Renewable Energy in Historic Buildings; The Capitol of Puerto Rico and its Annexes

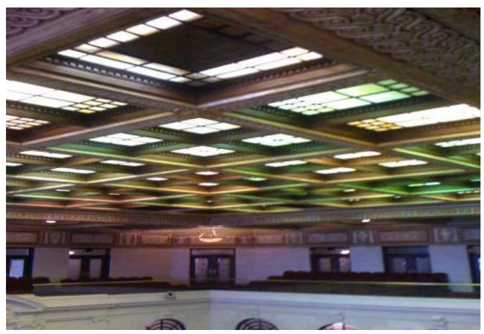
Eng. Alex E. Martínez
Project Manager PR Capitol Superintendence
Master in Engineering Management
Dr. Hector Cruzado, PhD, PE
Department of Civil and Environmental Engineering
Polytechnic University of Puerto Rico

Abstract *— The Puerto Rico State Capitol Superintendence (CS) is aligned with the new energy management challenges that the world is facing in order to reduce the energy consumption and CO2 emissions levels. A payback period of a 5 year minimum is required. The improvements options should be focused on the reduction of energy consumption and greenhouse emissions by the integration of new energy efficient technologies, including Renewable Solar Energy, and Feedback of the existing systems. The CS conducted an energy audit Level II ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) at the Capitolio facilities which consisted on the evaluation of all installed systems that make use of available energy sources. The main objective of the energy audit is the identification of new improvement opportunities that can be deployed within the facilities by making use of efficient and reliable energy systems. Finally the installation of a 168 kW Solar Energy System using the latest solar energy methodology and technologies could be done and the achievement of more than 30% of energy cost reduction with a payback less than five year.*

INTRODUCTION

The Capitol Building (*El Capitolio*) is a facility used by the ***Legislature of Puerto Rico*** composed by the House of the Representatives and the Senate Chambers. All administrative and legislative activities are conducted at this facility which represents an icon for the people of Puerto Rico. The facilities are significantly used and visited on a daily basis (more than 100,000 visits annually). It was constructed between 1925 and 1929 but, it was completed by 1961 (including all the finished work, mosaics and interior cupola). Since then, it has been exposed to several physical changes or modifications. This facility is located at the Old San Juan, adjacent to the Atlantic Ocean. The main building is composed of a basement and three (3) floor levels which includes two (2) hemicycles.

An imaginary line on the middle of the building divides the main building from the offices for the Senators and the Representatives. In the second floor are located the offices of both presidents, the entrance to the hemicycles for the senators and representatives, and offices for both chambers. Picture 1 shows a portion of the hemicycles.

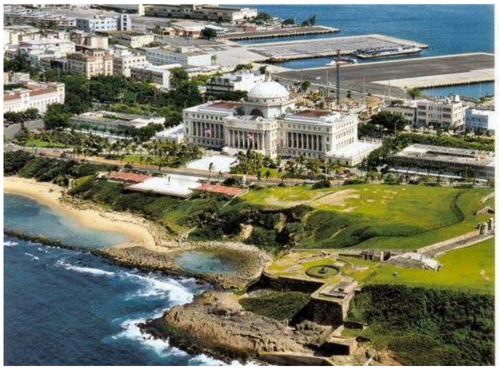


Picture 1
The Senate Public seats lighting conditions

Some chillers and air conditioning units are located at the roof of the building (as shown in Picture 2), but they are not visible from the street level.

Picture 2
Existing A/C units at the roof.

The two (2) building extensions are composed of two stories building each. The building extension located at the west of the main building accommodates the offices for the House of Representatives, and the one located to the east holds the offices for the Senate. Similar to the main building, the chillers and air conditioning units are located at the roof of the buildings. Picture 3 shows the complete building structure.



