COLLEGE OF ARCHITECTURE INTO A NET-ZERO-ENERGY-BUILDING BY 2018

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INTRODUCTION

The U.S. Federal Net-Zero-Energy Building Executive Order 13514, signed in October 2009, requires all new Federal buildings that are entering the planning process in 2020 or thereafter be designed to achieve zero-net-energy by 2030. In addition, the Executive Order requires at least 15% of existing buildings (over 500 m2) meet the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings by 2015, with annual progress towards 100% conformance.

Ironically, according to the 2010 Florida State University System Energy Conservation Report, Florida International University (FIU) topped all state universities in energy conservation for three consecutive years with a score of 61.9590 kBTU per sf. However, this deceptive celebrated energy score is not benchmarked against the AIA and U.S. Department of Energy 2030 goal to make buildings and campus facilities carbon-neutral by 2030. [1]

The major question is, can carbon neutrality for building be achieved? How can Net-Zero-Energy Buildings become a curriculum standard and practical routine in both education and the profession? To date, the basic curricular design process components with integrated project delivery metrics for a robust transformational Net-Zero-Design regulatory framework are either incomplete or missing in most accredited architectural schools in the U.S. [2]

The majority of architecture schools are still operated as energy hogs. This excessive fossil energy usage costs nationwide Schools and tax payers hundreds of millions of dollars every year. It is just a matter of time, when these hypocritical building management patterns of ‘how architectural schools are wastefully operated’ trigger negative national public attention and criticism.

The following overall master plan for applied research on energy retrofitting design and conservation strategies for the Paul Cejas Architecture School Complex shows how building operation cost and CO2e reduction through passive and active energy saving strategies will be achieved in the next years. The master plan entails daily real-time feedback monitoring data and yearly post-occupancy-evaluation techniques. The plan also offers hands on workshops, courses and training opportunities for staff and students in collaboration with the new Structures and Environmental Technologies Lab of the School of Architecture (completion in fall 2013), the FIU Facility Management and the FIU Sustainability Office.

The master plan will enhance student experience and faculty research, community engagement, and industry - government collaborations on how to transform the Paul L. Cejas School Complex into a future Net-Zero-Energy Building (NET-ZEB). (Figure 1)

FIU-PCA LOCATION AND BUILDING DATA

The Paul L. Cejas School of Architecture Building is named in honor of the former Ambassador to Belgium and South Florida civic leader who was one of the most important advocates and sponsor in the establishment of the FIU School of Architecture. PCA is located on the North West side of the Florida International University’s Modesto A. Maidique Campus. (Figure 1)

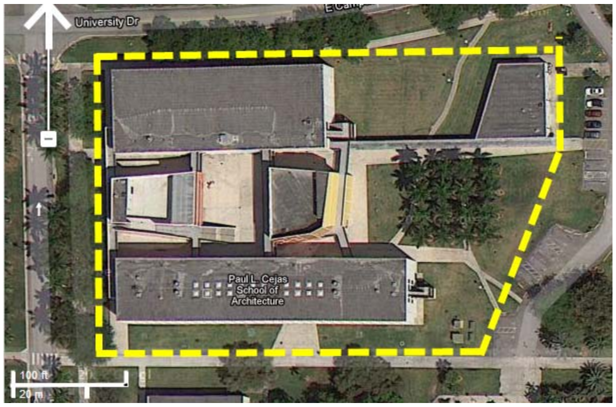


Figure 1: Research Boundary of the NET-ZEB Paul Cejas School of Architecture, Florida International University, Modesto A. Maidique Campus. Coordinates: +25°, 45'23.44',-80°, 22.'34,67, +25°, 45'23.44', 1m (3ft) a. s. l.
Address: 11200 SW 8th Street, Miami, FL 33199, Miami, Florida, 33199, USA. Climate: Subtropical Zone, Koeppken Climate Zone. Plan view: Author, 2013.

