2021

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ABSTRACT

This paper describes a Net Zero Energy Building (NZEB) being constructed on the engineering campus of the Universidad Nacional de San Augustín (UNSA) in Arequipa, Peru. The project is one part of a larger collaboration between UNSA and Purdue University called the Arequipa Nexus Institute for Sustainable Food, Energy, Water and the Environment (The Nexus Institute) that started in March of 2018. As UNSA seeks to become a leader in environmental engineering, there is an increasing need for a new building that has dedicated resources for teaching and research on sustainable design. Solar panels to achieve net zero energy were an important late addition to the building design. The Arequipa region of Peru is particularly well-suited for solar energy because it enjoys an abundance of sunshine throughout the year. The mild climate is also helpful because buildings do not require extensive HVAC systems that can consume significant amounts of energy.

1. INTRODUCTION

The Universidad Nacional de San Agustín de Arequipa (UNSA) in Arequipa, Peru and Purdue University have partnered to create a new research, education, and innovation institute to address key challenges for a sustainable future for the peoples of Arequipa. The Arequipa Nexus Institute for Sustainable Food, Energy, Water and the Environment (The Nexus Institute) launched its multiphase collaboration in March, 2018. The Arequipa Nexus Institute leverages the institution-level faculty, student, and infrastructure commitment of UNSA and the combined strengths of research faculty and infrastructure from Purdue University's Colleges of Agriculture, Engineering, Health and Human Science, Liberal Arts, Science, Purdue Polytechnic Institute, and Purdue libraries. A variety of faculty-led research collaborations are developing methodologies to improve air quality, water quality, and soil quality primarily for agricultural applications. Energy is also an important focus.

As UNSA also seeks to become a leader in environmental engineering, a new state-of-art building with modern resources for teaching and research in this area has been planned for some time. In addition to classrooms, the building itself will serve as a living laboratory for hundreds of university students who are interested in sustainable design. The building will be four-stories tall and provide approximately 3,716 m^2 (40,000 ft^2) of space. It's layout and construction are very similar to a new Architecture building that was recently completed on the UNSA campus.

Since energy is also part of the Arequipa Nexus Institute, a new goal for net zero energy was established late in the conceptual design of the Environmental Engineering building. In collaboration with faculty from Purdue University, solar photovoltaic panels were added to the design so that its renewable energy can be an example for future sustainable communities in Peru. The solar panels will be placed on the roof to generate electricity. This paper documents the solar analysis and design to make this Net Zero Energy Building (NZEB) a reality.

NZEB are becoming more common in the United States as a way to decrease environmental impacts and reduce energy costs. However, a NZEB in Arequipa, Peru is a more interesting challenge because solar panels are not as widely deployed in buildings. Overall there is a lack 1) of up to date solar maps for estimating the solar resource, 2) nationally recognized standards for net metering, and 3) standardized specifications for solar photovoltaic installations. Despite these challenges, a detailed design has been developed and work is underway to make this facility a reality.

Figure 1 is an early conceptual drawing when UNSA first decided to add solar panels to the environmental engineering building. This drawing was used to get a preliminary estimate of the number of solar panels that would fit on the available roof area. Solar panels are shown on the low roof to the left and a higher roof in the back corner. Overall this initial layout was not ideal due to the potential for shading the panels at certain times of the day.

Figure 1: Initial concept for UNSA Environmental Engineering building

2. AREQUIPA CLIMATE

One significant advantage for building design in Arequipa is that the region enjoys mild weather and abundant sunshine year-round. Figure 2 shows two views of the Edificio de Ingenería de Materiales (Materials Science Building), a typical school building at UNSA that takes full advantage of the mild climate. The building has three floors and an "open" design, with classrooms and offices directly connected to the outdoors. The windows and doors to the building are operable and are frequently left open to allow fresh air to enter the building. The image to the left is the front view of the building facing north. The image to the right is the rear of the building facing south. The new Environmental Engineering building is being constructed in the open lot in the picture to the right.

