A SOLAR FARM PROTOTYPE DESIGN THAT ACHIEVES NET-ZERO STATUS AND ECONOMIC DEVELOPMENT AT THE ORGAN PIPE CACTUS NATIONAL MONUMENT IN ARIZONA, USA

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ABSTRACT
Faculty and students of the House Energy Doctor (HED) Master of Science program at the University of Arizona's College of Architecture, Planning, and Landscape Architecture are currently engaged in a multi-year effort towards accomplishing a vision that would preserve the heritage of the Organ Pipe Cactus National Monument (OPNM) buildings while transforming its status into the first net-zero park in the United States. The project is a collaboration with experts in heritage architecture from the park and students and faculty of HED. During the years, 2015 and 2016, of the project, two major park-built areas have been redeveloped; the Visitor Center and the Residential loop. While the work on the visitor center was documented and published in WIT STREMAH 2017, Alicante, Spain, this paper presents the recent work performed in 2016 on the one-mile residential loop. Three major tasks have been accomplished in this built area and focused on transforming the existing 13 residences into net-zero operation. The first accomplishment is the energy efficiency achieved through the use of energy performance simulation and integration of advanced environmental systems. The second, is the economic impact through the alternative designs developed in Studio 601 that focused on regional sustainable energy efficient high-performance buildings using latest environmental technologies for indoor and outdoor spaces. Development of the residential loop conformed to Mission 66 standards while added an important education trail component to the complex. Finally, all environmental strategies used in the design development were verified by empirical research and experimentation in the House Energy Doctor laboratory. This paper demonstrates the methods of intervention used on the residential loop to achieve the net-zero status and three redesign schemes as well as the energy performance predictions and verifications. These valuable findings could then be transformed to the design profession to facilitate future net-zero performance buildings.
Keywords: net-zero, national park, energy efficiency, energy audit, solar farm.

1 INTRODUCTION

The Organ Pipe Cactus National Monument (OPCNM) in Arizona, USA is an International Biosphere Reserve that reveals a thriving community of plants and animals. Human stories echo throughout this desert preserve, chronicling thousands of years of desert living. It. extends its geographical borders from southwestern Arizona down south to Sonora, Sinaloa and Baja California in Mexico. The name of this National Monument comes from the Organ Pipe cactus plant, which can be only found in this part of the world. The park is a showcase that celebrates the life and landscape of the Sonoran Desert and its many wilderness of plants, animals, dramatic mountains and unique desert scenery converge within 500 square miles.

The House Energy Doctor "Design and Energy Conservation" program [1] at The University of Arizona's College of Architecture, Planning, and Landscape Architecture (CAPLA), directed by Professor Chalfoun, has initiated a 3-year contract with the OPCNM to conduct a level III energy audit [2] and water audit [3] that will achieve a sustainable net zero energy and water compatible campus with minimum carbon footprint that will become a showcase for all other park services in the United States.

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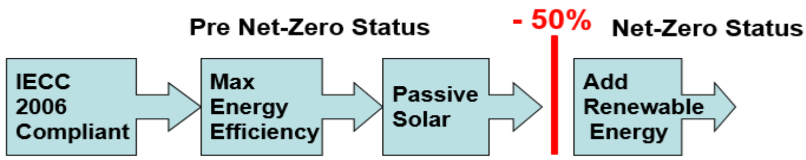

Figure 1: The pre-net-zero status.

2 THE NET-ZERO APPROACH

A net-zero performance indicates that a building is capable of producing energy equal to the total amount of energy it uses over a period of one year. Therefore net-zero buildings must be populated with photovoltaic or wind turbines that generates free and clean energy from the sun or wind respectively to match the conventional energy used. However, it is integral to the process that before building designers attempt applying this technology, a notable energy consumption reduction must be first achieved through energy conservation measures and passive heating and cooling design. This is called the pre-net-zero status [4]. This way the cost of technology to achieving net-zero is affordable.