The 9,246 m2 (102,000 sf) facility was designed by architect Bernard Tschumi and features a multi-level studio in the north area of PCA with space for 375 students. The architectural design consists of two three story wings made of a simple structural pre-cast concrete arranged around a central courtyard surrounded by two 3-story lecture, studio and exhibition buildings.

The daily occupancy load is estimated by 1,932 users (students, staff and faculty), which has a significant impact on the internal heat and moisture loads.

The space and occupancy breakdown entails administration, staff and faculty offices, lecture hall, exhibition spaces, studios, classrooms, printing and computer labs, 3D model workshop, storage, restrooms and mechanical rooms. All the spaces are color coded and visualized in percentages in Figure 2.

The building's mass is predominantly constructed out of precast concrete. RESEARCH PROJECT DESCRIPTION

OBJECTIVES FOR THE NET-ZEB MASTER PLAN DEVELOPMENT

The first phase included the deployment of a wireless smart-sensor infrastructure system, compatible with the existing Metasys®building management system from Johnson Controls, to collect real-time data, to identify and compare problems and strategies to significantly reduce operational building energy use, improve thermal comfort while reducing CO2 emissions and operating costs in the long-term

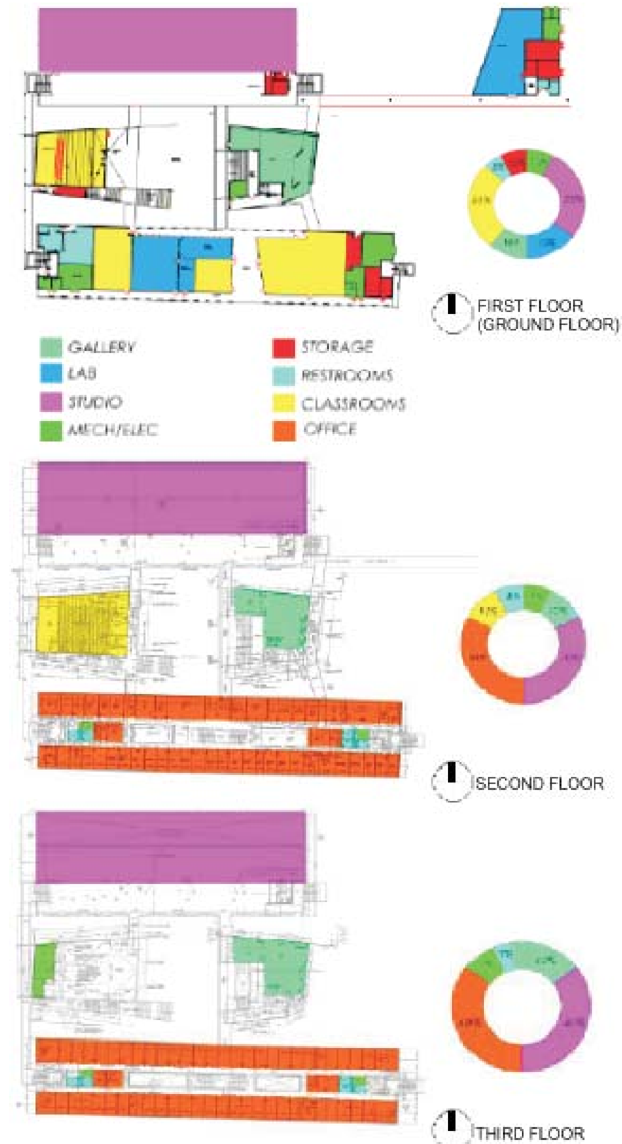


Figure 2: Building metrics of the entire PCA Complex with specific breakdown in percentages for all the occupancy types. Source: Author, 2013.