Picture 3
Aerial View of the Capitol and its Annexes from the north side

OBJECTIVES

The main objectives of the energy audit are:

- The identification of new improvement opportunities that can be deployed within the facilities by making use of efficient and reliable energy systems.
- To provide a detailed report that can be used for improvement strategies or for capital funding justification.
- Make a feasibility analysis for the installation of ***Solar Energy Technologies***. (Wind energy was discarded because of its high cost and long payback)

METHODOLOGY

The type of energy audit conducted at the facilities is classified as Level 2 by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). The information gathered during the energy audit was reviewed and analyzed to determine the current consumption, physical conditions and what type of retrofit could be implemented to increase the efficiency levels and to reduce the energy consumption which will result on a reduction of operational costs.

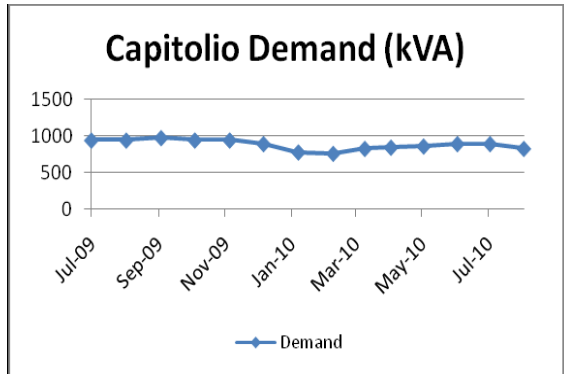
In many cases, there are systems that are not operating at their maximum reliability levels which cause an increment in energy consumption and maintenance expenses. The gathered data was analyzed in detail to determine the best alternatives available for improvements. During the analysis process, templates and computer applications were used to determine the different energetic aspects and improvement opportunities.

The illumination (lighting) system is not structured on the most effective manner. There are some lighting fixtures that have a combination of ballasts and tubes that are not the most recommended or optimum with respect to performance and energy efficiency. Our team (engineering professionals, contractors and Capitol's Superintendence personnel) proceeded to perform a more detail data gathering process during the energy audit to ensure that the information to be used as part of the analysis is accurate and represents the actual operating scenario. Also, when conducting the assessment on the HVAC system, it was determined that several systems were not operating as designed and that some system components were not sized as informed.

Based on the results of the ***energy audit***, it is recommended that the lighting system of the facilities be retrofitted with newer and more efficient technologies. The lighting system had been upgraded during the past years, but the majority of the technology is not aligned with the latest technological advances.

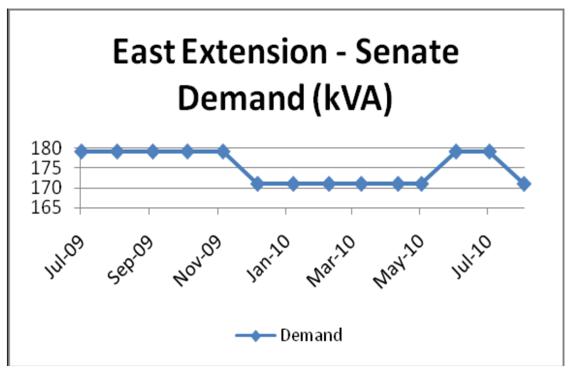
The main electrical consumption of the facilities is directly related to the usage of the lighting and HVAC systems. There are several recommendations with respect to the HVAC system which will provide energy benefits to the facilities administrator, but there is the need to improve maintenance management levels and potentially integrate a new chilled water system design. There are some improvement aspects that could potentially be integrated with a low capital costs, but a new chilled water design will require some significant capital investment. This new chilled water design should provide significant or outstanding potential annual savings.

After the analysis of the data, a lighting retrofit initiative should be deployed or implemented. But, a combination of lighting with air conditioning (A/C) units' retrofits with automatic A/C controls will provide similar benefits. After an estimate the capital investment would be from $600,000.00. Graph 1 shows the electrical demand monitoring of the Main Building (Capitol) facilities from June 2009 to August 2010.