3 THE ONE-MILE RESIDENTIAL LOOP AT OPNM

During the first year of the agreement [5] four major built area at the OPCNM campus are identified. They are, 1) the Visitor Center, includes administrative offices, bookstore, museum, projection/media room, and information center, 2) the one-mile residential loop consists of an administration building with 9 residential units, 2 attached duplex facilities, and two resource centers, 3) the Maintenance Yard which consist of 2 resource buildings, one Law Enforcement Facility and a series of attached maintenance labs arranged in two parallel blocks and three adjacent manufactured office trailers, and 4) the Campgrounds, a 208 space campground with RV sites up to 40ft, and a designated tent section and six restrooms. The focus of this research is the one-mile residential loop (Fig. 2).

During the second year of the agreement, in 2016, three major tasks have been accomplished by the House Energy Doctor's students and faculty. These activities included

Figure 2: The one-mile residential loop.

first conducting a level III energy performance prediction and analysis. This step was followed by a design intervention to the one-mile residential loop area that will transform the area into net-zero operation. Finally, some aspects of the design were tested through empirical analysis at the Environmental Research Laboratory of the House Energy Doctor Program to verify the performance of proposed designs and energy efficient strategies.

4 ENERGY PERFORMANCE PREDICTION AND ANALYSIS

Before any design intervention to be conducted a thorough level III energy audits were performed by the House Energy Doctor students. The energy performance have been documented and optimized through advanced energy efficiency strategies [6]. On average all building saved about 50% of the current operational energy usage.

In order to assure successful energy audits important information must first be obtained and processed. This information was used while conducting the actual audit and do inspection and measurements. This pre-audit effort requires the followings:

- Obtain construction documents of each building and equipment/mechanical system
- Obtain annual utility bills information and building occupancy schedule
- Distribute site forms and Coordinate visits date/time with building owners/managers

4.1 Level III energy audit and parametric analysis

On September 22nd, 2016, students and faculty visited the project site and used specific instruments and tools to conduct level III energy audit. A specially designed site forms were used to document the information in greater detail and to make sure all data needed by the computer simulation software is collected.

After the site visit and energy audit students investigate and predict the thermal performance of the existing buildings using two different software; E-10 [7] for residential construction and eQUEST [8] for commercial buildings. All buildings had to be verified for their code compliance using the REScheck^{TM} and COMcheck^{TM} software. Results of the as-is and code compliance case are documented to estimate the current energy consumption and cost of operation of the buildings.

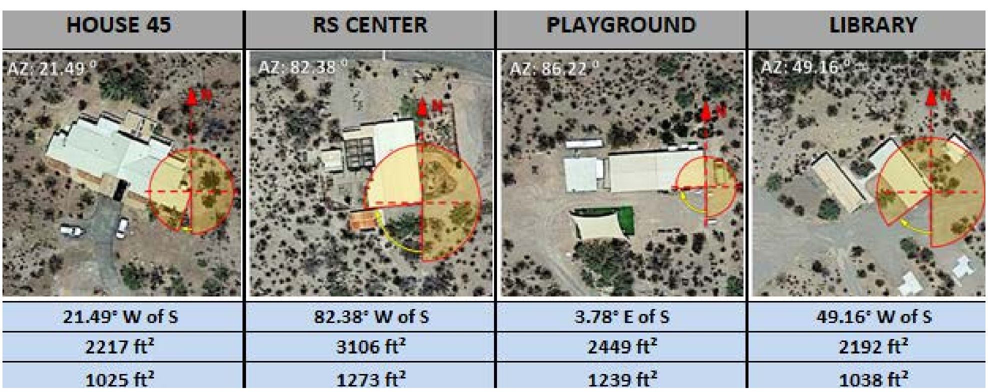

Figure 3: Sample of pre-audit data collected from the one-mile residential loop houses showing the orientation and areas of total and conditioned spaces.

