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DEVELOPMENT OF A LARGE SOLAR-SHADING STRUCTURE THAT PROVIDES HUMAN THERMAL COMFORT WHILE ACHIEVES NET-ZERO STATUS AT ORGAN PIPE CACTUS NATIONAL MONUMENT IN ARIZONA

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Development of a Large Solar-shading Structure that Provides Human Thermal Comfort While Achieves Net-zero Status at Organ Pipe Cactus National Monument in Arizona, USA

Synopsis:

The Organ Pipe Cactus National Monument in Arizona, USA, is transforming its campus to become the first Net-Zero operating park in the U.S.A. The House Energy Doctor Master of Science program's faculty and graduate students at the College of Architecture, Planning, and Landscape Architecture have been working on that project for the last three years. To achieve the Net-Zero goal, the existing four built areas of the park have been redesigned through Studio 601 faculty and students. These four areas are 1) the visitor center, 2) the one-mile residential loop, 3) the Maintenance Yard, and 4) the law enforcement and the research center complex. This paper demonstrates how the four built areas of the park were studied and how the maintenance yard energy consumption and operating cost was redesigned and redeveloped to include large solar-shading structures that provided human thermal comfort and achieve the goal of net-zero operation campus. 470 modules producing 345 watts distributed over 3 arrays on one of the maintenance yard scheme produced 1.1 GW capacity while acted as a water catchment and harvesting device for the research center.

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Keywords: Energy efficiency, passive solar, thermal comfort, sustainability, Net-Zero Design

ABSTRACT
The Organ Pipe Cactus National Monument in Arizona, USA, is transforming its campus to become the first Net-Zero operating park in the U.S.A. The House Energy Doctor Master of Science program's faculty and graduate students at the College of Architecture, Planning, and Landscape Architecture have been working on that project for the last three years. To achieve the Net-Zero goal, the existing four built areas of the park have been redesigned through Studio 601 faculty and students. These four areas are 1) the visitor center, 2) the one-mile residential loop, 3) the Maintenance Yard, and 4) the law enforcement and the research center complex. This paper demonstrates how the four built areas of the park were studied and how the maintenance yard energy consumption and operating cost was redesigned and redeveloped to include large solar-shading structures that provided human thermal comfort and achieve the goal of net-zero operation campus. 470 modules producing 345 watts distributed over 3 arrays on one of the maintenance yard scheme produced 1.1 GW capacity while acted as a water catchment and harvesting device for the research center.

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 Audits [2] and water Audits [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.

ORGAN PIPE CACTUS NATIONAL MONUMENT
The Organ Pipe Cactus National Monument consists 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 only be found in this part of the world. The Organ Pipe Cactus gets its name from its many vertical stems, resembling an Organ Pipe. In the Fall of 2017, the House Energy Doctor design team conducted a level III energy audits at the park.

Fig. 1: House Energy Doctor team at Organ Pipe Cactus Park

Figure 2: Location of Organ Pipe Cactus National Monument in Southwestern Arizona.

According to the FY14 utility cost information, the park consumed approximately 300kWh of electricity in 2014 which costs the park approximately $40,000 per year. The objectives include the production of a comprehensive assessment of the park's power consumption, identify ways in which the park can both reduce power consumption and support the development of sustainable energy sources, and encourage the general public to improve energy efficiency in their own home and reduce our Nation's dependence on fossil fuels. Recommendations from the reports would be used to develop funding statements and proposals and implementing recommendations would result in the park saving/producing as much or more energy than it consumes and achieve greater NPS-wide goals of becoming a "Green Energy Park."

OPCNM consists of 4 built areas: 1) the visitor center, 2) the one-mile residential loop, 3) the maintenance yard complex that also includes the resource management and research center and the is paper emphasizes a synthesis between "logic" and "intuition" to develop sustainable and green strategies for the Isaacson residence. The author collaborated closely with the homeowners to optimize the design and the thermal performance of the envelope. The well informed and knowledgeable owners combined with the gorgeous site views provided the necessary ingredient for the success of the design as a showcase for energy efficiency.

Figure 3: The four built areas of the Organ Pipe Cactus National Monument.