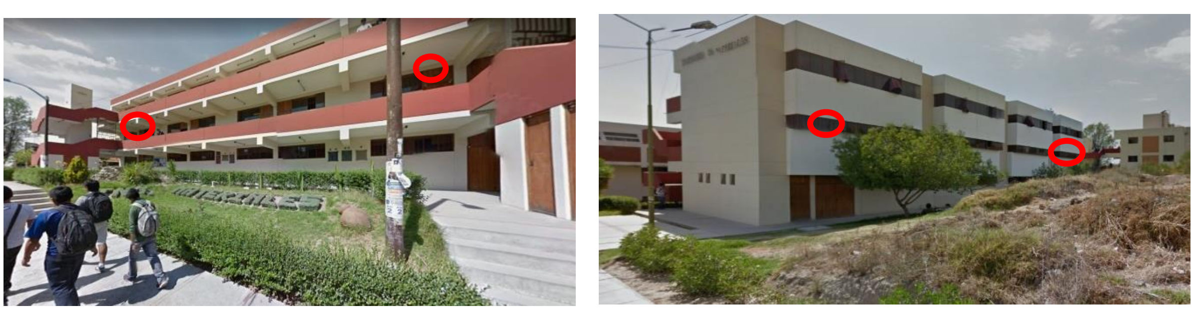

Figure 2: Sensor locations for environmental monitoring in the Material Science building at UNSA

To begin quantifying the weather-related impacts on building operations in Arequipa more accurately, data loggers were installed in the Material Science Building at UNSA. This data will be used to calibrate and improve the results of future energy modeling work. The data loggers were installed at the four locations circled in red in Figure 2. Two small data loggers for temperature and humidity were installed outdoors on the shaded South side of the building. Two more data loggers for temperature and humidity were installed indoors, on the North side of the building, and directly facing the sun. The only difference between the two sets of sensors is that one set is rated for indoor use and the other set is rated for outdoor use. All the sensors measure and record data at 15 minute intervals and store more than one year of data. The sensor data is manually downloaded to a smartphone app when it is placed near the sensor and transmitted to a computer in a spreadsheet format for further analysis.

Figure 3 is a brief summary of the data collected over an eight month period in 2018-2019, highlighting the mild climate of Arequipa. The blue bar is the monthly average temperature, which is close to 20 °C every month. The fluctuation between day and night temperatures is typically less than 3 °C. The orange bar is the average daily relative humidity. During the "dry" season from May to October the relative humidity is on the order of 30%, but in the "wet" season from November to April the relative humidity is closer to 50% on average. Overall these results reinforce the idea that the mild climate in Arequipa has allowed "open" building designs, where the indoor and outdoor climate are close to the same.