Figure 4: House Energy Doctor students conducting level III energy audit.

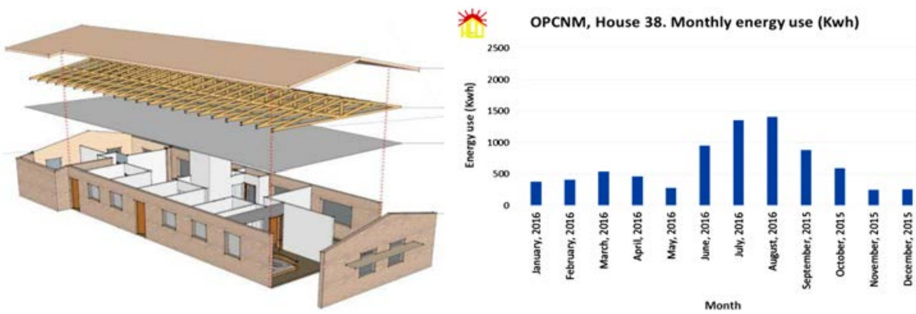

Figure 5: Building analysis and energy use.

4.2 Parametric analysis and energy performance optimization

Following base case performance prediction and code checks, a parametric analysis is conducted by student's teams to optimize the performance of the buildings they choose. The process helps verify and estimate the energy and cost savings resulting from each energy efficiency strategy including its carbon reduction and return on investment.

Before energy optimization, a list of environmental response deficiencies has been documented. Key features discovered were that the house were oriented in the North East manner, thereby receiving a higher amount of solar gain in the summer, leading to higher HVAC loads. The construction material was predominantly adobe CMU blocks (albedo value of 0.35) with some homes having converted their garages into dorm rooms with wood construction. Also, the houses had pitched roof with rainwater gutters already installed. Some houses had a Ramada area to the west side.

Figure 6: Some housing units at the OPNM subject to level III energy audit.

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After identifying the deficiencies, each design team put forth proposal for various measures to be undertaken for retrofitting the buildings. Some of these were:

1. Dividing some existing home into duplex of 750 ft² each unit for rent.
2. Introduction of cool 15 feet high towers that would provide roughly 3400 cfm of air flow within the cooled space and reduce loads on HVAC systems.
3. Replacement of existing single pane windows with light shelves that would allow for maximum solar gain in winter while minimizing solar gain in summer.
4. Rain water harvesting mechanism with a 350-gallon cistern to be used for xeriscaping.
5. Replacement of gas powered water heater with solar water heaters.
6. Introduction of 7kw Photovoltaic panels with 20% efficiency occupying 320 ft² of roof space and also serving as vented roof.
7. Energy retrofit strategies in each house will be demonstrated for educational purposes converting the houses into a showcase of desert architecture design.

5 NET-ZERO DESIGN INTERVENTION

The one-mile residential loop including the community center had to be redesign by integrating sustainable energy efficient high-performance strategies emphasizing latest technologies for indoor and outdoor spaces.

After two visits to the park by the studio 601 faculty and students, design and climatic analysis have been conducted to verify some of the current building deficiencies and a summary of observations has been developed. Some of the observed deficiencies dealt with building's orientation, uninsulated CMU of the envelope, lack of shading, lack of connectivity between the building and its surroundings, minimum use of passive and active strategies such as natural ventilation, daylight, rainwater harvesting, or renewable energy. Analysis of these deficiencies resulted in student development of three alternative design schemes for the residences and community center. All themes suggested environmental technologies that would transform the one-mile residential loop into a net-zero facility.

Figure 7: Proposed energy efficiency and environmental strategies.

The schemes titles and students’ names are:

1. Desert Reconnection: Abdulla Alnuami, Cesar Rojas, and Heather Havelka
2. Rising through the Desert: Ambar Gardner, Michel Fernandez, and Fatemeh Sharaf Zadeh
3. Vision of a Model Desert Habitat: Osama Imam, Suhaib Noor Wali, and Monica Shanchez.