During the Fall of 2017, Studio 601 lead by Professor Chalfoun, developed the maintenance yard built area. They visited the site and conducted an energy analysis and evaluated the buildings and the landscape to suggest a series of interventions that will potentially achieve the net-zero status.

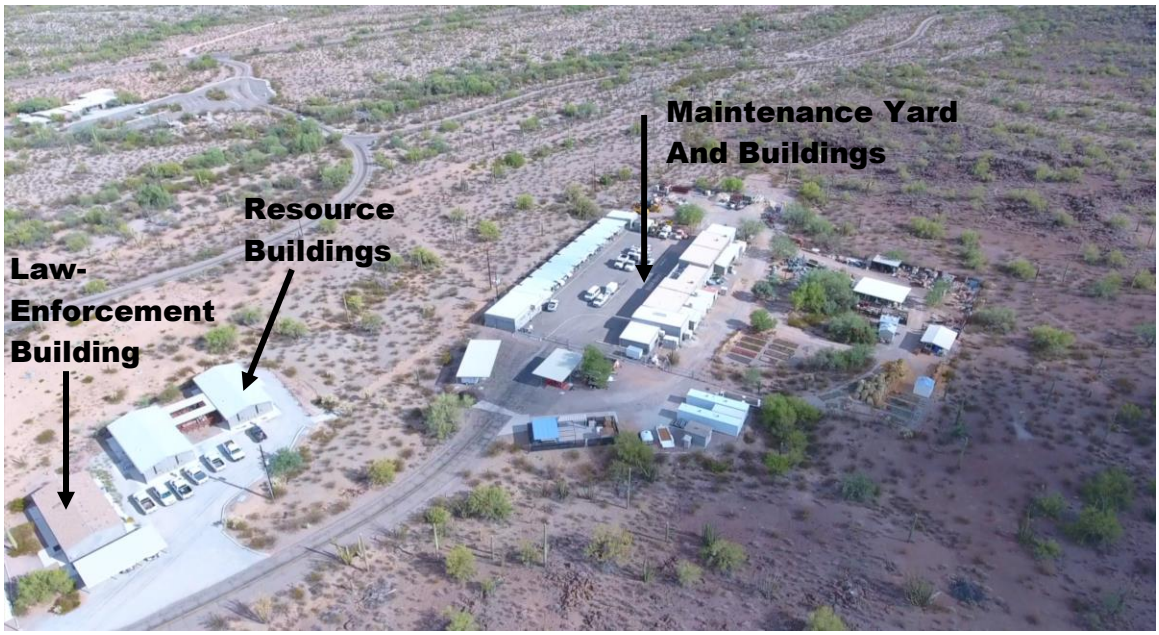


Figure 4: Maintenance Yard Complex

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.

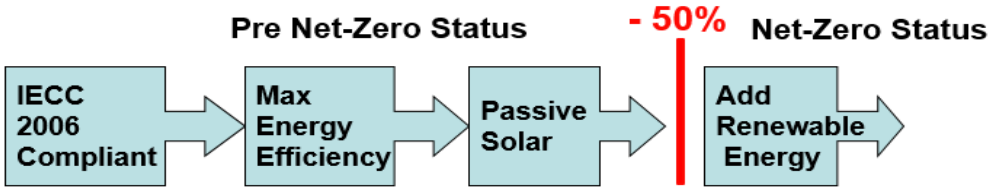


Figure 5: The Net-Zero Approach

ANALYSIS OF THE MAINTENANCE YARD COMPLEX

the Maintenance Yard complex consists of two resource buildings 1,860 ft, one Law Enforcement Facility 1,600ft^2 and a series of attached maintenance labs arranged in two parallel blocks and three adjacent manufactured office trailers.

During the site visit three major tasks have been accomplished by the House Energy Doctor's students and faculty. These activities included first conducting a survey of all buildings including take-off dimensions and photos, second, conduct a level III energy audits on all buildings, and third, interview with the maintenance engineer to establish design guidelines that meet the expectations of the yard operation. Some of these activities are presented in figure 6 below.

