Low Energy Design:
An Evaluation of a Vacation Home in Panama

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ABSTRACT: This paper will discuss a low impact and low energy vacation home in the surfing capital of the world, Venao Panama, using the standards for zero site energy as well as other performance factors as the basis for the analysis. The home was designed to achieve net zero energy use, but given the climate and irregular occupancy, its design and systems are unique. The focus of this paper is to highlight the construction type, energy use, active and renewable systems, and other features of this particular zero energy building. The objective is to facilitate a better understanding of efficient and sustainable residential design for tropical climates. This understanding is critical to bringing Net Zero Energy to the public.

Keywords: low energy construction, residential, tropics, Panama

1. INTRODUCTION

The construction and operation of residential and commercial buildings have a significant environmental impact. In the last quarter century, global temperatures and CO_2 emissions have increased dramatically, increasing both the risk and reality of catastrophic environmental disasters (RMI, 2002). Analysts estimate that global carbon emissions will more than double by 2050 if changes are not made in the way we build and live.

There is a growing global awareness of the need for energy conservation and this awareness is increasingly reflected in the way we design and build. Efficient HVAC equipment, better insulation, smarter design, and occupant awareness of energy efficiency and renewable energy are now bringing the concept of Net Zero Energy Buildings to the mainstream (Farhar & Coburn, 2008). Net Zero Energy Buildings, or NZEB, are buildings that produce as much energy as they consume on an annual basis. A Net Zero Energy Building is capable of producing, at minimum, an annual output of renewable energy that is equal to the total amount of its annual consumed/purchased energy from energy utilities (Fortmeyer 2006).

This paper describes the design process and specific characteristics of a vacation home in Panama that is intended to be net zero energy. The project illustrates opportunities and challenges of designing and building low-energy structures in a different climate and cultural context. The discussion highlights design parameters, construction techniques, and supporting environmental (mechanical, plumbing, and lighting) systems that were specified for the house with the intention of achieving net zero site energy. It will also describe additional efforts by the designers and owners to not only meet the criteria for zero site energy use, but also to be locally rooted, resource efficient, and healthy. The intent is to show how construction practices, technologies, sustainable materials, innovative mechanical, electrical, and plumbing systems, and lifestyle choices impact home energy performance in a tropical climate.

2. BACKGROUND

Panama borders the Caribbean Sea and the North Pacific Ocean, between Colombia and Costa Rica. The country occupies the southeastern end of the isthmus forming the land bridge between North and South America. The climate is described as tropical maritime- hot, humid, and cloudy (Ward and Ostbo, 2010). Panama has an average of 3600 cooling degree days and its seasonal variations are marked by hot and wet in the dry season and hotter and wetter in the rainy season. Lowlands line both the Caribbean and Pacific coasts. Venao is situated on the easterly tip of Panama's Azuero Peninsula in the province of Los Santos. The world-famous Playa Venao, a 2-mile long beach, is a half-moon bay facing south towards the Pacific Ocean (Fig. 1).

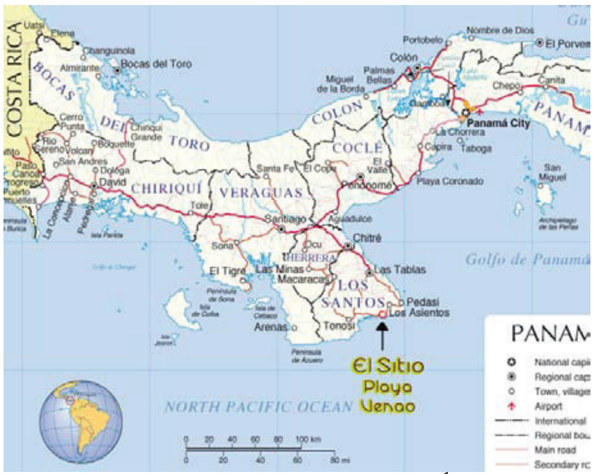

Fig. 1: Map of Panama with the site (El Sitio).[1]

In a cooling dependent climate like that of coastal Panama, reducing a building's annual cooling load is vital to energy efficient design. The prevailing design strategies include a well-ventilated and light building envelope, high-efficiency windows, controlled shading, and passive solar considerations. Net Zero Buildings further minimize cooling and electrical consumption loads by using high-efficiency mechanical ventilation and air conditioning (MVAC) equipment and solar powered lighting. Solar thermal systems are used to satisfy domestic hot water demands.

