reuse the waste, especially the organic ones, turning them into fertilizer or compost, which links the concept of energy saving with a more natural and organic food production, which is part of the concept of self-sustainability of this home.

This house aims to adapt to the aspirations of its owners who wanted a construction of this architecture style, since they needed a house able to adjust to sustainable requirements. Likewise, they chose a hill as the location because of the spectacular views of the valley and the crops. The concept of sustainability involves the human well-being and as one of its pillars, and this in turn invests psychological well-being and the pursuit of its emotional aesthetic illusions, and the expression of its preferences.

The goal of this construction was to achieve self-sustainability in several aspects.

The followed path was:

- To understand the family's requirements and wishes for a vacational home in a semi-warm place with an excellent view, and design it based on sustainability concepts.
- Shuffle style options that can adapt to the sustainability requirements and plan the house.
- To build this uncommon design as a challenge since there are scarce examples of these kind of buildings in the region.
- Attach alternative technologies.
- Create a bio-sustainable garden.
- Measure the results based on the user's satisfaction.

## 2 Location and general information

The case study is located in Paute, Uzhuput (a town located in the northeast of the province of Azuay), specifically in the Chicán village, approximately forty-five kilometers from the Capital of the Province of Cuenca. The land has an area of 2700 m<sup>2</sup>, and its altitude is 2100 m.s.n.m. The climate varies between 15 ° C to 26 ° C., which allows the production of a large variety of flowers and fruits. A privileged place because its climate and landscape has become a touristic place.

### 2.1 *The architectural role*

To complete sustainability goals its necessary to consider the human well-being, which also includes emotional aspirations. The owners are two scientists, an Ecuadorian master engineer specialized in wind, photovoltaic systems, sustainability and energy saving. The other owner is an Italian expert engineer in agricultural bioculture without chemicals, the perfect combination to achieve the best results. They already have a house in Cuenca city, near the universities where they are professors. That house is made of adobe, but advised by the architect (this article's author) they considered something different for their weekend house. After seeing a project built by the author, a shell construction of experimental concrete and vegetal covers, they decide to build their house based on this concept. The shell construction was part of an investigation done in the University of Cuenca a couple of decades ago.



**Fig. 1** Project "Cascarones" with vegetal cover at the Universtity of Cuenca

So, the agreement arises, taking Pier Cardan houses as a reference, with less budget, but with more emotions and clear goals such as: green covers,





**Fig. 4** House result (Author photograph )

### **3 Architectural aspects**

The shape of the house is based on the concept of a highly efficient double-curved structure of natural structures, for instance, tortoise shell or insect skeleton.

Only by folding a sheet of paper with a slight curvature, it is demonstrated that the structural strength increases exponentially with double curvature surfaces using less material.

Another example is the resistance of the egg that supports weight beyond the expected with a minimum thickness. In fact, whenever nature constructs a resistant surface it chooses one of double curvature.

This kind of structures generate better interior spaces. The exotic sinuous forms create better and more relaxing environments. Besides, these forms generate interesting acoustic effects since the walls act as sound amplifiers.



**Fig. 5** Double curvature (Author's photograph)

The construction technique is ferrocement, and consists of 10mm cross section rods with a 2400 kg /cm<sup>2</sup> yield strength , with plaster meshes receiving a 1-3 mortar in layers of approximately 2 cm on each side and two layers of elastomeric paint.

Ferrocement, likewise the shells made of reinforced concrete, saves the cost of formwork. However, the result of fibrocement is less perfect, but more economical.

Functionally, the house has a game room, dining room, kitchen, living room, two bedrooms on the ground floor and a master room on the upper floor. All rooms have a panoramic view of the valley through curved windows that open upwards. When they open, there is cross ventilation, and new environments are also created as the photography below shows.