The second phase entailed an interdisciplinary research team consisting of one graduate student, one faculty and staff from the FIU Facilities Management to assess with 3-D modeling tools the water and energy consumption of the PCA complex. This baseline assessment of the PCA complex then serves for multiple 'what-if scenario" in how to reduce efficiently the environmental footprint through passive and active water and energy saving implementation strategies. In overall the Paul L. Cejas NET-ZEB Master Plan aims to implement conservation strategies and produce onsite renewable energy to match the AIA 2030 Agenda and U.S. Federal NET-ZEB 2018-2020 criteria for the PCA building in the long run.

NET-ZEB-STRATEGY IMPLEMENTATION

After an intense gap analysis of the PCA monitoring capabilities the following implementation steps have been identified:

Install the missing flow meters for chilled water; domestic and reusable condense water, and submeters for electricity (power/lighting).

Establish a wireless Network Drop for the new SET lab to connect the NAE to the existing Johnson Control Metasys®Campus network and ADX Server. Deployment of a new wireless smart-sensor infra-structure system, compatible with the existing Metasys® building management system to collect real-time data. This includes sensors for space occupancy patterns, thermal comfort related occupancy and activity control problems, energy and water use, temperature and humidity, lighting patterns, heat transfer through the building enclosures, and typical thermal bridges.

The sensor data will help to identify and compare problems and strategies to significantly reduce operational building energy and water use, improve thermal comfort while reducing CO_2 emissions and operating costs in the long-term.

Below is the summary of the five most important steps of the two phases for the baseline development of the Paul L. Cejas Net-Zero-Energy-Building Master Plan: (Figure 3)

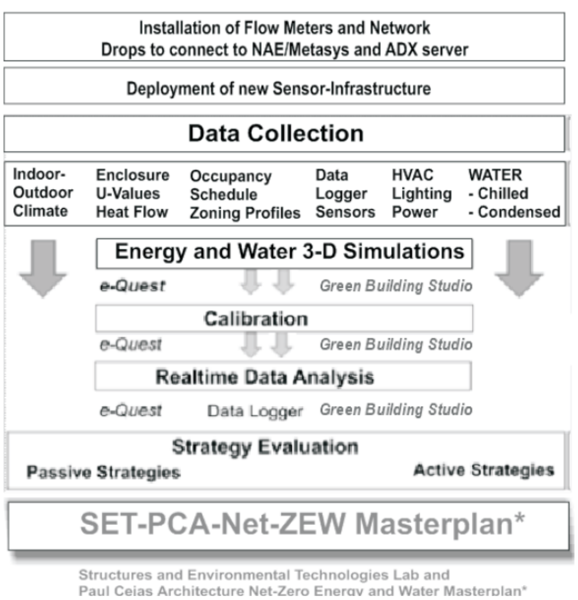
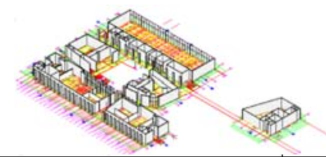


Figure 3: Work plan of the five steps of implementation. Source: Author, 2013.

PARAMETRIC 2-D/3-D- SIMULATION AND SCENARIO RESULTS

The baseline run with the existing construction properties and performance parameters and the alternative multiple scenario simulations were conducted with Autodesk REVIT MEP, eQuest and Green Building Studio Cloud Software. Additional plug-ins were used such as Ecotect, Vasari and the Heat Load ISO EN 12831 Code Calculation. Figure 4 shows a baseline excerpt of the occupancy and performance metrics. Figure 5 and 6 reveal the problem, that Universities in Florida do not comply with the energy code. That's why the annual total energy for space cooling, lights, vent fans, equipment and hot water is much higher than if university buildings would comply with the Florida Energy Code. However, the existing Florida Energy Code is anyway insufficient to achieve a Net-Zero-Energy Building by 2030.



