Net zero station design for the Cooper Center for Environmental Learning in Tucson, Arizona

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Abstract

Many old buildings in Tucson were built in the pre-energy code era, have poor performance, and consume immense amounts of energy. By optimizing performance of these buildings, energy consumption is reduced while also presenting the opportunity for the buildings to be converted into an energy generating stations. This research project focuses on promoting environmental awareness by ensuring that the reader acquires relevant conceptual tools and skills to address climate changes and reduce air pollution through wise choices in the built environment. To accomplish this goal, an existing structure at the Cooper Center for Environmental Learning in Tucson, Arizona was re-designed into a Net-Zero energy building. This paper describes the process of design and evaluation of the performance of two of the old buildings at Cooper Center site and how they could be converted into Net-Zero stations that supply the whole campus with energy. The process was divided into two stages; Pre-Net-Zero and Net-Zero. After designing passive strategies for the existing cabins on-site, it was found that the required energy is approx 29,282 kW/hr, which can be produced by adding a 58 PV panel shade structure on the Net-Zero station.
Keywords: net zero station, performance, energy generating, passive strategies.

1 Introduction

Cooper Center for Environmental Learning is an environmental educational facility located in Tucson Arizona. In 1950s, Herbert Cooper, Tucson District Administrator, reserved a 10 acre site at the base of the eastern side of the Tucson Mountains in order to building a new school. A decade later, a need for

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outdoor educational facility emerged and the site was utilized for nature study activities. The buildings consist of bathrooms, storage space, an amphitheatre, large shaded seating area (ramada), cook out grill and concrete slabs on which tents could be placed. The tents were built on those slabs in 1972 and the site was named "Camp Cooper". Now there is an intention for this project to expand its educational scope to include the built environment. The educational program for children at this site allows the overnight experience of nature and lasts 2–3 days. The Cooper Center officials would also like to develop a facility that promotes adult education as well (research groups, different ecological conferences, teachers' courses, etc.) [1].

Since the existing cabins were built in the 70s without any insulation, their thermal comfort is extremely poor. Therefore, one of the goals would be to maximize thermal comfort in the cabins. To reach these goals, different passive strategies were applied. This also became the basis to build a Net Zero station on the site.

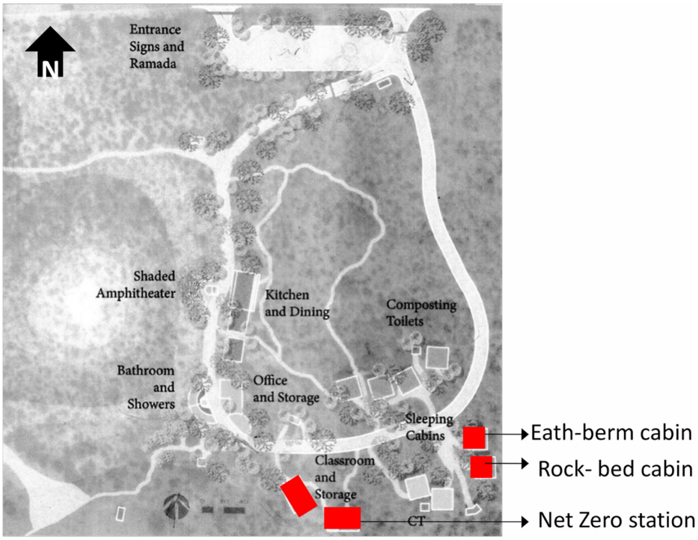

Figure 1: Cooper Center site map.

2 Project description

One of the early steps of the site analysis was to check if buildings were in compliance with Pima County Energy Code. After entering all the required parameters, it was found that the buildings do not comply with the code. These calculations used REScheck Software, developed by the US Department of Energy, as a tool to determine whether new residential projects or additions to existing structures meet the requirements of the Model Energy Code (MEC) or the International Energy Conservation Code (IECC). The buildings failed the REScheck by 128.6% (as shown in Figure 2) [2].