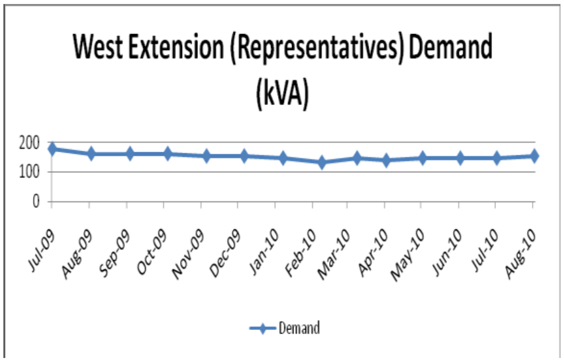
Graph 1
Capitol demand in KVA

Graph 2 shows the electrical demand monitoring of the East Extension (Senate) facilities from June 2009 to August 2010. As it is observed, the demand was very steady from June 2009 up to November 2009. Then, it decreased down to 171kVA from November 2009 to May 2010. The average demand for the period of time under analysis is approximately 175kVA.



Graph 2
Senate Demand in Kva

Graph 3 was developed for the West Extension (Representatives) facilities. The average demand for the period of time under analysis is approximately 153kVA (monthly).

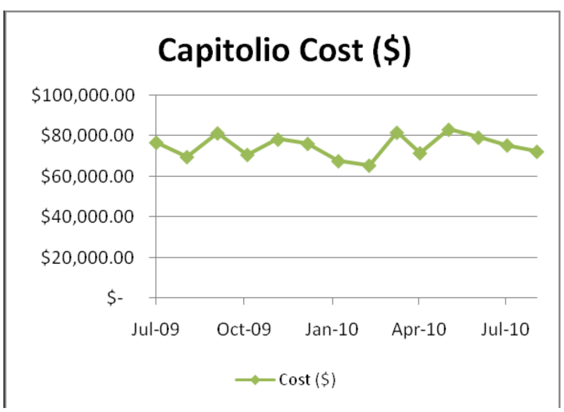


Graph 3

House demand in Kva

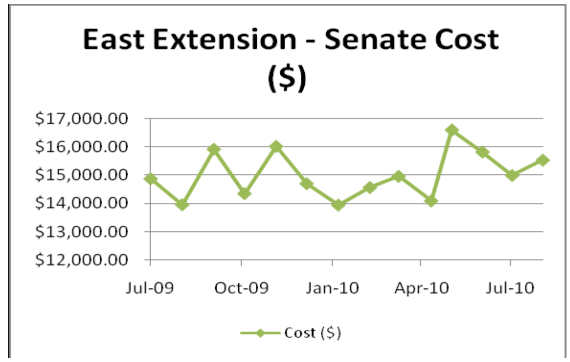
Graphs 4 to 6 show the energy costs tracking for each one of the facilities under analysis. Fluctuations of the costs are associated to fuel adjustment and energy consumption levels. These representations will be essential for comparison basis when the improvement alternatives are selected and implemented because the reduction of energy consumption will be traceable.

Another important aspect that was observed as part of the analysis process is the electrical rate during the last six (6) months of 2010, which was approximately $0.22/kWh. Right now is near $.28/kWh.



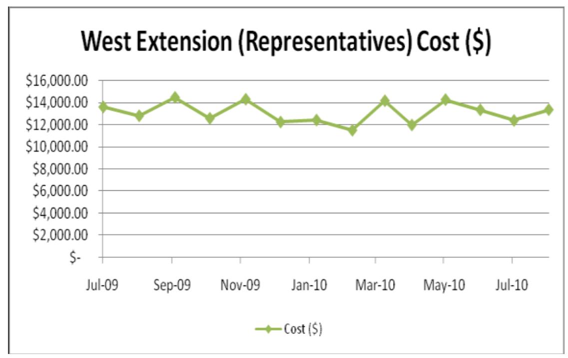
Graph 4

Capitol average energy cost



Graph 5

Senate Annex average energy cost



Graph 6

House Annex average energy cost

Lighting System

The current interior lighting system is composed of different lighting fixtures such as: 1x4 Strips, 1x8 Strips, 2x4 Fixtures, 2x2 Fixtures, Conventional Lamps (incandescent & spot lighting – halogen), MH175W, 400W HID1,000W, 1,500W and Compact Fluorescent Lighting (CFL)

The following information provides specific details of the installed lighting systems at the three (3) building facilities. The information is segregated by building, but the required documentation for the improvement options will be consolidated.