**Fig. 6** Casement window (Author's photography)



**Fig. 7** Interior view (Author's photography)

## **4 Bioclimatic or eco-sustainable technology**

Although the house has practically all the resources of alternative technologies, it has also applied a new concept, the use of windows for the management of external and internal climate agents. Making possible a good ventilation, lighting, sight, aesthetics and landscape as part of the architecture.

### ***4.1 Cross Ventilation***

Cross ventilation is a concept used by bioclimatic architecture, to define a correct ventilation of buildings. Depending on each place and the time, there are characteristic winds that generate zones of high pressure and low pressure to windward. As a consequence, it is necessary to create a ventilation, that can make the entrance of the wind homogenously in every room.

### ***4.2 Vegetable coverings***

A few decades ago vegetal coverings were innovative, although they had some antecedents in the popular and historical architecture of some countries in the North tropic, this technique was uncommon. Some research projects and several architectural degree thesis were carried out to understand vegetal coverings from a technical point of view, like their agricultural management, or their thermal insulation capacities.

Today the application and design with vegetation cover is widespread and more projects incorporate this technology in their design. Even some traditional constructions place them in their terraces for having a natural space. They offer several benefits such as the slow evacuation of rainwater and specially temperature insulation. (Table 1 includes data that shows the temperature achieve inside the house if study)

Likewise, this is an alternative that contributes to the natural landscape. It rescues the green spaces around that architecture usually destroys, allowing a better relation between the project and its surrounding landscape.





**Fig. 8** Vegetal covering in one of the facades. (Author's photography)



**Fig. 9** Vegetal covering in one of the facades. (Author's photography)

## 5 Thermal confort

The indoor climate assessment showed a correct behavior of the desired climate inside the house, ratifying its inhabitants experience.

**Table 1** Temperature of the walls, temperature of the windows y temperature of the interior environment (C°)

n.	Date and hour	Tw (C)	Tg (C)	Ta (C)
1	Date=2015/12/02 10:11:03	14,6	19,8	19,9
2	Date=2015/12/02 10:11:18	14,6	19,8	19,9
3	Date=2015/12/02 10:11:33	14,6	19,8	19,9
4	Date=2015/12/02 10:11:48	14,6	19,8	19,9
5	Date=2015/12/02 10:12:03	14,6	19,8	19,9
6	Date=2015/12/02 10:12:18	14,6	19,8	19,9
7	Date=2015/12/02 10:12:33	14,6	19,8	19,9
8	Date=2015/12/02 10:12:48	14,6	19,8	19,9
9	Date=2015/12/02 10:13:03	14,6	19,8	19,9
10	Date=2015/12/02 10:13:18	14,5	19,8	19,9

Using around 300 data every day, the following observations are inferred:

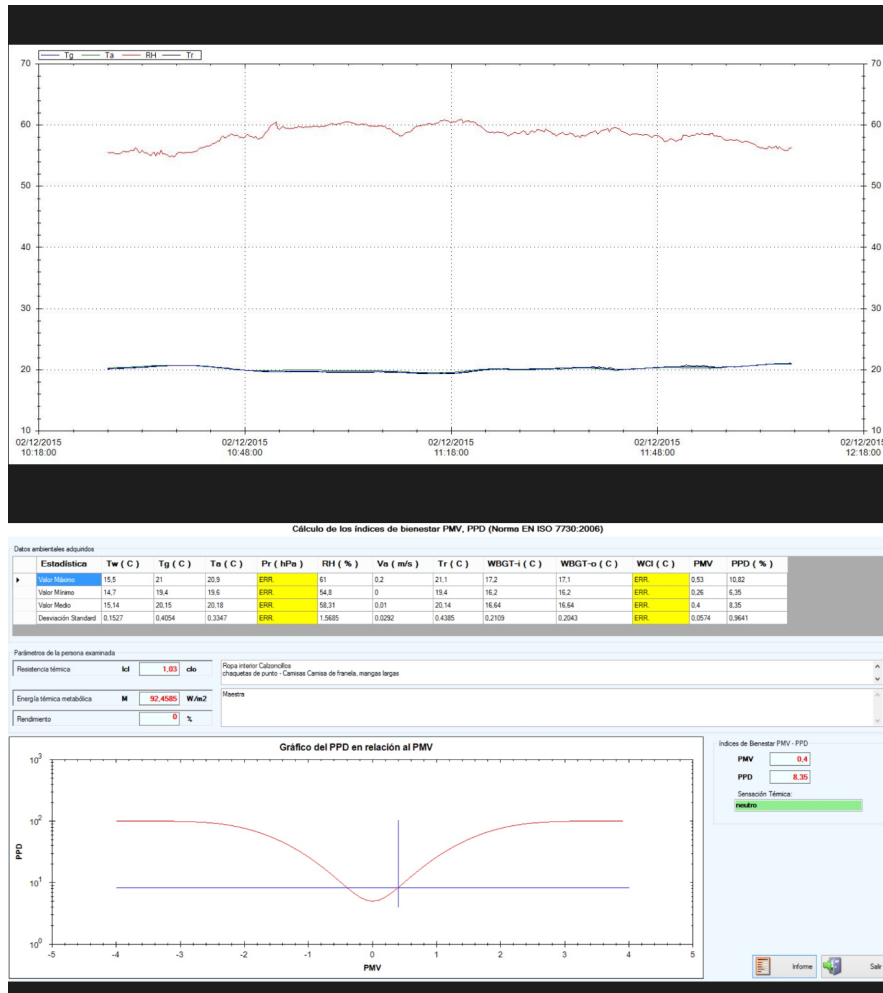


Fig. 10 Graphics of the PPD in relation to the PMV

According to Edison Castillo Carchipulla, (Head of Department of Bio Climatismo, Faculty of Architecture) data containing the thermal resistance (1.03 clo) and the metabolic thermal energy (92.4585 W / m<sup>2</sup>), generating a PMV of 0.4 and a PPD of 8.35, and the analysis of the Fanger diagram demonstrates that the house offers a neutral thermal sensation, which represents neither cold nor heat. Consequently, for the measuring range no thermal inconformity is generated.

It should be considered that the measuring range can vary because the amount of clothes entered may differ generating different information just like the metabolic thermal energy. Notice that the ventilation of doors generates a variation of the interior comfort, which can be handled at will.

### ***5.1 Solar thermal utilization***

This system harnesses the sun radiation through a solar collector to heat a fluid. Hence, the heat absorbed by the solar collector is transferred to the water and can be directly used or stored.

In our case, the housing incorporated a system of solar thermal utilization. The designed solar collector absorbs the energy coming from the Sun through the different elements that compose it. It is composed of a wooden box covered by a plastic that causes the greenhouse effect. Inside the box is placed an absorber that transforms the solar radiation into heat. The water circulates through tubes attached to the absorber and raise its temperature.

The solar collector has been placed directly on the roof of the building without any additional structure. The hot water produced by the solar collector varies according to different elements: position, geographical area, daily solar radiation, inclination, orientation, among other aspects. The orientation in which the solar collector is placed is oriented to the south, since it is the most advantageous position. The roof has a slope of 25 °. We must be careful with shadows that may avoid the sun rays reaching the collector.

The water heating system consists of two panels of 2 square meters each, and a storage tank of 200 liters. There is also an auxiliary system composed of nickelines which is not connected at the moment, but is it could connect to the eolic system when the batteries have energy excess, but that installation is not yet done.



**Fig. 11** Solar collector location (Author's photography)

## **6 Electric power generation system**

Wind energy and solar energy belong to renewable energies, both have their origin in solar radiation, but wind energy in an indirect way. The proposed system, contributes to the energy self-sufficiency of the housing, the fight against pollution, climate change, and many other contributions.

In this case, the system is based on the design of a wind vane and photovoltaic panels. With the electrical energy supplied by these renewable energy sources, we illuminate the housing through LEDs.