Zero Energy Buildings mean freedom from variable energy prices, a reduced cost of living, and higher resale values as demand increases for high-efficiency homes. In a remote region like Venao, where the supply of energy from the grid can be unstable and vulnerable to tropical storms, the importance of zero energy is magnified. Potential barriers include higher initial costs of construction and renovation, lack of reliable technology for installation, the lack of builder experience, and the reality that building occupants need to become more involved in daily maintenance and operation of the buildings in which they live and play (Tobias & Vavaroutsos, 2012).

This paper focuses on the Espave House, which is adjacent to a 140 hectare (346 acre) reforestation project in Eco Venao, Panama. The home is one of several 'low impact' accommodations in the region that supports activities at Playa Venao, Panama's best beach break (Fig. 2).


Fig. 2: Playa Venao Beach Break.[1]

3. METHOD AND ANALYSIS

The Espave House is a 2-story 125 square meter post-and-beam structure on an 11-acre lot (4.5 hectares). The site is located between two hills and overlooks the Pacific Ocean to the south and south-east (Fig. 3).


Fig. 3: View to the south-east from site, Playa Venao.[2]

The house has an open floor plan, 3 bedrooms, 3-1/2 bathrooms, living room, dining room, and kitchen (Fig. 4). The home maximizes passive ventilation and daylighting, uses photovoltaic panels to provide for 90% of the electrical load, supplies 100% of the domestic hot water load with a solar hot water system, and is equipped with energy efficient appliances.

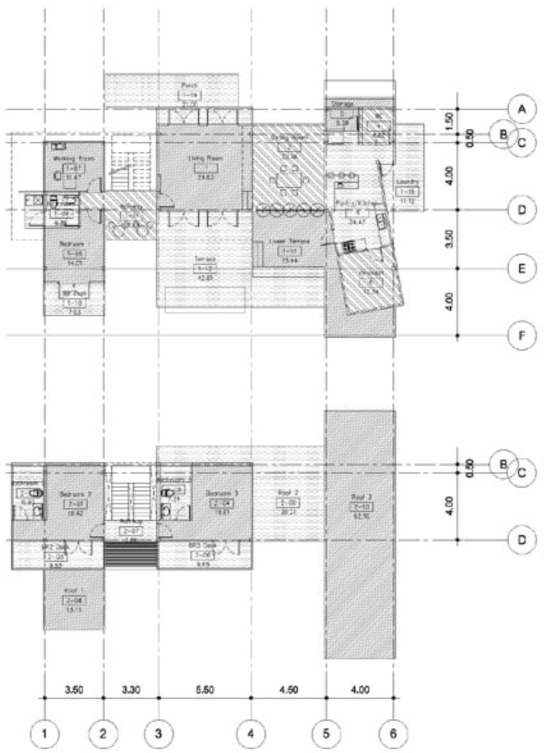

Fig. 4: Plan of first and second floor.

There are three analytical metrics that were adopted for this research: an examination of the home's overall massing, spatial organization, and orientation, an evaluation of the materials and resources needed for its construction, and analysis of its predicted MVAC system performance. The data was based on the narrative documents submitted by the owners during pre-design, design documents created during the design/build phase, and emails/telephone conversations with the contractors and owners.

4. RESULTS AND DISCUSSION

Panama is booming. It has the highest economic growth rate in the hemisphere. Manufacturing, mining, utilities, and construction together account for 19 percent of GDP. Private construction is one of the key growth areas in Panama and new condominiums, hotels, and office towers are being built across the country (CIA, 1995). These buildings consume natural resources and energy.

Despite the positive outlook for Panama's construction-related economic activities, very little has been done to define provisions for conservation and sustainability in the built environment. Building codes for private construction are based on minimum design requirements for safety, focusing only on fire prevention and egress. Durability, energy conservation, and minimum performance are not considered a high priority. In this paper, the Espave House is presented as a case study on how local attitudes towards sustainable design can be influenced.