Specialized tables were developed and used for data collection which is the baseline for the proposed improvement options. These tables could be used as actual lighting fixtures inventory. The information included on these tables is the following: Location Area Type, Foot-candles (fc), Type of Fixture Quantity, Operational Conditions (hours, days &

weeks), Electrical Rate ($/kWh), and Yearly Costs (Actual vs. Future)

Financials (Estimated Costs and Annual Savings)

There are a total of 3,245 fixtures installed at the facilities which could be retrofitted in order to reduce electrical consumption and become more efficient. These fixtures make use of low efficiency technologies or not-efficient combinations. Some of the lighting lamps make use of T-12 technology which is under replacement with new high efficiency T8 and T5 because they provide better illumination and reduce the levels of mercury content. At the same time, this provides the opportunity to standardize the light tubes for ease of maintenance and help on the reduction of energy consumption.

Also, by reducing the energy consumption (kWh) it will provide another important aspects which is the reduction of CO2 emissions. Some other lamps such as Metal Halide, Incandescent and HID were evaluated; and integration of T-8 or LED technologies are proposed. This type of integration will provide a significant reduction of electrical energy consumption and operational expenses. The audit took into consideration the levels of illumination (fc) at the different locations within the building.

The illumination levels are essential when doing different type of works and helps on individual's mood levels. In general, the illumination levels are acceptable because most of the office spaces are located near to the four (4) building side walls which have windows or glass doors. By having these windows or doors, natural light provides an incremental on the illumination levels within the rooms, but it increases to certain point the HVAC cooling load.

Currently, the lighting system for the entire complex has an approximated annual consumption level of 1,200,000kWh. This consumption level represents approximately 14% of the total electrical bill.

Another aspect that was observed during the energy audit is that there is no control of the lighting fixtures during non-occupancy period of times which is considered a waste of energy. The integration of light controls such as motion sensors and timers will provide energy management levels and potentially a reduction on energy consumption. But, the selection or location in which these lighting control systems will be installed (as recommended), has been studied and analyzed in details to ensure that the maximum benefits are achieved.

There are several observations that can be made with respect to some of the installed lighting systems. There is a high utilization level of chandeliers in a significant number of offices. These chandeliers are making use of 40W light bulbs that goes from 3 to 38 per fixture. The energy consumption levels of these lighting fixtures is high because the operational time frame is approximately nine (9) hours per day, five (2) days per week and forty eight (48) weeks per year. The integration of this type of lighting fixtures is correlated to the furniture used on the office spaces under analysis.

Calculation Assumptions

- Operational timeframe of the administrative offices is 9 hrs/day 5 days/wks 48 wks/yr.
- Operational timeframe of the restrooms at private offices is 5 hrs/day 5 days/wks 48 wks/yr
- Operational timeframe of the exterior lighting system is 12 hrs/day 7 days/wks 52 wks/yr

There is a minimum potential energy saving of fifteen percent (15%) with the integration of lighting motion sensors. Due to the significant usage of the facilities the most accurate reduction level (potential) is fifteen percent (15%).

General Observations

Most of the office or working areas met the recommended illumination levels (standards). Most of the areas that were below of the recommended illumination levels are some vestibules, restrooms and offices. The majority of the areas were small conference rooms within private offices or restrooms (private). There are a total number of 63 working spaces that are below the recommended levels.

Table 1 shows some of the most recommended illumination levels for different building areas.