5.1 Scheme 1: Desert Reconnection

The team vision is to create an architectural intervention within the Organ Pipe Cactus National Monument’s residential loop that is aimed at reconnecting both nature and social levels of the built area and through the implementation of energy efficiency education trail and demonstration through design on a community educational platform.

Different educational chapters would be introduced within this educational trail that would allow for further exploration and understanding of sustainable desert-dwelling. The three chapters of education proposed within this scope of the educational trail was a) solar awareness where people would understand how the sun would move throughout the day and how that affected the built environment, b) water knowledge be demonstrating how water is used within the desert properly in terms of landscaping and collection, and c) earth integration strategies inspired by the Kiva concept that allows further understanding of earth's thermal inertia and the benefits of dwelling beneath the surface in the desert.

Figure 8: Proposed educational trail at the one-mile residential loop.

Figure 9: Proposed educational trail at the one-mile residential loop.

Figure 10: Proposed community center design and technologies.

The community center on the residential loop in organ pipe cactus national monument is an image of reconnecting on the social and natural levels. The function of the community center has three main programs of an educational environmental laboratory, a multi-functional centered space, as well as a fitness area. All these three programs are linked to a greater outdoor social space that allows for the connection of the community to one another. The three functions also have exterior spaces that allow activities within the three distinct programs to be exhibited outside and be connected with nature and the greater desert context. It is also designed to become the net-zero PV station [9].

5.2 Scheme 2: "Rising through the Desert"

The overall vision of the "Rising through the Desert" team is to create a net-zero residential community at OPCNM that is based on strengthening the social and cultural aspect through greenways and providing a potential design/build community center that demonstrates principles of living in harmony with the desert. Rising through the Desert's vision was based on three areas of improvement recognized throughout the design process that were; 1) connection & seamless edges, 2) landmarks, and 3) gathering and recreational activities. The proposed design scheme adapts the unique natural environment of the Sonoran Desert with the existing built environment to positively impact the human experience and create a net-zero educational community to become the first net-zero national park in the world.

The houses in the team's scope are 24, 27, 39, and 38. They are made of frame construction with stucco on the exterior and house 39 is adobe (slump block) masonry as seen in Fig. 12. Due to their orientation, the existing houses are exposed to maximum solar gain on the east and west façade. One of our challenges during this design process was to retrofit the built environment to provide a more thermally comfortable space without disrespecting mission 66. None of the vegetation throughout this design was damaged or removed. The main facades of the buildings facing the main entryway were left untouched to comply with Mission 66.

The application of environmental strategies was applied to achieve a net-zero status. The following image depicts the proposed environmental strategies for each of the residences in the team's scope.

The community center is located approximately half a mile northwest from Kriss Eggle Visitor's Center and is composed of five main areas which are; 1) a gym, 2) a children's playground, 3) a basketball court, 4) a shaded gathering space, 5) and a south facing courtyard totaling an area of 4521 ft^2. The following chart divided the Community Center's square footage including the scarred area.