Number of People:	1,382 people
Average Lighting Power Density:	0.67 W / ft²
Average Equipment Power Density:	1.01 W / ft²
Specific Fan Flow:	0.8 cfm / ft²
Specific Fan Power:	0.580 W / cfm
Specific Cooling:	308 ft² / ton
Specific Heating:	25 ft² / kBtu
Total Fan Flow:	53,485 cfm
Total Cooling Capacity:	224 tons
Total Heating Capacity:	2,797 kBtuh

Figure 4: Baseline bun with occupancy and imperial building performance metrics of the entire PCA complex. Source: Author, 2013.

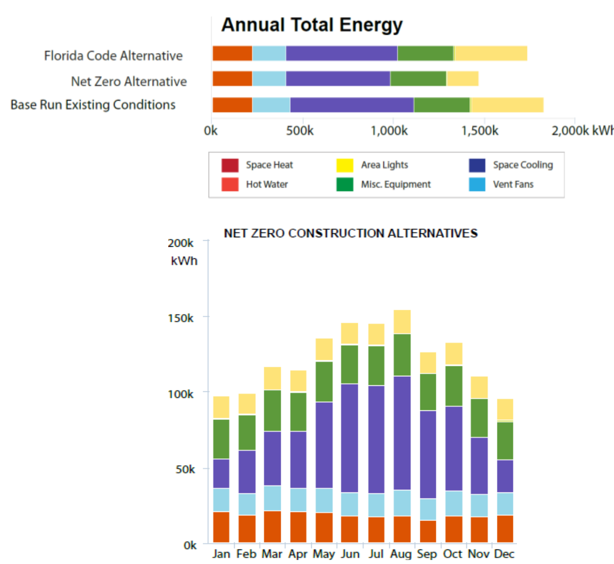


Figure 5: Comparative annual total energy simulations: Florida Code, Net-Zero and Existing PCA Construction Base Run. Source: Author, 2013.

All the alternative scenarios were carry out on an hourly baseline using the TM2 weather file for Miami IAP, Climate Zone 1A, and the ASHRAE 90.-1-2010, Appendix G assessment. The baseline comparison and the Net-Zero-Energy alternative were also simulated with the Energy Use Intensity (EUI) values and the U.S. Energy Star TARGET FINDER scoring 73 from the Energy Star Portfolio. [3]

NET ZERO CONSTRUCTION ALTERNATIVES		
	R60 over Roof Deck	
	U-Value: 0.02	
Roofs		1,128 ft²
	R30 8in Concrete	
	U-Value: 0.03	
Exterior Walls		56,442 ft²
	R0 Metal Frame Wall	
	U-Value: 0.41	
Interior Walls		52,256 ft²
	Interior 4in Slab Floor	
	U-Value: 0.74	
Interior Floors		53,083 ft²
	R0 8in (203mm) CMU UnderGnd Wall, assembly U-0.645	
	U-Value: 0.03	
Underground Walls		1,787 ft²
	Air Surface	
Air Walls	U-Value: 15.32	51,901 ft²
	R5 Door (90 doors)	
	U-Value: 0.19	
Nonsliding Doors		1,828 ft²
	North Facing Windows: Triple pane, clear, low-e (4 windows)	
	U-Value: 1.26 W / (m²-K), SHGC: 0.47 , Vlt: 0.64	6,425 ft²
	Non-North Facing Windows: Triple pane, clear, low-e (15 windows)	
Fixed Windows	U-Value: 1.26 W / (m²-K), SHGC: 0.47 , Vlt: 0.64	2,267 ft²
	North Facing Windows: Triple pane, clear, low-e (52 windows)	
	U-Value: 1.26 W / (m²-K), SHGC: 0.47 , Vlt: 0.64	1,092 ft²
	Non-North Facing Windows: Triple pane, clear, low-e (65 windows)	
Operable Windows	U-Value: 1.26 W / (m²-K), SHGC: 0.47 , Vlt: 0.64	1,365 ft

Figure 6: Net-Zero-Construction simulation alternatives with better U- and R values. Source: Author, 2013.