Table 1

Illuminating levels recommended by Illuminating Engineering Society (IES)

Area	Light level Lux	Light level Footcandles
Office (high contrast – typical)	200-500	20-50
Office (computer use – ambient level)	200-300	20-30
Manufacturing	500-700	50-70
Warehouse	200	20
Research	500-1000	50-100
Parking lot	50	5
Hallways (short)	50-100	5-10
Hallways (long)	100-200	10-20
Stairways	100-200	10-20
Elevators & Restrooms	100-200	10-20
Conference Rooms	300-500	30-50
Lobbies	200-300	20-30
Auditoriums	100-200	10-20

There is a significant number of 2x2 2 Tubes fixtures installed at the facilities, but there are different combinations of technologies with respect to the T8/T12 tubes and type of ballasts. It was significantly observed that retrofits or maintenance activities were performed over some of the system components, but they weren't conducted effectively or correctly. There were some combinations of T-8 technology with magnetic ballasts which causes that the life cycle of the tubes to be reduced. The same pattern was identified or detected with electronic ballasts and T-12 tubes. This is something that could happen for many reasons, budget limitations, no-maintenance schedule and/or lack of understanding from maintenance personnel.

As part of the analysis, it was necessary to develop an energy profile for the three (3) main categories in order to identify the percentage of usage by system. Table 2 shows the electrical energy consumption at each one of the building sections of the *Capitolio*. Also, it shows the related annual operational costs for the actual consumption levels. This table was developed by making use of the actual information included on the monthly electrical billing statements for the facilities. The *Capitolio* is divided into three (3) different electrical bills or electrical metering points.

Table 2

Energy Consumption and Cost of the three main buildings

Annual (Aug-2009 to Aug-2010)

Location	Consumption (kWh)	Costs ($)
Senate & Representatives	4,595,250	$ 971,777.62
East Extension (Senate)	918,700	$ 195,464.88
West Extension (Representatives)	799,260	$ 391,837.32
	6,313,210	$ 1,559,079.82

The same table was expanded (as shown in Table 3) to include other important aspects such the annual costs and consumption levels of the different energy systems. The engineering calculations were conducted to the maximum level that could be assumed for the administrative operations which are held at the facilities. There is a potential difference of twenty six percent (26%) if the systems are operated as included on the assumptions section. This table allows us to determine the actual percentage of the lighting system which respect to the other energy installed system. Currently, the lighting system consumes approximately 1,200,289 kWh on a yearly basis which represents about fifteen percent (15%) of the total consumption. Again, these calculations are taking into consideration the maximum assumed operational level.

Most of the exterior lighting fixtures are spot light fixtures (MH, HID) which could be retrofitted by the integration of T-5, LED and Induction technologies. There are different types of fixtures installed that are used for illumination of the parking areas, building surroundings and signs.

Table 3
Energy Consumption and Cost of the three main facilities by type of consumption

	Annual (Aug-2009 to Aug-2010)		Lighting System		HVAC System		Other Load (6%)	
Location	Consumption (kWh)	Costs ($)	Consumption (kWh)	Costs ($)	Consumption (kWh)	Costs ($)	Consumption (kWh)	Costs ($)
Senate & Representatives	4,595,250	$ 971,777.62	855,889.72	$ 188,295.74	4,756,316.88	$ 1,046,389.71	275,715.00	$ 60,657.30
East Extension (Senate)	918,700	$ 195,464.88	179,668.71	$ 39,527.12	751,185.23	$ 165,260.75	55,122.00	$ 12,126.84
West Extension (Representatives)	799,260	$ 391,837.32	164,730.24	$ 36,240.65	733,896.22	$ 161,457.17	47,955.60	$ 10,550.23
	6,313,210	$ 1,559,079.82	1,200,289	$ 264,063.51	6,241,398	$ 1,373,107.63	378,793	$ 83,334.37

$ 1,720,505.51

	$	kWh
Potential Difference	$ 161,425.69	1,507,270
	9%	19%

Location	Demand (kW)
Senate & Representatives	855
East Extension (Senate)	148
West Extension (Representatives)	126

Lighting System	14.0%
HVAC System	80.0%
Other Loads	6.0%

Note: The difference shown above could be caused by the assumed working loads of the systems which is based on information provided by government representatives. The acutal consumption was obtained from monthly electrical bills.