In addition to those three tasks, students were asked to conduct a thorough investigations on the existing conditions of the site and buildings and summarize a set of observations (acknowledgments and/or deficiencies) on how this built area respond to the environmental conditions of the site including the surroundings and accessibility. A summary of these observations is presented in Figure 7 below.

Figure 6: House Energy Doctor Students conducting Level III Energy Audits and Interviewing Park's Officers and Rangers

Figure 7: Site Observations: 1) Outdoor spaces underuse, 2)disconnected built environments, 3)entrance not celebrated, 4)office functions, 5)lack of vegetation for comfort, 6)inefficient mechanical systems, 7)lack of storage spaces, 8)no insulation, 9)lack of research collaborative spaces, 10)lack of covered equipment storage spaces, 11) not recommended solar orientation, 12) use of daylight, 13) lack of windows shading, 14) overuse of non-shaded asphalt, 15) no consideration for renewable energy sources, 16) no consideration for water harvesting systems.

PROPOSED DESIGN INTERVENTION

Several design schemes were analysed and presented by the students after visiting the site and analysing its buildings. Since most of the Organ Pipe Cactus National Monument buildings are on the national registry of historical buildings, any proposed new intervention must comply with Mission 66 guidelines.

Mission 66: is a federally-sponsored program to improve deteriorated and dangerous conditions in the national parks, the result of a massive visitor boom after World War II. Mission 66 represented the largest program for park improvements ever initiated by the National Park Service. It began in 1956 and ended in 1966. During those ten years, more than $1 billion was spent on infrastructure and other improvements in the parks. Although there are many restrictions on how to develop Mission 66 buildings, the Secretary of the Interior's "Standards for the Treatment of Historic Properties" allowed the use of some sustainability guidelines. These are as follows:

1. Add Green Roof: Must consider water sealing, not visible from public access road, structurally sound, uses native plants.
2. Use Solar Cells: Must consider minimum visibility, cause no damage to existing roof, low profile, Tesla new technology.
3. Use Wind Energy: Must validate feasibility as it needs minimum 12 mph annual average wind, cause no damage.
4. Use of Daylight: Add doors, windows, and high windows to corridors, use light well or solar tubes, must consider controls.
5. Site Development: Use of shade trees, permeable paving, replace impermeable surfaces, use of native plants, add bioswales, rain gardens, rain barrels, rainwater collection tanks and cisterns.
6. HVAC: Replace with High Efficiency (SEER) rating, programmable thermostat, use of split systems, add flex and exposed ducts, use ceiling fans, use of geothermal exchange heat pumps.
7. Insulation: Add to unfinished spaces, add air tightening weather-stripping and caulking technology.
8. Add windows: Windows, trombewalls, low emissivity coating.

Design Schemes: Three students design teams (listed in the acknowledgement section) investigated all components of the maintenance yard and came up with three proposed schemes called 1) "Living Greenway", 2) "Ramp of Knowledge", and 3) "Endless Desert"(not presented).

Scheme 1: Living Greenway, is intended to develop a net-zero network of spaces that exhibit and promote the principles of sustainability and conservation within the Sonoran Desert. The vision will be accomplished though harvesting renewable energy, enhance walkability, Integrate buildings with the natural environment, promotes desert education, and encourage collaborative Research

Figure 8: Design Scheme 1 "Living Greenway"

The design proposal suggests the use of a large shade space-frame modular structure that overarches the maintenance yard while integrates about 500 PV panels imbedded into the structure itself. These panels are capable of providing 1,100 Megawatts hours annually.