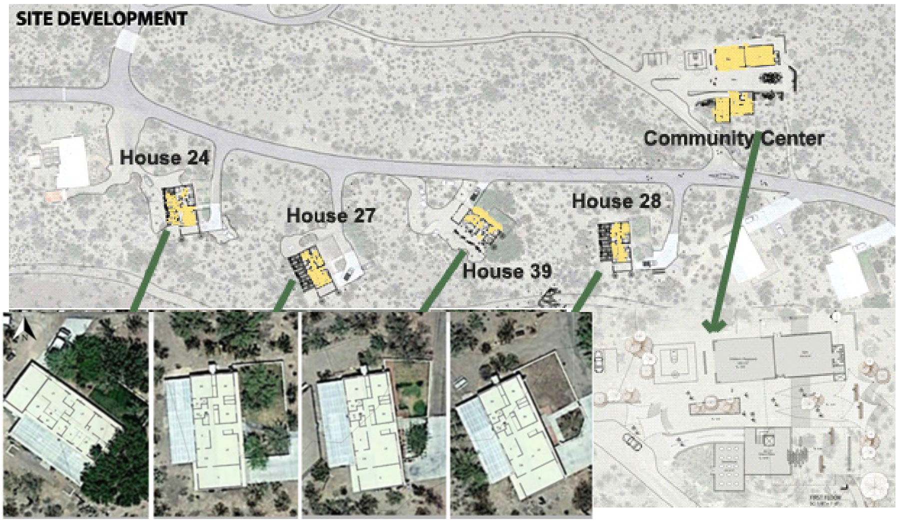

Figure 11: Proposed educational trail at the one-mile residential loop.

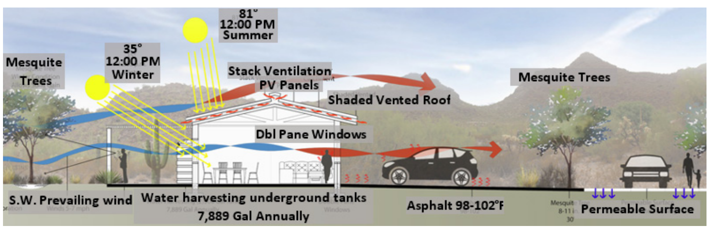

Figure 12: Proposed environmental strategies for the residences.

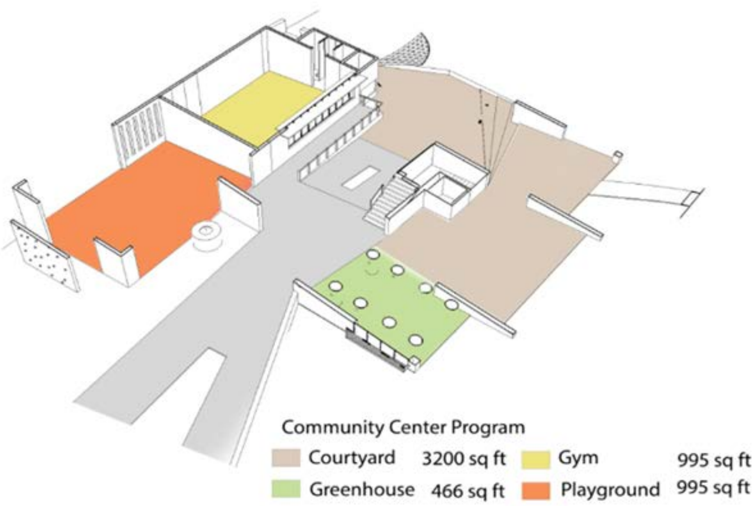

Figure 13: Proposed community center program.

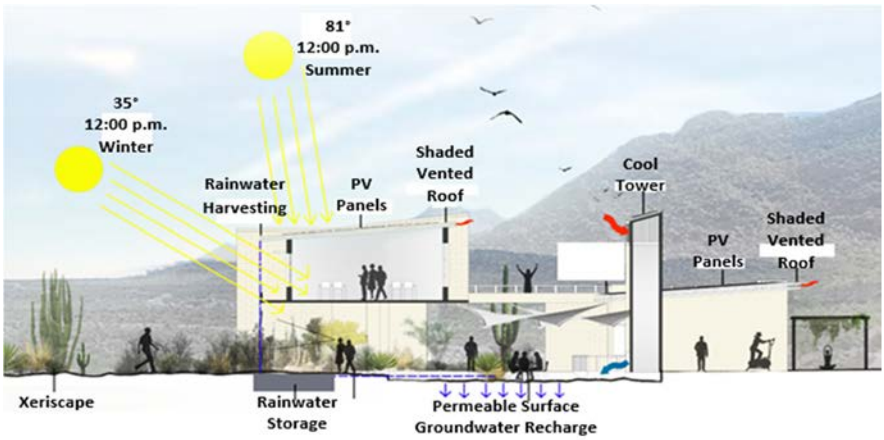

Figure 14: Proposed environmental strategies for the community center.