AIR CONDITIONING SYSTEM

Another system that was audited during the energy walkthrough was the HVAC. The installed system is used for the cooling conditionings of the building at the different building levels. In general, the building is composed of administrative offices (closed & open), cafeteria, conference rooms, restrooms, mechanical-electrical rooms, a computer center and training rooms (basement). The Capitol Hill Building has several types of HVAC components in order to provide the required cooling loads. These systems were audited by conducting physical inspection of the components, technical data collections and temperature measurements at the supply locations. The gathered information was included as part of an analysis table that was developed for reference purposes and identification of improvement opportunities. The following information will provide different aspects that are used as part of the analysis.

CALCULATION ASSUMPTIONS

- Twenty percent (20%) of rated cooling capacity reduction in Air Handling Units (AHU's) and Fan Coils. This assumption is established because in many cases fresh air (outside air) is not used. Currently, many air conditioning units work with re-circulated air.
- Temperature difference is equal to ten degrees ($\Delta t = 10\ ^{o}F$) for chilled water flow calculations (at Chillers).
- Temperature difference is equal to twelve degrees ($\Delta t = 12\ ^{o}F$) for chilled water flow calculations (at AHU's and Fan Coils).
- Equipment working hours from Monday to Friday is twelve (12) hours daily (6:00AM to 6:00PM) for DX units.
- Five percent (5%) downtime for total working time of equipment due to repairs and/or maintenance.
- Two (2) weeks of equipment downtime per year due to major repairs and/or major maintenance.

General Observations

- Severe Air Quality Issues observed mainly at Annex Buildings.
  - Zero Percent (0%) of fresh air used. At least twenty percent (20%) of fresh air is recommended for commercial use.
  - All return air of the ceiling mounted equipment returns by plenum and all bathroom exhaust fans discharge to plenum.
- Most of AHU's and Fan Coils already use two way control valves, but most of them are not operational.
- Distribution piping insulation is heavily damaged and it needs to be replaced.
- Windows are single pane glass. This allows significant thermal heat transfer.
- Abundant legacy thermostats were observed throughout the buildings.
- All Chilled Water Systems are operating in Off Design conditions exceeding the rated capacity of the Chillers. These conditions may be possible due to:

- higher chilled water temperatures than designed
- reduced chiller loads due to reduced flow at AHU's and Fan Coils (non automated control valves)
- diversity of the system

➢ load shifting (conference and audience rooms)

➢ ii. twenty percent (20%) load reduction due to no fresh air

➢ Relatively high chilled water distribution pressures (80 to 85psi) were observed.

Camera Annex Building Observations

- Humidity control problems evident on the hallways.
- One (1) out of two (2) available Chillers on duty, the second chiller units is used as for spare capacity.
- One (1) out of two (2) available Chilled Water Pumps on duty, the other pump unit is as spare capacity.
- Two (2) out of four (4) available Chiller Condensing units on duty, the other two (2) units are used as spare capacity.

Senate Annex Building Observations

➢ There is a considerable amount of chilled water being lost due to an apparent malfunctioning pressure relief valve.

➢ There is a considerable amount of sludge in the chilled water distribution loop.

➢ One (1) out of two (2) available chillers units on duty, the other unit is out of service due to a heavily damaged heat exchanger.

➢ One (1) out of two (2) available Chilled Water Pumps on duty, the other unit is used as spare capacity.

➢ Two (2) out of two (2) available Chiller Condensing units on duty, no spare capacity is available.

***Capitolio* Building Observations**

➢ All chiller units are on duty, four (4) out of four (4), no spare capacity available.

➢ All Chilled Water Pumps are on duty even though that two (2) of them should be used as spare (eight out of eight).

➢ There is extensive Direct Expansion (DX) equipment installed in order to help (support) the Chilled Water system.

➢ One (1) 15TON DX unit out of service in Senate's Hemicycle.

➢ One hundred and five Cooling Tons (105TONS) are used to cool the two Hemicycles.

➢ One (1) 10TON DX unit used to cool the electrical substation room because of the dry type transformers are used.

Tables 4, 5 and 6 include the required cooling loads of the three (3) building extensions. This information was used as reference purposes for the different improvement alternatives.