The Espave House focused on site and climate as a starting point for low energy design. We mapped the site with regard to wind, sun, and rain to define building orientation, layout, massing, and footprint (Fig. 5).

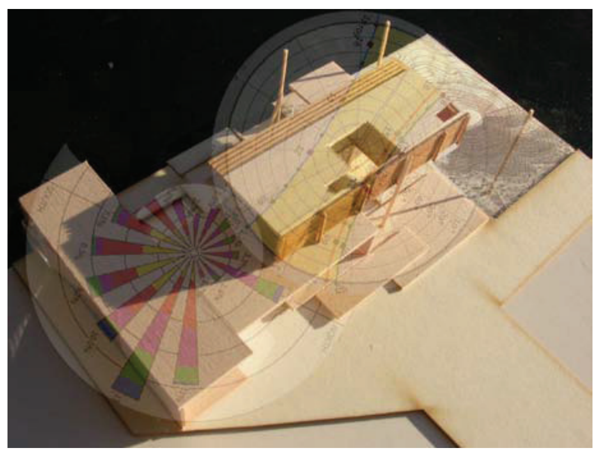

Fig. 5: Site Planning and Analysis.

Site mapping was an important first step in the design process given the sloping topography and wind conditions. Building footprint as well as the relative usable area of the home was an equally important issue as size is one of the most significant contributing factors to the resource efficiency and the environmental impact of building construction activities (Wilson & Boehland, 2005). The main difference between Espave House and other vacation homes in the region is that the Espave House is almost 30% smaller, which accounts for significantly less materials and resources, both in construction and operation.

The spatial organization of the Espave House is optimized working daylight and passive cooling and ventilation. The home has an open floor plan with permeable walls along a long south-facing axis that is mostly open to views of the ocean below. The house also utilizes very deep thresholds on the southern face that act as sun shades, allowing primarily indirect and diffuse light to the interior. The deep overhangs prevent direct solar radiation from raising interior temperatures during the day (Fig. 6). The shallow width of the house allows diffuse light to penetrate all the way to the north side. This eliminates the need for artificial lighting during daylight hours.

Fig. 6: South-eastern elevation, deep overhangs.

The eastern side of the house is subject to very strong and gusty winds, which we harnessed to create cross-currents within the house for passive cooling. We designed slit windows with slated shades that can be adjusted according to ventilation needs. Because of this, the house does not need air conditioning except for the very hottest and most humid days in the year (Fig. 7).

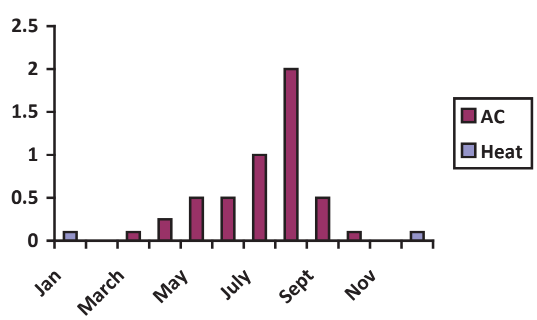

Fig. 7: Average space conditioning kW.

We also worked with the reforestation program at Eco-Venao and mapped out a solution involving tree and shrub plantings to create a shelter belt along the entire eastern façade. The reforestation efforts have been on-going for the past twenty years, converting degraded and abandoned agriculture and pasture lands back into the tropical forests that used to flourish in this region. Studies of shelter belts have shown that trees can provide wind breaks to reduce wind speed and alter the characteristics of air flow around them. It is well-known that the structural characteristics of shelterbelts and the individual tree are important factors influencing their effectiveness (Vigiak et al. 2003). The shelterbelt we designed on the eastern side of the Espave House was composed of Acacia, Macano, Balo, Guácimo, Teak and Balsa trees. These are known to rapidly develop large, dense crowns and attained canopy closure after just two years (Wishnie et al., 2007). We also hope that these species can stabilize soils in what has now become eroded and infertile land.