The proposed Community Center also incorporated a variety of sustainability features and passive cooling strategies [10] demonstrated in the introduction of a cool tower, shading, alternative building envelope materials [11], water harvesting, and rooftop Photovoltaics to help achieve the net-zero status.

The design focused on making connections between the users, the natural settings, and the built environment. The spaces give the users the opportunity of a visual and physical connection with the outdoors. All spaces incorporated in the Community Center were designed to allow the user to always have the opportunity to connect with the desert. For example, the built environment like the gymnasium, children's playground, the library, and orientation room all have complete access to the outdoors. Each space has the opportunity to function outdoors. Some examples of seamless edges are illustrated in Fig. 15.

5.3 Scheme 3: A Model Desert Habitat

This student team goal is to create a new net-zero residential community at Organ Pipe Cactus National Monument, Arizona that is based on strengthening the social and cultural aspects through greenways and providing a potential design/build community center that demonstrates principles of living in harmony with the desert.

Figure 15: Educational trails and enhanced family activities at the community center.

Figure 16: Living in harmony with the desert at the one-mile residential loop.

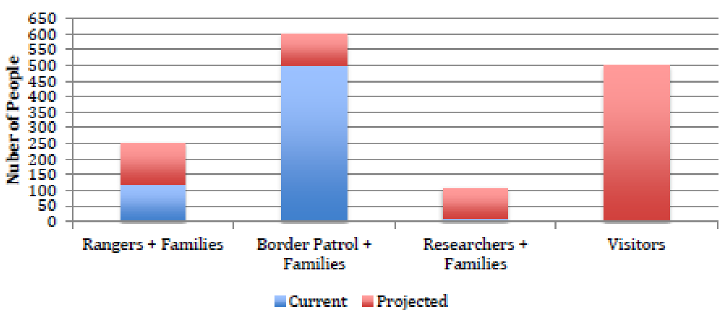

Figure 17: Existing and projected population at the residential loop.

The design vision is to develop a model desert habitat residential loop that achieves net zero energy goal while serving as a world-renowned education and research facility that brings communal harmony and integration.

An important aspect of the project was to analyze the population of the site and examine how it may be possible to enhance their experience at the site. One of the essential goals was to increase population figures at the site and provide for a new category, i.e. visitors.

The community center proposed design doubled the floor space of the currently existing (~1000 ft^2), providing for a "heart and arteries" design flow, whereby it functions as the hub for the residential loop. Salient features developed at the Community space were Active zones consisting of enhanced children's playground, basketball court along with recreational gym facility. This was done taking into consideration the different user types and ages that visit the site. In order to ensure maximum population engagement of all visitors, we sought to create multiple zones such as the north part where we put the library or the south part with

Figure 18: Design of the new community center showing a proposed PV panel's canopy (upper) and different proposed activities at the southern portion of the site (bottom).

the activities zone. The design of the community center was such that it may serve as inspiration for visitor in order to educated them on what an arid land design should be, through emphasis on features such as shading, natural ventilation and other passive design elements.

6 CONCLUSION

The Organ Pipe Cactus National Monument one-mile residential loop has been re-envisioned to become a net-zero operation. The design was targeted to ensure that the site achieved the goals of energy efficiency and energy independence while have a higher communal harmony and integration though the utilization of sound environmental policies. Realizing the project's goal at addressing global status, the one-mile residential loop including the community center had to become an educational facility as well. Each design team justified their suggestive strategies and the environmental rationale backing it. Through the implementation of the three-part intervention (Housing, Community space, multi-purpose educational loop), the project aimed and designed a site that encouraged residents to stay back over weekends and brought a higher number of visitors bringing higher revenue to the site.

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