Table 4
House Annex cooling loads

Anexo Camara Cooling Loads		
Current Chiller Capacity	120	TONS
On Duty Capacity	60	TONS
Cooling Load - Chilled Water	114	TONS
Corrected Cooling Load (20% reduction)	91.2	TONS
Actual Cooling Load Excess	**31.2**	**TONS**
Conference rooms cooling load	12.4	TONS
Total Cooling load w/o conference rooms	78.8	TONS

Table 5
Senate Annex cooling loads

Anexo Senado Cooling Loads		
Current Chiller Capacity	60	TONS
On Duty Capacity	60	TONS
Cooling Load - Chilled Water	103.5	TONS
Corrected Cooling Load (20% reduction)	82.8	TONS
Actual Cooling Load Excess	**22.8**	**TONS**
Conference rooms cooling load	18	TONS
Total Cooling load w/o conference rooms	64.8	TONS

Table 6
Capitol Building cooling loads

Capitolio Cooling Loads		
Current Chiller Capacity	209	TONS
On Duty Capacity	209	TONS
Cooling Load - Chilled Water	407.5	TONS
Corrected Cooling Load (20% reduction)	326	TONS
Actual Cooling Load Excess - Chilled Water	**117**	**TONS**
Conference rooms cooling load	15.5	TONS
Total Cooling load w/o conference rooms	310.5	TONS
DX Cooling Load	273.5	TONS
Total Cooling Load	**599.5**	**TONS**

RECOMMENDATIONS

There are many options or improvement alternatives that could be developed and structured in order to reduce the operational expenses, but the ones recommended on this section are based on the following important parameters:

- Life Cycle
- Single Payback
- Capital Investment
- Technology Reliability and Stability
- Efficiency and Maintenance Levels

There are many activities that could be deployed or integrated as part of the daily activities (utilities systems) at the *Capitolio*. This improvement process will be dictated by the available capital funding for investment and the commitment of the system owners or administrators with respect to sustainability.

Project Initiative #1: Interior & Exterior Illumination System Retrofit

This improvement alternative proposes the integration of advanced and high efficiency lighting components that could be incorporated as part of the actual system. The integration of T5, T8, LED and Induction high efficiency components and motion sensors will provide lower operational costs and better maintenance conditions of the system components. Also, this improvement option will provide a more efficient system with higher illumination levels. Figure 1 shows one a quick and easy retrofit for Parabolic 2x2 or 2x4 fixtures.

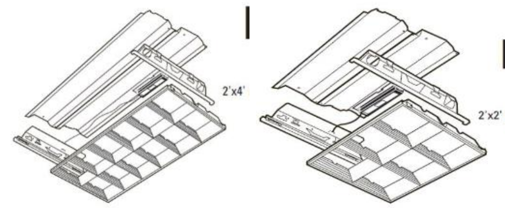


Figure 1
Retrofitting of 2x2 and 2x4 fixtures

Also, as part of the improvement process, it was identified that there are several lighting fixtures that are installed at two (2) specific locations (Hemicycles) which required a significant amount of energy for illumination purposes and A/C. Currently, the heat that is generated by the MH400W fixtures requires the integration of an A/C unit that is fully dedicated to cool down these system components.

Another fixture that will be integrated is the VT1F32 (shown in Figure 2), which replaces the 70W ceiling mounted fixtures. This retrofit option makes use of a high output electronic ballast, reflector (95% polished) and T8 F32 tube. It reduces the energy consumption by up to fifty percent (50%).

Figure 2
VT1F32 high efficiency lighting fixture

The integration of LED technology is recommended for parking lighting posts (175W). It is recommended the integration of Beta LED Edge technology (60W) (shown in Figure 3) because it provides a better illumination pattern and reduces the energy consumption. In addition, it is a fixture that provides an outstanding aesthetic look for the facilities.

Figure 3
BetaLED Edge technology (60W)

In summary, the integration of these technologies will provide to the *Capitolio***,** the opportunity to reduce the operation costs (yearly) up to forty five percent (45%) which represents $114,735.99, as shown on Table 7. Also, the single payback for this type of improvement (overall project initiative) is approximately 3.6 years which is within the recommended timeframe. The required capital investment cost is approximately $424,671.25.