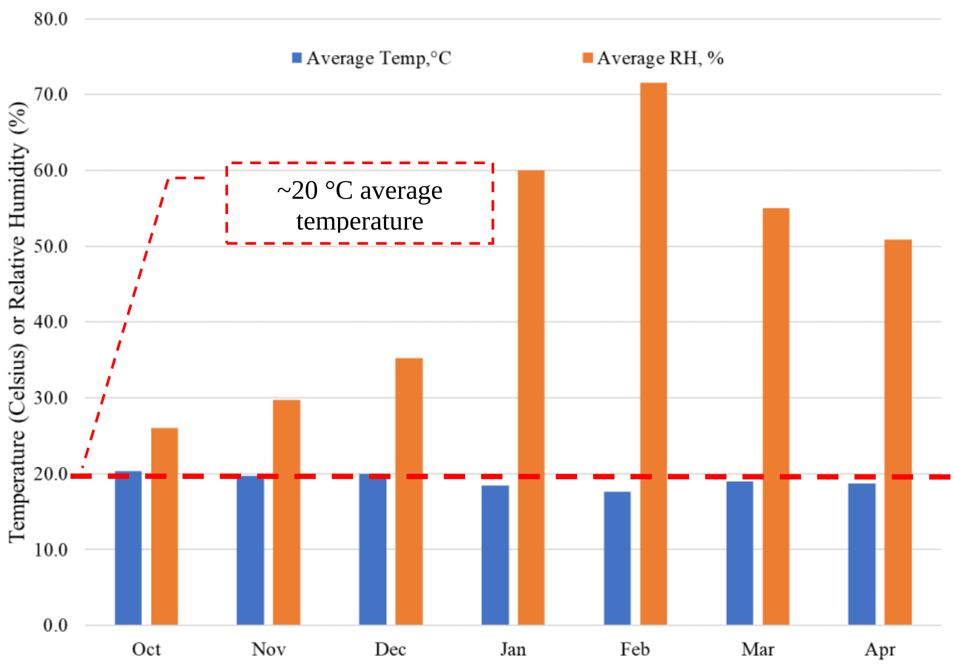

Figure 3: Daily temperature and relative humidity trends in Arequipa

3. BUILDING ENERGY ANALYSIS

Estimating the overall energy use in the Environmental Engineering at UNSA is a straightforward computation based on knowing 1) energy use of building systems and 2) the amount of time they are used. The building is all electric. Due to the mild climate and typical construction used in Peru, the building does not have a central HVAC system. The rooms in the building open directly to an outside corridor and ventilation is from operable windows. The building follows an operating schedule similar to many other universities, with two full semesters per academic year plus a limited summer calendar. Campus buildings are busy during the week-days with limited operation on weekends.

3.1 Building Energy Use

Table 1 shows the peak electric loads provided by the electrical engineers in Arequipa responsible for the building's design. The table is broken down into standard room categories like classrooms, which have similar electrical requirements. The electric loads in Table 1 are further broken down into general lighting and plug loads. For example, the building has 10 laboratories with a total of 5 kW of lighting and 3 kW of plug loads. All electric loads are added at the bottom of Table 1 to show 27.1 kW of peak electric use.

Table 1: Electric loads in Environmental Engineering building

Category	**Peak Demand (kW)**	
	General Lighting	Plug Loads
Laboratory (10)	5.0	3.0
Classroom (5)	4.5	0.3
Workshop (2)	1.8	0.2
Computer Lab	0.7	2.3
Library	1.1	0.2
Multipurpose Room	0.5	0.1
Office	2.1	2.3
Recirculating Pump	-	3.0
Elevator	-	-
Subtotal	15.7	11.4
Total	27.1	

There are several reasons why the electric loads in Table 1 are significantly less than what would be expected for a comparably sized building in the United States:

- Several large electricity consumers were consciously omitted from the list to avoid skewing the results. As an example, the "elevator" listed in Table 1 uses up to 8 kW power but is not frequently used and was left out.
- Abundant use of daylighting keeps the electricity for lighting to a minimum. The building is designed around a central open courtyard that receives sunshine every day and that is where people congregate.
- The overall building design is relatively simple, without things like vending machines, so plug loads are kept to a minimum.

3.2 Comparison to U.S. Buildings

Equation (1) shows how the daily energy use in kWh was estimated for the Environmental Engineering building. *Peak Demand* is 27.1 kW as shown in Table 1. The *Daily Hours of Operation* is 12 based on UNSA's classroom scheduling from 8 AM to 8 PM daily. A *Diversity Factor* of 0.6 is applied to account for times during the day that electrical equipment is not being used. The three terms multiplied together predict that the building will use approximately 195 kWh on a typical day.

$$\text{Daily Energy Use (kWh)} = \text{Peak Demand x Daily Hours of Operation x Diversity Factor} \tag{1}$$
$$195\ \text{kWh} = 27.1\ \text{kW} \times 12\ \text{hours/day} \times 0.6$$

Equation (2) illustrates the assumptions made for estimating the annual energy use of the Environmental Engineering building. *Daily Energy Use* is 195 kWh from Equation (1). It was assumed that the building is used for 50 weeks in a year and 6 days a week, a total of 300 days. The three terms multiplied together predict that the Environmental Engineering building will use approximately 58,500 kWh annually.