The total annual energy load to operate the PCA complex is calculated with 1,473,720 kWh and theoretically indicates that PCA is more energy efficient than the Energy Star baseline building comparison through the use of increased insulation levels, highly efficient glass and lighting retrofitting, and the use of occupancy sensors.

ANNUAL ENERGY CONSUMPTION	
Energy Use Intensity (EUI)	73 kBtu / ft² / year
Electric	1,249,023 kWh
Fuel	224697 kWh
Total	1473720 kWh

HEAT EXCHANGE + ABSORPTION CHILLER SYSTEM	
Total Annual Cooling Load	260000 kWh
Heat Exchange + Absorption Chiller System Efficiency	75%
Total Annual Energy Savings	195000 kWh

PHOTOVOLTAIC SYSTEM	
PV Type	Monocrystalline Silicon Solar Panel
Module Efficiency	20.1
Total Panel Area:	58,000 ft²
Annual Energy Savings:	1280000 kWh

NET-ZERO ENERGY BUILDING PROPOSAL	
Annual energy consumption	1473720 kWh
Photovoltaic System	-1280000 kWh
Heat Exchange + Absorption Chiller System	-195000 kWh
Total Energy	-1280 kWh

Figure 7: Summary of the Total Annual Energy Savings based on the best selected Net-Zero-Energy-Building Proposal. Source: Author, 2013.

In addition, the best alternative scenario includes a 75% efficient Heat-Energy-Recovery and Absorption Chiller system to provide 260,000 kWh cooling by 195.000 kWh total energy savings compared to a standard system with electrified compressor chillers.

The onsite renewable energy production also includes new proposed large-scale photovoltaic arrays composed of 5,388 m2 (58,000 sf) Sun Power SPR-435-NE-WHT-D monocrystalline silicon panels with 21% efficiency rating to produce 1,280,000 kWh/year of the building's estimated annual energy demand. (Figure 7)

Figure 8: Images 1 show the existing PCA complex. Images 2 show the Net-Zero-PCA simulation with the new building integrated 5,388 m2 (58,000 sf) Sun Power PV arrays. Source: Author, 2013.

CHALLENGES IN ACHIEVING ACCURACY IN MEASUREMENT AND DATA COLLECTION

The user behaviour pattern (number of occupants, schedules, etc.) and the real-time measurement of the energy and water consumption for all loads (HVAC, lighting, etc.) as it relates to indoor and outdoor environmental variables (temperature, relative humidity, illuminance, etc.) over a period of time are the most important components of this NET-ZEB master planning project. To ensure the validity of the planned implementation, processing and benchmarking effort, the following have been identified as key criteria for the measurement process:

a. Accuracy
b. High temporal and spatial resolution
c. Adequate aggregation for trend and pattern identification
d. Synchronization of measurements of different parameters for correlation studies

As previously mentioned, based on these criteria, two complementary systems have been selected to collect the data of interest. The first one is the preinstalled sensor and actuator system of Johnson Controls Inc. (JCI). JCI sensors continuously measure the temperature and relative humidity in every room at a single point, temperature of the room air supply and return air in all individual HVAC air ducts, electrical power consumption of lighting systems and water pumps on all floors, and electrical power consumption of the central HVAC units. The measured data is uploaded to JCI's proprietary METASYS server for real-time monitoring and archiving through a dedicated network. Even with its extensive capabilities, the current JCI system has some deficiencies for this project. It measures temperature in only the rooms and at only a single point. According to the JCI engineers, humidity sensors were not placed in each room but rather, they were located on each unit at the return air far away from the regular 3 feet (90 cm) thermal comfort measuring locations. Most of the space zonings however, do have both a CO2 sensor and wireless zoning sensors which record the room or zone temperatures based on thermal comfort.