REScheck Software Version 4.4.3

Compliance Certificate

Energy Code:	**Pima County for Locations < 4000 ft**
Location:	**Pima County, Arizona**
Construction Type:	**Single Family**
Conditioned Floor Area:	**420 ft2**
Glazing Area Percentage:	**12%**
Heating Degree Days:	**2100**
Climate Zone:	**2**

Construction Site: Owner/Agent: Designer/Contractor:

Compliance: **Fails on UA trade-off**

Compliance: **128.6% Worse Than Code**

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Glazing or Door U-Factor	UA
Roof Left: Flat Ceiling or Scissor Truss	210	0.0	0.8		80
Roof Right: Flat Ceiling or Scissor Truss	210	0.0	0.8		80
Side Wall 1: Solid Concrete or Masonry:No Insulation	160				39
Window 1: Other SHGC: 0.40	44			3.000	132
Side Wall 2: Solid Concrete or Masonry:No Insulation	160				39
Window 2: Other SHGC: 0.40	44			3.000	132
Front: Solid Concrete or Masonry:No Insulation	205				61
Door 1: Solid	21			0.360	8
Rear: Solid Concrete or Masonry:No Insulation	205				68
Floor 1: Slab-On-Grade:Unheated Insulation depth: 0.0'	82		0.9		85

Figure 2: Compliance certification generated using RES-check, shows that the cabins are not in compliance with the energy code of Pima County, Tucson.

In order to make buildings Net-Zero, we followed the two step strategy: 1. Pre Net Zero – all building performances were enhanced to meet the Pima County Energy code standards; 2. Net-Zero was achieved by adding PV panels to previously enhanced buildings [3].

3 Pre-net zero strategy

One of the project requirements from the owner was to try to maintain the existing structure, preserve existing vegetation, and minimize the negative impact of humans to existing land structure. Different passive strategies were applied such as, rock bed, solar chimney, sky-therm, and earth berm. These

Figure 3: Existing cabins on the South East part of the site.

strategies not only make the cabins more energy efficient and thermally comfortable, but they are also a potentially valuable teaching tool for children about environmental systems that they can experience by an overnight stay in each cabin. As a part of educational process, one of the cabins was left without modifications so that children could compare it with enhanced cabins.

Figure 4: Proposed South East part of the site.

3.1 Rock bed cabin

The cabins from the figure above are ‘earth berm’ and ‘rock bed’ cabin. For the ‘rock bed’ cabin, main system elements are a thermpsiphon which is a flat plat solar collector on the south side of the building consisting of a glass plate over a 2″ air gap over a black steel plate and rock bed placed above the existing slab. Air is superheated in the space between the glass and black steel plate. The energy source is the sun, while the collector is a thermosiphon, the distribution system is fan and duct, and the energy storage is rock bed. A back-up system consisting of a Samsung duct line split heating and cooling system is provided.

Figure 5: Proposed cabin design – rock bed.

Operable windows were also introduced in the cabin to aid with system operation and provide for natural ventilation. The passive strategies work as an integrated system whose operation is described below.

After applying the passive strategies, a set of instructions was developed for each cabin as a part of interactive learning process for the children staying overnight at the camp.

In the summer, the air collector (thermosiphon) is blocked to prevent the super heated air from circulating. In the summer night, all the windows are opened allowing the night flush in the cabin while the envelope loses part of its heat to the night sky. In this process, “coolth” is stored in the rock bed by circulating air thru the rock bed that removes heat energy from the rocks and cools them for the following day. Air is then cooled by the rock bed and distributed using mechanically operated fan during summer day. During the day, all the windows are shaded from the high solar angle by an overhang not allowing the direct solar gain into the cabin [4].

During winter days, the thermosiphon that is facing south is open to collect solar radiation that superheats air which is distributed to the space by a mechanically operated fan. Since cool air is heavier in density that hot air and it naturally settles near the floor in the space, the mechanical fan will draw the cool air from near the floor, to be heated in the thermosiphon collector and is distributed again to the room. At night the rock bed that got heated during the day, by direct solar gain from the low winter sun angle radiates the heat into the space.

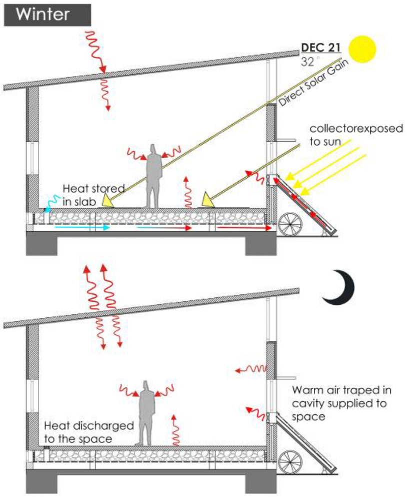

Figure 6: Rock bed cabin environmental system diagram - winter day and night.