$$\text{Annual Energy Use (kWh)} = \text{Daily Energy Use x Weeks in a Year x Days in a Week} \tag{2}$$
$$58{,}500\ \text{kWh} = 195\ \text{kWh} \times 50\ \text{weeks/year} \times 6\ \text{days/week}$$

Energy Use Intensity (EUI) is a common metric used for evaluating and comparing energy use for commercial buildings. The EUI for the Environmental Engineering buildings was computed from equation (3). EUI is the *Annual Energy Use* from equation (2) divided by the *Gross Floor Area* of the building. Dividing the Annual Energy Use (58,500 kWh) by the gross floor area (3,716 m^2) yields an EUI of 16.

$$\text{Site EUI} = \frac{\text{Annual Energy Use (kWh)}}{\text{Gross Floor Area (m}^2\text{)}} \tag{3}$$
$$16 = \frac{58{,}500\ \text{kWh}}{3{,}716\ \text{m}^2}$$

Table 2 illustrates the significant differences in EUI for a typical higher education building in the U.S. as compared to the new Environmental Engineering building in Peru. The U.S. value of 265 is a median value for an adult higher education building as reported by the U.S. Environmental Protection Agency's Portfolio Manager program. This value was converted from its English value of 84.3 kBtu/ft^2 to its equivalent SI value of 265 kWh/m^2. The more than ten-fold difference highlights significant differences in climatic conditions and building operations. The larger EUI in the U.S. is not "better", but is indicative of significantly higher energy use in all areas of a building in the U.S.

Table 2: Comparison of Energy Use Intensity (EUI) for Higher Education

Country	**Site EUI for Higher Education Building** (kWh/m^2)
United States	265
Peru	16

4. SOLAR ENERGY ANALYSIS

The addition of solar panels to achieve net zero energy came about fairly late in the design of the Environmental Engineering building. One of the key constraints was the amount of space on the roof for locating the panels. The design fills all of the available roof space and will come close to achieving net zero energy

4.1 Solar Array Sizing

Equation (4) is the fundamental computation for achieving net zero with a solar photovoltaic array. The array size in kW is computed by dividing the daily energy use in kWh by the sun hours at a given location along with a correction to account for energy losses in the system. Since both energy use and sun hours change by season, this computation was made in different months to get an average that accounts for the variation. A free web-based tool from the U.S. National Renewable Energy Laboratory (NREL), was used to make this computation over an entire calendar year. It was a little surprising that NREL had solar mapping information for this relatively remote region of Peru.

A sample of the calculations for computing the *Array Size* in kW for an average day is presented here. The *Daily Energy Use* of 195 kWh from equation (2) is divided by 6 *sun hours* and a *correction factor* of 0.8 to get an array size of 41 kW. The initial estimate of 41 kW is done for different months so that an overall average can be computed.

$$\text{Array Size (kW)} = \frac{\text{Daily Energy Use (kWh)}}{\text{sun hours} \times \text{correction}} \tag{4}$$

$$41\ \text{kW} = \frac{195\ \text{kWh}}{6\ \text{h} \times 0.8}$$

Equation (5) estimates the number of solar panels needed. The *Array Size* of 195 kWh from equation (4) is divided by the *Rated Power of One Panel.* The calculation shows approximately 128 solar panels, each rated at 320 Watts, are needed to achieve a net-zero-energy building. The roof will accommodate on the order of 120 panels, so the building has a good chance of providing most of its own power from the sun.

$$\#\ \text{of panels} = \frac{\text{Array Size (kW)}}{\text{Rated Power Of One Panel}} \tag{5}$$

$$128\ \text{panels} = \frac{41\ \text{kW}}{0.320\ \text{kW}}$$

The orientation and mounting angle of the solar panels is determined by geographic location. Arequipa, Peru is located in the southern hemisphere at a latitude of 16 °S. To optimize performance, a rule of thumb is to mount solar panels at an angle roughly equal to their latitude. Therefore, the panels in the Environmental Engineering building should be mounted facing north at an angle close to 16 ° with respect to horizontal.