In general, maintaining comfortable temperatures with passive strategies is difficult, because there are no controls to ensure the interior spaces do not overheat or over-ventilate. To prevent overheating, a simple massing technique is employed along with second floor overhangs and a light colored exterior to prevent mitigate heat gains. We designed deep thresholds with the flooring as a thermal mass element. The thermal mass in the threshold is locally sourced stone tiles that absorb heat during the day, creating a thermal break between the interior floor system and the exterior shaded space. The thermal mass absorbs the heat from the sun during the day – like a heat storage battery – and at night, radiates the heat back to the atmosphere. This 12” (305 mm) stone slab helps to regulate the temperature of the house at around 78°F (25°C) with little need for air conditioning (Fig. 8).

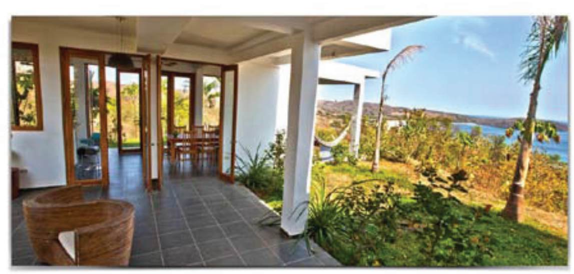

Fig. 8: Thermal mass stone slab in threshold.

In the Espave House, using locally sourced and sustainably harvested materials and products was an imperative for minimizing embodied energy. Building and construction activities worldwide consume three billion tons of raw materials each year (Roodman & Lenssen, 1995) and sustainable building materials can help reduce the environmental impacts associated with extraction, transport, processing, fabrication, installation, reuse, recycling, and disposal. Furthermore, due to the close proximity of the Eco-resort which would provide an additional source of rent income for the owners, we considered how the building could promote the basic principles of those who vacation at Eco Venao- conservation and durability.

The Espave House walls are post-and-beam construction using sustainably harvested teak pressure-treated wood. In general, it is unusual in Panama to construct walls out of wood, rather than concrete. But not only are wood walls cheaper to build, they have less embedded energy than concrete. Furthermore, teak is grown within 10 kilometers from the site, whereas concrete would have to be transported from a town 300 km away. Other local materials such as glass countertops and sustainably harvested clay tiling further reduce embodied energy. In addition, all paints and finishes are low/no VOC, and the white-painted reflective metal roof is highly durable.

The Espave home’s exterior walls are constructed with light-colored materials that are punctuated with ventilation and/or window gaps to allow the interior to be passively daylit and ventilated. The mostly opaque walls on the north, east, and western facades are insulated with straw in the stud cavities, with a mixture of plasterboard and clay for sheathing. The entire wall assembly has an R-value of 3 °C-m^2/W (17 °F-ft^2-hr/BTU). The ceiling is insulated with fiberglass batts and has an R-value of 4 °C-m^2/W (23 °F-ft^2-hr/BTU). The roof is a metal deck that is painted white and reflective to help block radiative heat transfer. The roofing element is also from below ventilated to prevent heat transfer from its surface to the interior spaces. Double pane, low-e windows are used for additional energy efficiency. Whereas most homes in the area do not have any insulation and use jalousie windows that have no insulative or air sealing capacity at all, the Espave House outperforms its neighbors simply due to its construction specifications.

Moisture control is particularly important in the Panamanian climate and has a significant effect on building durability and occupant comfort. Bulk water (rain) penetration is controlled with well-placed down spouts and gutters to drain water away from the building, deep overhangs to keep water off the walls and windows, and free-draining building materials around the building perimeter. Free-draining materials such as crushed stone permits the flow of groundwater downwards and when properly installed, prevents water from collecting at the foundation walls and slab.

Due to an innovative passive dehumidification system, the Espave House can mainatain the level of relative humidity around 50-60% year-round. In conventional houses the relative humidity rises to about 70-90% during the summer season. The side effects of higher humidity are reduced comfort and the energy it takes to cool and dehumidify interior spaces. Furthermore, a typical house absorbs hundreds of gallons of water during the summer months and cooling system has to do more work to dry the interior at considerable energy expense (2254 KJ/kg or 970 BTU/lb of water).

The passive dehumidification system for the Espave House is a cold water plunge pool in a small covered pavilion connected to the southern-eastern part of the house. The plunge pool is a bi-level four square meter outdoor ‘tub’ that is designed to be like an outdoor hot tub (with cold water) for relaxation and play (Fig. 9). The water from the plunge pool is significantly colder than the surrounding air temperature, and serves a surface against which moisture from the humid air can condense. Ceiling fans and prevailing eastern winds help to circulate the cooled dehumidified air through open windows into the house.