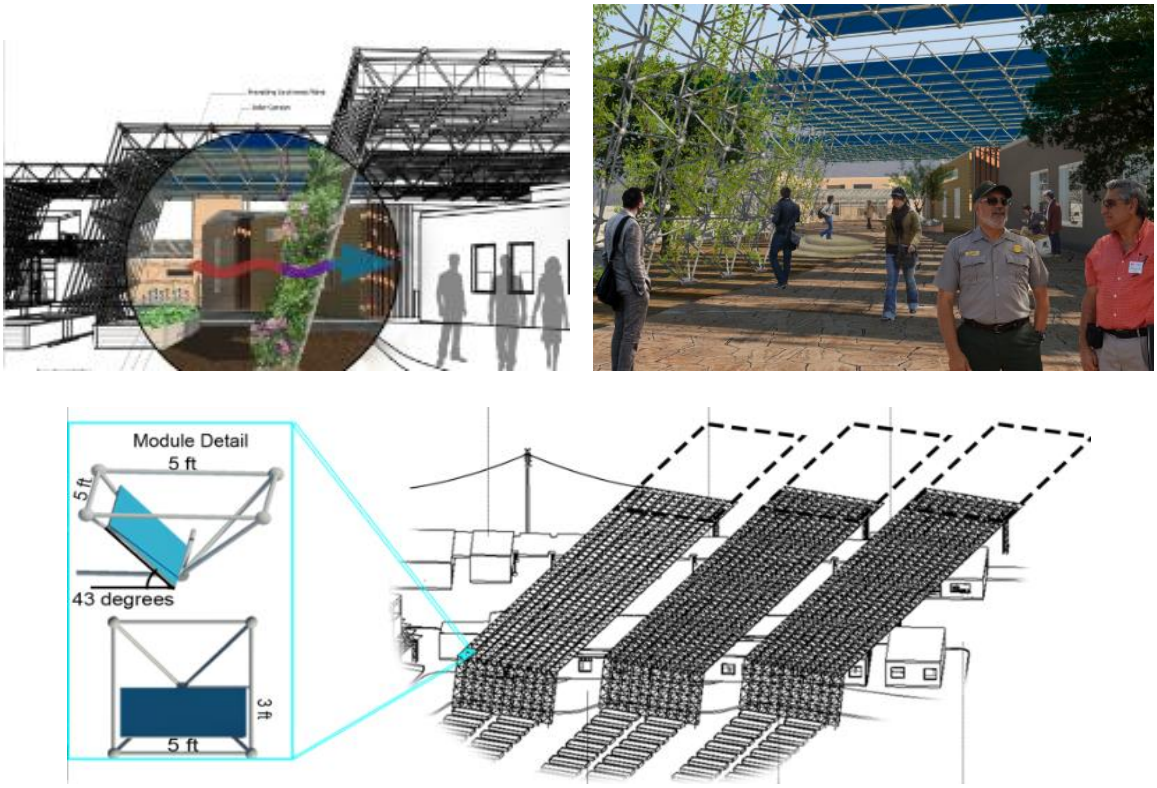


Figure 9: Greenway and PV systems providing 1,100 Megawatt Hours of energy

The new research center building is designed with passive solar technology and in proper response to sun in terms of orientation and placement of windows. It is also equipped with passive cooling technology from a 40 feet high “Cool Tower”. Cool towers are natural down-draft evaporative cooling devices topped with a hydro unit typically equipped with wetted pads, sprays, and other cooling devices which provide cool air by gravity flow. A water harvesting and storage system is provided from the butterfly shaped roof.