4.2 Grid Interaction

The initial design of the photovoltaic array included batteries to store electricity on sunny days when the energy production of the array exceeded energy use in the building. This would have allowed the Environmental Engineering building to operate on its own power even at night, adding resilience to the building operation. Upon further investigation, the battery installation for achieving grid independence was too expensive and was dropped from the final design.

A less expensive grid interactive design was pursued using rules for distributed generation that are regulated by the Ministry of Energy and Mines in Peru. The Peru Distributed Generation Code states that to promote distributed generation 1) excess power can be delivered to the grid and 2) there is a maximum amount of power allowable for each renewable technology. The methodology for using solar panels is the same as what is used in the U.S.

DC power from the solar panels is routed to an inverter for conversion to AC. The AC power is first used within the Environmental Engineering building. Excess power is then used by nearby buildings on the UNSA campus. The amount of excess energy is small enough that it will always be used within the confines of the UNSA electrical infrastructure. The amount of solar electricity is relatively small compared to the overall campus power consumption.

The rules for net metering are not fully defined in Peru. In other words, it has not been clearly established whether local electric utilities provide reimbursement for the solar electricity provided to the grid. Without these rules in place it is more cost effective for UNSA to use the electricity within its local network.

4.3 Operation & Monitoring

Purdue provided assistance to UNSA engineers on safety, operations, and long-term monitoring of the photovoltaic array in the form of a sample Request for Proposal (RFP). The RFP was adopted from a template published by the National Renewable Energy Laboratory in the U.S. to promote best practices for solar array operation (Kiatreungwattana, 2018). This document provides guidance on applicable codes, design requirements, equipment specifications, commissioning, and long term monitoring. The RFP was provided in English with key parts translated to Spanish.

Possibly the most important piece of information in the RFP was detailed provisions for web-based monitoring of the photovoltaic array. The monitoring parameters included DC energy, AC energy, solar irradiance, energy use by the building, and equipment status. The data should be available in real-time and archived in 5-minute averages. The purpose of the monitoring is two-fold. First, the monitoring is important for students and faculty who will use the new Environmental Engineering building as a living laboratory. Secondly, the monitoring is crucial to ensure that the solar array is performing as intended. Arequipa is an arid climate that does not receive much rain and dirt tends to accumulate on solar panels. The web-based monitoring platform will detect the resulting performance degradation, indicating that the solar panels need to be cleaned.

5. ONGOING WORK

Figure 4 is the most recent architectural renderings showing the final plans for the Environmental Engineering building at UNSA. Although substantial changes were made to the building layout, the overall roof space available for solar photovoltaic panels is about the same. Figure 4 shows that the panels are located at both upper and lower levels of the building. Even with the re-design, the overall building should be very close to achieving net zero energy based on the original estimates of energy use discussed in this paper. Construction started in October of 2020 and the building should be fully operational in less than two years.