Fig. 9: Plunge pool passive dehumidification system.

The final design strategy towards net zero energy in the Espave House are the energy systems. This includes energy consuming equipment as well as the energy generation systems. The first consideration is to size the major equipment in the home correctly and select systems that are very efficient. That includes the air-conditioner and water heater as well as the duct and piping systems that deliver air and water to the outlets. The next opportunity to reduce energy loads is to use higher efficiency lighting and appliances. Once the home's energy demand is reduced, a renewable energy production system (PV, in this case) is installed to provide the electricity used in the home and offset electricity supplied by the utility when averaged over the course of one year.

In the Espave House, the owners worked to eliminate or find less energy intensive alternatives for major household appliances. For example, they also choose to use a solar-thermal hot water system rather than an electric hot water heater, as is common in the area. Appliances like the wall-mounted air conditioning unit, refrigerator, laundry machine, and dishwasher were all Energy Star-rated top-of-the-line American products. Almost all lighting in the house is florescent and plug loads are unplugged or put on a switched outlet strip.

The energy production system is a 2 KW PV system that generates all the home’s electrical power. The PV is oriented due south to maximize yearly power output and achieve the lowest cost per watt. A 100-amp hour 48 volt battery pack can power the critical loads during a power outage when the sun is not shining. For the home’s domestic water load, a solar hot water system using 110 evacuated glass tube collectors (112 square feet; 10 square meters), coupled with a stainless steel hot water tank, and a circulator pump was installed. Once the tank has met the set point temperature, excess hot water from the collectors is used for the plunge pool.

5. CONCLUSION

Every building, no matter how well-conceived, designed, and operated, loses and gains heat, moisture, and air as a result of differences between indoor and outdoor conditions. These factors, to a large extent, determine the amount of energy a building will consume. There is a growing interest, driven by changes in the global climate, rising fuel prices, and attitudes of the public, in the design and construction of buildings that consume less energy. The house analyzed in this study illustrates that there are numerous strategies to achieve net zero energy for homes in tropical climates. The significance of this analysis, showing a wide range of possible strategies, indicate that there are a variety of different ways to reduce energy demand even in remote regions around the world.

There are no standard designs for zero energy homes. Shape, size, orientation, climate, equipment, occupancy behavior, and energy production systems are part of the range of decisions that must be considered. There are three primary areas that must be considered for *any* building that strives towards net zero site energy use. The first step is to focus on the overall architectural organization, size, orientation, massing, roof forms, and location, and to assess their contributions to overall building loads. Second, the building envelope must be characterized – in terms of its construction type, materials, insulation, and air and moisture barriers – to ensure reduced energy use and well as improved comfort for the building’s users. Only when these first two steps have been optimized can the building’s operational costs be lowered – by selecting efficient systems, appliances, and lighting. For each one of these areas of consideration, there are a variety of approaches – and much of it depends on the aesthetics, budget, and expertise of the design team and its ability to work closely together to optimize the functioning of the whole building as a system. In this case study, the owners and designers worked closely with the builders to ensure that site design, lighting, window fenestration, energy delivery systems, etc., were considered *together*, rather than discrete parts of the project. The results of such coordination (called integrated design) contributed to lowered first costs (PV system was sized smaller than originally estimated) and produced long term benefits (better humidity control due to efficient thermal envelope).

Future improvements in residential energy efficiency can be made by better modeling and monitoring of energy consumption data to determine where to make changes and how these decisions impact the environment. Simply accounting for net zero site energy use does not fully encompass the scope of the sustainable building movement. Other categories for concern, such as occupancy patterns and behavior, site selection and building location, water efficiency, indoor air quality, and construction resources, must be addressed. The development of accurate energy models that are dynamic and can calculate the complex interactions between various components ought to be used to propose energy conservation measures (ECMs). The process is iterative and necessary at all stages of design to inform the development of energy efficient housing and the systems within them. In the coming years, providing examples of successful net zero energy buildings and an accurate means to evaluate their environmental impact will help to facilitate the widespread acceptance of and enthusiasm about Net Zero Energy.

6. REFERENCES

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