Figure 9 shows a typical hot and humid August Design Cooling Day with 92 F (33,3 C) outdoor air and 0.017 lb/lb specific humidity content. The central cooling coil outlet temperature is approximate 52 F (11 C) whereas the Supply Fan Outlet is 55 F (12,7 C). The room air is measured by 78 F (25,5 C) whereas the reclaimed ventilation outlet is at 82 F (27,7 C). The preliminary assumptions show that most of the existing PCA enclosure systems lack efficient U-and R-values and are subject to major thermal bridge problems with extreme high heat transfer impacts through the building enclosure into the cooled spaces of the PCA complex. The author assembled real-time infrared images of selected typical façade details and compared the heat transfer temperature with the outdoor and indoor temperature values. (Figure 10) The thermal bridges were then eliminated and the R-Values of all façade elements were then increased in the alternative 3-D NET-ZEB scenario model. The comparative and parametric 3-D heat transfer analysis helped to identify retrofitting strategies with higher R-values in order to minimize significantly with passive means the total annual cooling load and CO2 production.

The preinstalled JCI system neither monitors the outdoor environmental variables, nor the occupancy of the zonings under reliable monitoring conditions. Illumination levels are also not measured at any point. It was therefore necessary to install a complementary sensor network with different components. A wireless sensor system from MONNITTM has been chosen to measure the temperature, relative humidity, and intensity of light in lux (luminescence/unit area) at multiple points in each room. The points have been selected to allow for the extraction of the spatial gradient of the measured parameters. The measured data is wirelessly transferred to a dedicated web server for storage and further processing. To monitor the occupancy level in the rooms and lecture hall, wireless network cameras have been adopted for installation. These cameras can be remotely controlled and the acquired video processed using in-house developed software to extract the number of people in the rooms or assembly spaces. Outdoor environmental variables are monitored using the HOBOTM outdoor weather station which continuously measures temperature, relative humidity, light intensity, rain, wind speed, direction and barometric pressure.

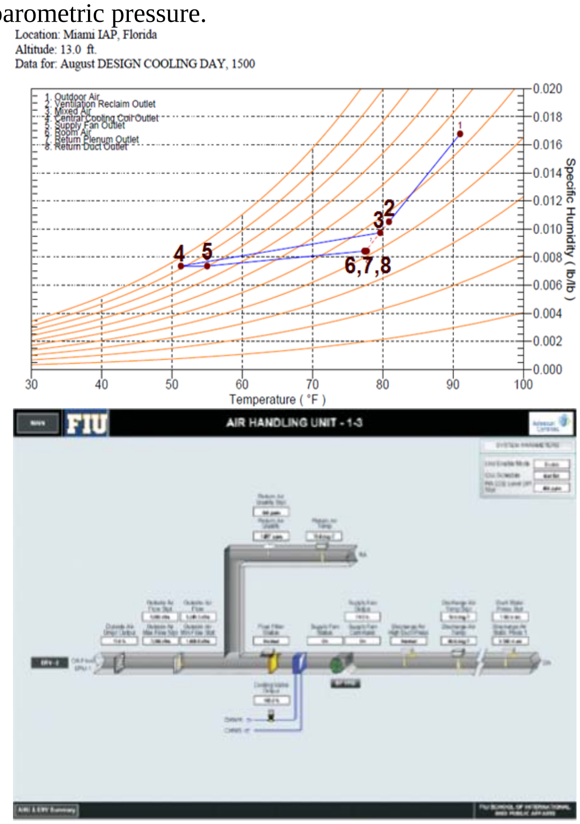


Figure 9: Image above: Design Cooling Day in August: 1. Outdoor Air; 2. Ventilation Reclaim Outlet; 3. Mixed Air; 4. Central Cooling Coil Outlet; 5. Supply Fan Outlet; 6. Room Air; 7. Return Plenum Outlet; 8. Return Duct Outlet. Image below: JCI MetaSys Interface of an Air-Handling Unit. Source: Author, 2013.