As shown in Figure 7, in summer night all windows and rock bed are open to allow night flush to cool the envelope for morning.

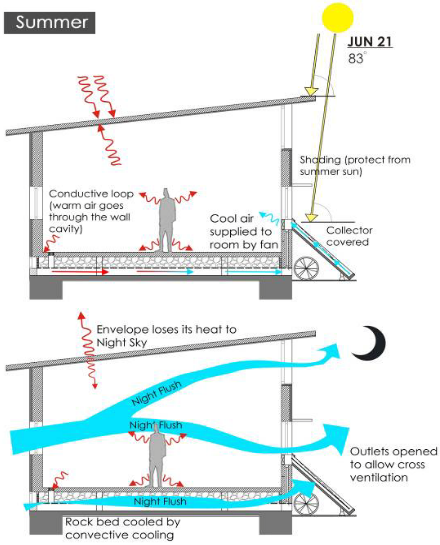

Figure 7: Rock bed cabin environmental system diagram - summer day and night.

Whereas in summer day, direct solar gain from the high summer sun angle is blocked by the overhang, the thermosiphon is covered to avoid receiving any heat. Since the envelope and rock had been cooled during the night, the warm air gets withdrawn by mechanical fan and cooled by rock bed and distributed back into the space as cool air.

One of the goals of the entire project is learning from built environment. This entire process would be explained to children and they would be involved in the process by operating the mechanical fan and opening and blocking the thermosiphon depending on the season.

3.2 Earth berm cabin

Another example of an applied passive environmental system is ‘Earth berm’ cabin. The existing cabin was mostly preserved, while a new earth bermed cabin was built on adjacent land already disturbed by human activity.

The earth-berm cabin is taking advantage of the thermal inertia of the earth acting as a thermal mass offering extra protection from the natural elements. In addition to that, earth shelter is known for its energy efficiency as it can save up to 80% on heating and cooling and it has low life-cycle cost as it is using material onsite as a building material (earth sheltered technology).

This cabin not only provides underground experience for children but it also has windows oriented to allow for exquisite mountain and city views.

In addition to the use of thermal mass and courtyard, cross-ventilation was also one of the passive strategies to make the cabin thermally comfortable. Cross ventilation was tested and validated using wind-tunnel test, after which, a set of

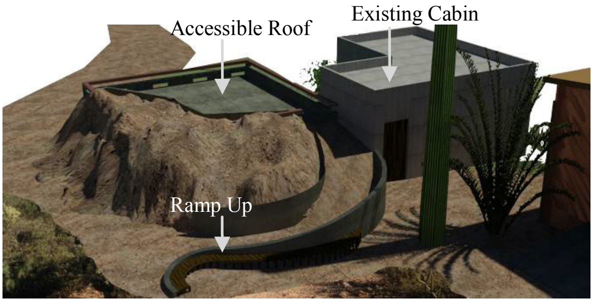

Figure 8: Proposed cabin design - Earth Berm.

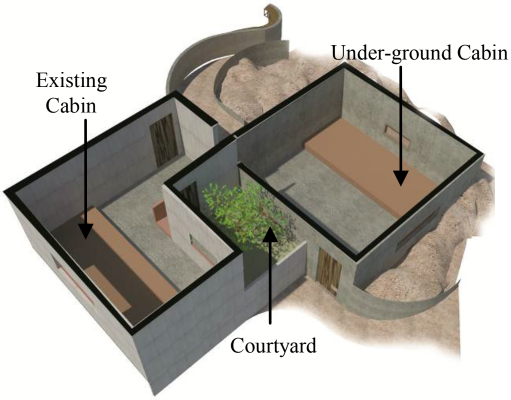

Figure 9: Earth-berm cabin.

recommendations were concluded, in order to control the cross ventilation in summer and winter during day and night [5].

As shown in figures 10 and 11, the windows will be opened during summer day in order to allow cross ventilation. Whereas in winter, the inlet windows of above-ground and under-ground cabins will be closed in order to block the cold winter wind. During night, the prevailing wind would change direction from South east to North west. So the windows are recommended to remain open during summer night, to allow night flush and cool down the envelope for Summer day. On the other hand all the inlet windows are proposed to be closed during Winter night, to block the cold wind from entering the space.