As a result, the lighting and services of sustainable housing are ensured, even in unfavorable environmental conditions since electricity may be generated from the sun or wind.



**Fig. 11** Wind turbine (Author's photography)



**Fig. 12** Solar panels (Foto de autor)

In detail the house electrical generation system is a hybrid, which means that is composed by a photovoltaic system plus a wind system, that is constituted by a 500 watts' wind generator with three blades, (a triaspa), the diameter of the Asp is 1.5m.

The hybrid system supplied by the photovoltaic part plus a regulator that controls the energy input and output from the wind system to the batteries, and from the batteries to the house installation. Another system was incorporated, that makes the energy excess go to a nickel to heat water when the batteries are fully charged. In addition, it has an electric generation system for the refrigerator that is composed of:

- 2 panels of 100 watts
- A battery of 150 amps – hour
- A small refrigerator (4 cubic feet)
- The refrigerator's feed system is independent

La casa tiene un sistema energético de la siguiente manera:

- 8 panels of 100 Watts to illuminate
- A battery of 750 amps – hour
- 2 regulators of de 30 amps each
- 3 inverters (Devices that pass from direct current to alternating current)  
The inverters are 3, 2 of 250 and 1 of 400 watts (the largest)

## **7 Waste management**

One of the main goals of a self-sufficient house is to generate less waste. And if they create it, they must recycle it and transform it. In this house, organic waste is recycled daily within composters, that waste will be later transformed into compost and manure for the garden.

The house also has solid waste treatment systems such as a Biodigestor, and it is complemented by a free fungicides and chemical fertilizers agriculture. This system is carried by one of the house owners who is a scientist specialized in sustainable agriculture.

The house counts on a system composed of a biodigestor that processes the wastewater from the bathrooms and gives us a leachate, substance that is quite good to fertilize the field. It is also obtained solid organic or pasty fertilizer that is dried, and then occupied only for the soccer field and for the lawn.

The house has two large composters of 7 square meters each, there compost is prepared and the biol which is made with some plastic tanks. They use compost, humus.

## **7 Organic agriculture**

The entire property is built on a slope that is terraced based on Inca (ancestral civilization) style, which works the best way. Organic matter is being inserted in each terrace, and agricultural production is increasing.

One of the main elements sought in this house is self-sustainability both energetic and food, causing the least possible environmental impact and having healthy products. Therefore, they work with strictly organic crops, without chemicals.

For the tomato cultivation, they have a small greenhouse system, which produces products that need a little more heat plus the pests are avoided. It also has a shade room where it has begun to work with orchids, in order to repopulate the area with these plants that are typical of the sector. Fundamentally, there are vegetable plantations and a vegetable garden of medicinal plants and fruit cultivations of the zone, recovering the cherimoya. It also has crops of pepper, pepper, etc. The interesting thing about the crop area is that it is terraced. They had to work very hard balancing Ph from the ground, because it was too alkaline. The site was neutralized, depending on each area, using nets, meshes, etc. They produce their own insecticides, using natural products such as pepper, pepper, tobacco, etc.

The 2000 m<sup>2</sup> land is used to produce the necessary food and for its users.

## **7 Conclusions**

This house is not connected to the public energy grid because the energy obtained by photovoltaic and wind systems, as well as solar heating, are sufficient.

The role of the architectural design is an important factor to develop sustainable habitats.

The production of organic food in the same land represents the energy saving in terms of transport. In addition, they guarantee a better health for its inhabitants, the food products are even enough to serve the visitors.

It is important to analyze buildings that count with sustainable systems as a reference to improve those systems in other buildings.



A house like the one studied was possible to reach because its owners are scientists, however, there should be more attempts to make these technologies available for everyone.

The owners and the architect are proud of the achievement. The strange thing is that a house like this, despite the many benefits that has achieved, has been the object of much criticism. It raises divided opinions in our region, just like every beginning of something new.

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