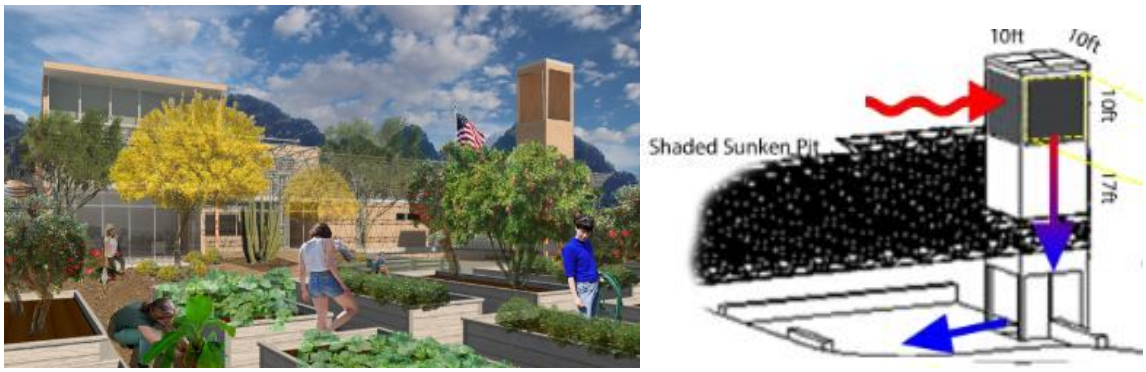


Figure 10: Passive down-draft cool tower technology

Scheme 2: Ramp of Knowledge proposal is to develop a Net-Zero Energy, State of the Art Maintenance Complex that is optimized to work in tandem with Organ Pipe Cactus National Monument's Majestic Desert surroundings. This vision will be accomplished through guiding principles of sustainable design for the purpose of interactive design.

Figure 11: Design Scheme 3 “Ramp of Knowledge”

A compelling aspect of this scheme is the redesign of a celebrated entrance to the whole complex that will integrate all three components of the required built environment; the maintenance yard, the research resource centre and its research garden, and the law enforcement building.

Figure 12: Proposed new entrance to the maintenance yard complex.

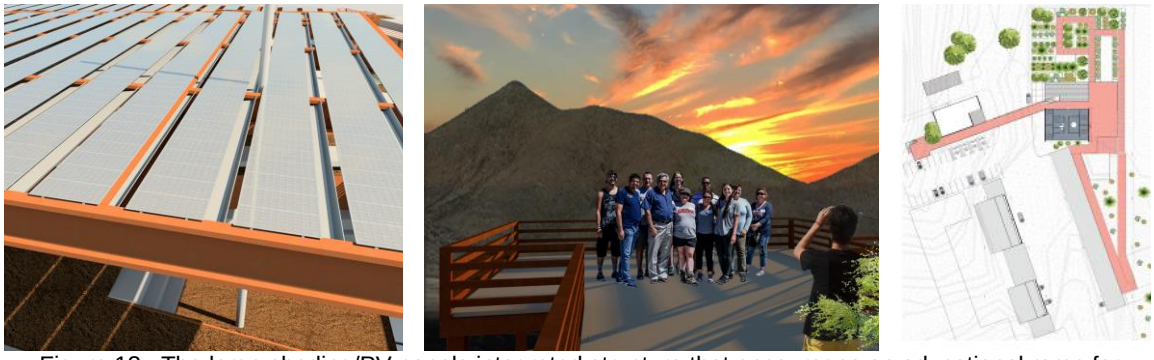


Figure 13: The large shading/PV panels integrated structure that encourages an educational ramp for visitors to learn about net-zero technology while exploring the majestic desert views at the Organ Pipe Cactus National Monument site.

Scheme 3: named “Endless Desert” suggests a mix use maintenance complex with a harmonious integration of the built and natural environments, reducing the existing building foot print, reusing existing structures and infrastructures, limiting the environmental impact and achieving net zero. Due to space limitation this scheme is not detailed in this paper.

Figure 14: Design Scheme 2 ““Endless Desert””

THERMAL PERFORMANCE

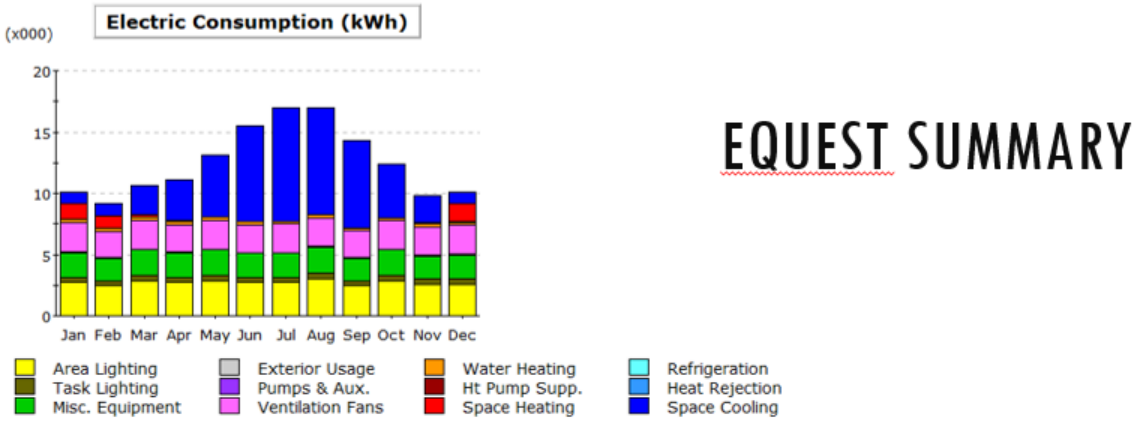
The last step to achieving net-zero operation is to run energy simulation to predict the required annual energy consumption for Park operation. All the redesigned buildings were simulated using advanced eQUEST© energy simulation software. In addition, physical aspects of the project were tested through empirical analysis at the Environmental Research Laboratory of the House Energy Doctor Program to verify the performance of proposed designs and energy efficient strategies.