Figure 10: Right image: The FLIR infrared Image shows the outside surface temperature of the concrete precast of 98,8 F (37 C) and higher; while the air outside temperature is only 79 F (26 C) by a relative humidity of 78 % and 15 mph (24 km/h) wind pressure. Left image: The infrared image show the indoor surface temperature with 79 F (26 C) and higher of the noninsulated window frame area as a typical thermal bridge, while the air cooling supply in the Interior space is set by 54 F (12 C). Recorded on March, 12, 2012. Source: Author, 2012.

This system can also wirelessly upload the measured data to a dedicated web server for further scenario 3-D BIM modelling. The data collected from different sources are time-stamped to study the correlation between different parameters, specifically the effect of environmental variables and space usage patterns on energy and water consumption.

CARBON-NEUTRAL RETROFITTING - RETURN ON INVESTMENT?

In average a typical 4,645 m2 (50,000 sf) higher-education building in the U.S. uses more than $150,000 worth of energy each year. Energy-saving measures thus represent a substantial resource for freeing up funds that a college or university can use elsewhere. Moreover, an energy and water efficient building can result in improved occupant comfort, academic performance, staff retention, and community support.

The largest consumers of electricity in the PCA complex are lighting, ventilation, and cooling. Excessive all year round space cooling, thermal bridges in window frames and doors, 7/24/365 operated lighting, computer and office equipment accounts for the vast majority of the expensive and the environment impacting fossil fuel use in PCA. As a result, these areas are the best design retrofitting and conservation targets for longer-term energy-water-saving solutions.

By implementing all these economical energy and water efficiency measures, the PCA-complex has the potential to cut the building operation bills and Greenhouse Gas Emissions by 30 percent or more by 2018.

CONCLUSION

This paper demonstrates a critical examination of how integrated smart sensor-technology and parametric 3-D modelling can assist architects in producing a detailed 'what if' resource-usage scenario, which enhances the design, operation, real-time monitoring, and benchmarking of a future Net-Zero-Energy-Campus Building's target towards carbon neutrality by 2018.

The current energy performance benchmarking system of the PCA building shows considerable variance between the actual energy use and the estimated and simulated energy and water use. The proposed general pathway to achieve a Net-ZEB status for the PCA complex has two major steps: first, reducing energy and water demand by means of conservation (avoiding excessive heat transfer into the building with passive means) and energy efficiency measures (implementing a smart integrated sensor infrastructure to better control HVAC and lighting, occupancy schedules). Second, generating onsite or distributed renewable energy mix carriers, by means of energy supply options for green credits to achieve the balance needed to make Paul L. Cejas College of Architecture a NET-ZEB. (Figure 11)

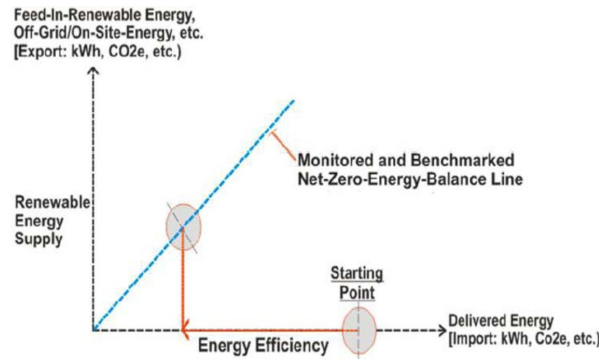


Figure 11: PCA-CARTA-Energy efficiency improvement graph representing the Net-ZEC balance to match the AIA 2030 agenda of Carbon Neutrality. Source: Author based on IEA TASK 42

For the PCA building operators, and in long run for the University et all, this becomes a tool that is updated yearly and used to expand environmentally progressive practices and applied research continually on the campus. It provides a critical means and feedback loop for universal environmental research and education for the students, staff, and faculty. It helps to create leadership in defining how to achieve carbon neutrality and provides a model for the campus community and the surrounding local community at large.

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