3.3 Net zero station

These set of recommendations will allow the children to have a more interactive role in the cabin. In order to have a successful passive design, it is not only important to apply passive design strategies, but also to change the behaviour of the user in the space.

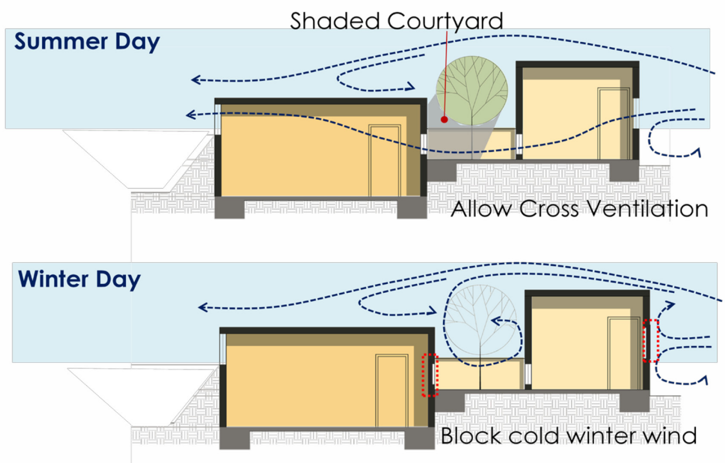

Figure 10: Recommendations for controlling the openings in Winter and Summer day.

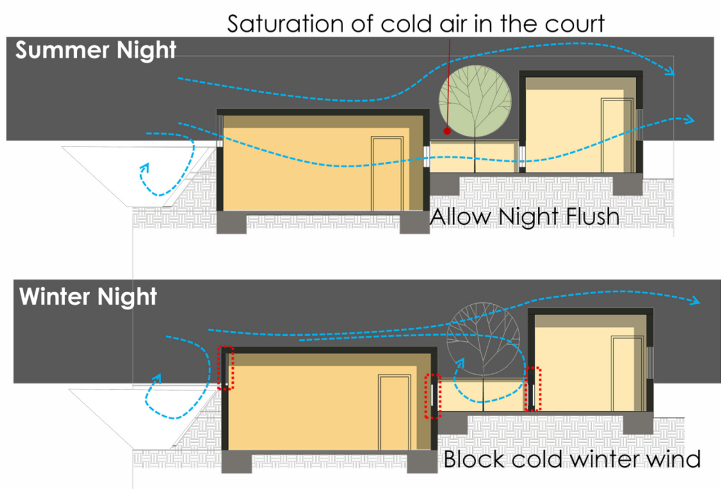

Figure 11: Recommendations for controlling the openings in Winter and Summer night.

These strategies are just a few of several applied to achieve Pre-Net-Zero path for the entire campus. Two classrooms located in the Southwest portion of the site were chosen to be part of a new Net-zero station.

The Pre-Net-Zero strategy process was not only applied on the sleeping cabins but it was also used on the buildings chosen for the Net-Zero station.

Since one of the requirements was to maintain the existing structure, in order to increase the R-value of the existing structure it was decided to add a layer of adobe to the outside of the existing masonry wall leaving a gap of four inches between the new and old wall. Adobe was selected due to its high thermal mass and low embodied energy [6].

Since one of the core educational ideas was to represent different environmental strategies, adobe was used to create an educational experience for children who could touch the thermal mass surface and learn about heat transmission due to conduction.

Since adobe has low thermal resistance, it was shaded from direct solar gain with a self-standing wooden canopy which allowed night flush during summer nights and direct heat gain from the low un angle during winter days.

The roof profile was changed from pitched to flat roof to absorb less solar heat.

In summer night, the windows are open in order to allow the night flush ventilation which cools down the envelope for the morning. The "coolth" is stored in the Adobe thermal mass and since the envelope is shaded, it blocks additional heating.

Whereas in winter day, the envelope is heated by direct solar gain and the heat is stored in the adobe thermal mass walls. During winter night, the envelope is closed to retain stored heat inside the space.

After application of passive strategies in the cabins, the next step was to convert the cabins on site into net zero.

4 The net zero strategy

In the Net-Zero strategy, the energy requirements for the buildings on site were determined and number of required PV panels was calculated.