In this paper the author will present the energy analysis results of the newly proposed resource management and law enforcement buildings.

Figure 15: Existing (left) and newly proposed (right) resource management and law enforcement buildings

To run a thorough energy analysis building information must be surveyed and collected in detail to be inputted into the eQUEST© computer model. A set of architecture drawings was created for simulation purposes that includes building floor plans, sections, elevations, and most importantly a building schedule that documents all spaces areas, construction materials, lighting fixtures, mechanical systems, and thermal zones information.

Preliminary computer simulation results depicted that the building will consume 150.14 MkWh annually with 53.08 MkWh for cooling and 4.07 MkWh for heating and the rest is for lighting and miscellaneous appliances such as computers and other office equipment.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.92	0.96	2.31	3.33	5.12	7.86	9.22	8.75	7.10	4.37	2.21	0.92	53.08
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.25	1.02	0.21	0.02	-	-	-	-	-	-	0.09	1.48	4.07
HP Supp.	0.02	0.03	0.00	-	-	-	-	-	-	-	-	0.08	0.14
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.21	0.18	0.22	0.22	0.24	2.85
Vent. Fans	2.36	2.13	2.36	2.28	2.36	2.28	2.36	2.36	2.28	2.36	2.28	2.36	27.78
Pumps & Aux.	0.07	0.06	0.02	0.01	-	-	-	-	-	-	0.02	0.07	0.23
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	1.98	1.79	2.07	1.98	2.07	1.98	1.98	2.15	1.81	2.07	1.89	1.90	23.67
Task Lights	0.42	0.38	0.44	0.42	0.44	0.42	0.42	0.46	0.38	0.44	0.40	0.40	5.02
Area Lights	2.73	2.47	2.86	2.73	2.86	2.73	2.74	2.98	2.48	2.86	2.61	2.61	32.66
Total	10.09	9.15	10.61	11.08	13.15	15.54	16.98	16.98	14.29	12.38	9.78	10.12	150.14

Figure 16: Energy analysis results as predicted by the eQUEST© energy simulation model.

Because this is a cooling dominated desert region, the predicted cooling load was larger that the heating. The focus was then on reducing the cooling load utilizing passive and active design strategies to reduce the consumption load before sizing the PV panels that will transform the building into a net-zero operation. These strategies included:

1. Optimize roof and wall insulation
2. Increase air tightness of the envelope
3. Use of high performance windows
4. Outside Windows shading
5. Use of blinds
6. Implement an economizer
7. Use light sensors and integrate daylight design
8. Use external solar reflective materials
9. Specify high efficiency mechanical systems
10. Apply LED light

The outcome of these strategies resulted in a 51% energy consumption reduction and allowed efficient sizing of PV panels. 97 panels were used that produced and annual 73,155 kWh on-site energy and achieved the required net-zero operation in the most effective way.

CONCLUSION

The efficient design and outstanding thermal performance of the proposed new buildings in the maintenance yard complex of the Organ Pipe Cactus National Monument in Arizona as predicted by computer simulation established a new benchmark in net-zero national parks operations. The proposed set of energy efficiency and passive solar technologies all conformed to the Secretary of the Interior's "Standards for the Treatment of Historic Properties".

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