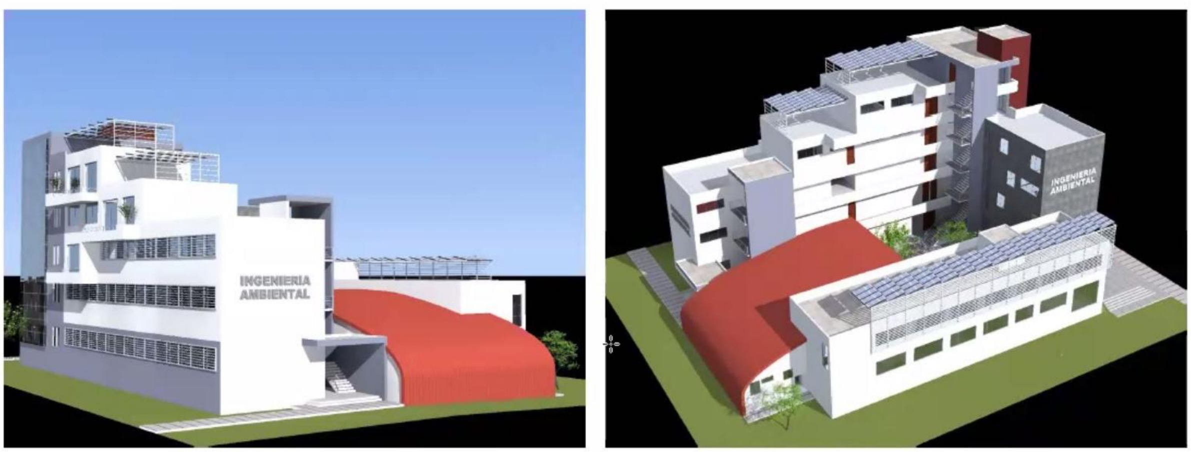

Figure 4: Final design of UNSA Environmental Engineering building

There are a number of opportunities for using the new Environmental Engineering building at UNSA as a platform for future teaching and research:

BIM Modeling - Figure 5 is a Building Information Model (BIM) for the exterior of the Environmental Engineering building using two dimensional CAD drawings provided by UNSA. Even though the layout of the building changed prior to construction, this model is still an example of the software tools that can be used for teaching design to undergraduate students in UNSA’s engineering and architecture programs. This BIM model will be modified to include final details of the overall layout, mechanical systems, electrical systems, and other equipment that can be used for record keeping and scheduling maintenance.

Figure 5: BIM model of UNSA Environmental Engineering building

Energy Modeling - Figure 6 is an early layout for the Environmental Engineering building that was the basis for additional energy modeling. This model was used to estimate energy use and energy generation from solar photovoltaics. Energy models are increasingly used for life cycle evaluations of carbon emissions to provide a more holistic view of overall sustainability. As stated earlier, this model will be updated according to the final design and used for teaching undergraduate students in engineering and architecture.

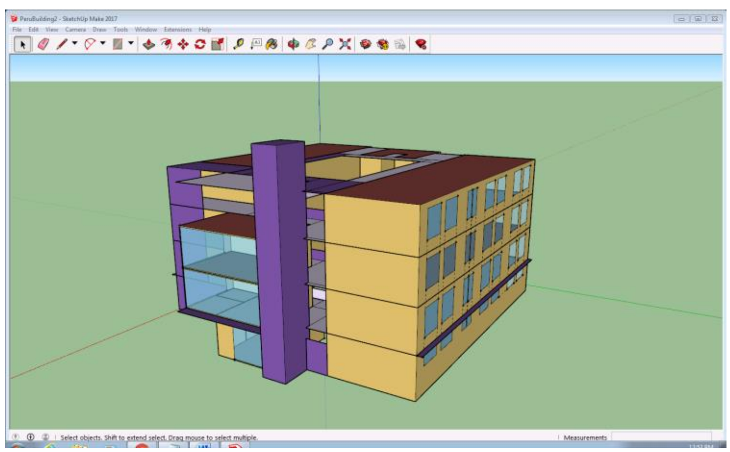

Figure 6: Basic 3-D model used for energy modeling

6. CONCLUSIONS

An international university partnership between the Universidad Nacional de San Agustín (UNSA) in Arequipa, Peru and Purdue in the U.S. is focusing on several dimensions of sustainability. One outcome of this collaboration is a net zero energy Environmental Engineering building for the UNSA campus. Solar panels on the roof of the building will provide all of its energy on an annual basis. Solar photovoltaics is a good renewable energy solution for Arequipa due to the abundant solar resource and the relatively low energy used by the building. Long term monitoring of this installation is needed for teaching, research, and to ensure that the solar panels are achieving their full potential.

NOMENCLATURE

AC	alternating current	(Watts)
DC	direct current	(Watts)
EUI	energy use intensity	(kWh/m^2)

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ACKNOWLEDGEMENT

The authors acknowledge the Facilities Engineering department at UNSA and the architect for the overall building design, including the drawings of the Environmental Engineering building used in this paper.