The most important consideration for sizing a PV system for a Net-Zero electrical energy building is the annual electrical load, which the PV system is capable of generating.

First step in calculating the needed number of PV panels was to calculate the total area of all the cabins on-site (5000 sqf). Then, the module of PV panel was chosen which was 300 W_MC_48V.

Entire cabin area of the site 5000 sqf x20Kbtu/sqf/3413=29282 kW/hr, which is total annual electrical load needed. The Capacity Factor Method: In a sunny climate like Tucson, we might expect an annual capacity factor of 20%. An initial decision was made to face the array to the south tilted up at an angle equal the latitude of the site, in this case 32 degrees [7].

The 285 W modules will produce: 0.2 x 8760 x 285 x / 1000 =499 kWh

Then the number of needed PV panels were calculated (29282kW/hr / 499 kW/h = 58 panels). So the number of PV panels required to produce energy for the cabins on-site is 58 panels. Dimension of selected modules are 4.2′ width x 6.2″ height = 26.04 sqf. (1.28m x 1.89m = 2.42 meters sq.). This means that the area required for placing 58 panels, is around 1,511 sqf.

The PV panels were placed on a self-standing structure above the existing cabins at an angle equal to latitude of Tucson facing South (32°). By placing the structure that holds the PV panels above the existing cabins, an additional benefit of reducing the direct solar gain on the roofs of these buildings is realized. A second, no less important, benefit is the creation of a shaded outdoor space suitable for gathering or acting as a teaching area.

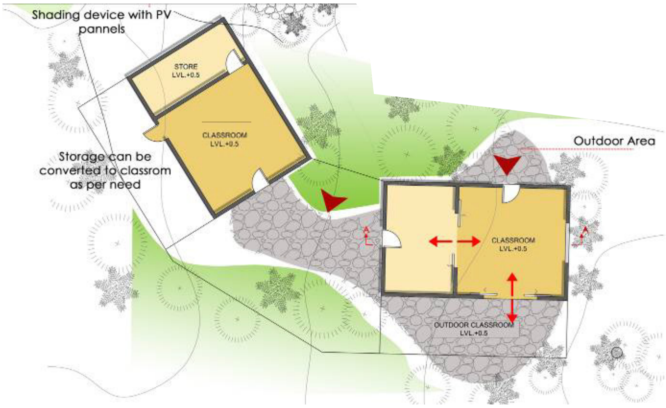

Figure 12: Proposed net zero station layout.

The figure above shows the proposed plan of the classrooms along with outdoor teaching area and the outline of the PV panel canopy.

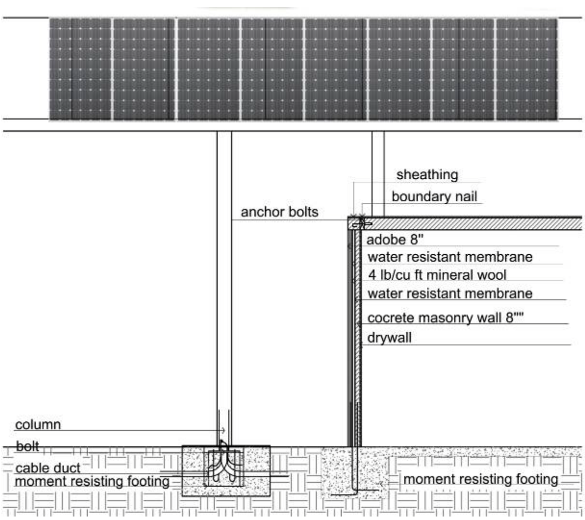

Figure 13: Cabin wall and shading device detailing.

The canopy which holds the PV panels allowed additional shaded space that can be used for outdoor activities.

Figure 14: Visualization of proposed cabin design.

5 Conclusion

In a hot climate like Tucson, where number of average daily equivalent full sun hours is around 6.57 hours, making use of solar energy as a source of generating energy is a logical choice. In this project, the strategy of Net-Zero was applied after the entire site was designed passively, which is considered to be an important aspect for any Net-Zero project. It was found that energy required for the cabins is approximately 29,282 kW/hr which was achieved by adding 58 PV panels on the shading structure. Once an energy inefficient site with cabins built in the 70s was converted into a self sufficient, energy generating site.

The final outcome of this project is not only energy efficiency but also educating children at young age about environmental systems and energy generation.

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