Table 7

Simple payback analysis

Overall Lighting System

Location	Investment	Savings	Payback
Senate & Representatives	$ 227,281.25	$ 69,722.59	3.3
East Extension (Senate)	$ 92,042.50	$ 22,680.22	4.1
West Extension (Representatives)	$ 105,347.50	$ 22,333.18	4.7
	$ 424,671.25	**$ 114,735.99**	**3.7**

Consumption (kWh)

Actual	Future	Savings
856,973	539,910	317,063
179,792	76,700	103,092
166,760	65,246	101,514
1,203,524	**681,855**	**521,669**

Interior Lighting System

Location	Investment	Savings	Payback
Senate & Representatives	$ 227,281.25	$ 69,722.59	3.3
East Extension (Senate)	$ 40,417.50	$ 6,992.79	5.8
West Extension (Representatives)	$ 54,816.25	$ 10,138.12	5.4
	$ 322,515.00	**$ 86,853.49**	**3.7**

Exterior Lighting System

Location	Investment	Savings	Payback
Exterior - East Extension	$ 51,625.00	$ 15,687.43	3.3
Exterior - West Extension	$ 50,531.25	$ 12,195.06	4.1
	$ 102,156.25	**$ 27,882.49**	**3.7**

Motion Sensors Integration

Location	Actual (kWh)	Future (kWh)	Savings
Senate & Representatives	25,483.17	20,386.54	$ 1,121.26
East Extension (Senate)	11,485.68	9,188.54	$ 505.37
West Extension (Representatives)	7,000.78	5,600.62	$ 308.03
	43,969.63	**35,175.71**	**$ 1,934.66**

Note: Actual (kWh) is the consumption after the implementation of lighting retrofit

HVAC System Optimization

This improvement alternative proposed the integration of advanced and high efficiency HVAC components or optimization sub-systems**.**

- Automation and upgrade of AHU's, Fan Coils, Pumps and Chillers controls.
- Programmable thermostats
- Variable Frequency Drives
- Variable Air Volume boxes

Table 8 includes a quick analysis of the potential improvements and financial benefits that could be achieved by the integration of automation elements over the AHU's fan coils, chillers and pumps. There is a potential of fifteen percent (15%) energy reduction by the integration of these controls. It is important to perform a system integration assessment and layout a potential system design.

Table 8
Automation of A/C units

Automation of AHU's Fan Coils, Chillers and Pumps				
Building	Consumption per year (kWh)	Savings Proposed	New Consumption per year (kWh)	Savings per year ($)
Camera Annex	733896.2	15%	623811.8	$ 24,218.58
Senate Annex	751185.2	15%	638507.4	$ 24,789.11
Capitolio	2470330.6	15%	2099781.0	$ 81,520.91
			Total Savings per year	$ 130,528.60

Savings based on an average cost of $0.22 per kWh

Replace all DX units by inverter units or higher efficiency units (A Central Chiller Plant is not feasible due to limited capital). Average Energy Efficiency ratio (EER) is 9.0 and the Proposed will be EER 11.5. Actual Consumption is 1,859,117.1kWh/yr and the consumption after retrofitting will be 1,053,047.0kWh/yr. Annual savings are near $177,335.42. Estimated Capital Costs are $450,000.00 and the Simple Payback will be 2.53 years.

SOLAR ENERGY AFTER LIGHTING AND A/C RETROFITTING

After the implementation of the full lighting retrofit and replacement of the A/C units, a Solar Photovoltaic (pv) system could be installed as shown in Figure 4.

Feasibility Analysis

- Preliminary analysis shows that a total of 703 pv modules divided in the following roofs:

  a) West Annex Building: 324 pv modules

  b) Capitol Building: 147 pv modules

  c) East Annex Building: 232 pv modules

- With a range of pv modules of 210 watts to 240 watts a total of 147 KW to 168 KW is possible for the Capitol and its Annexes

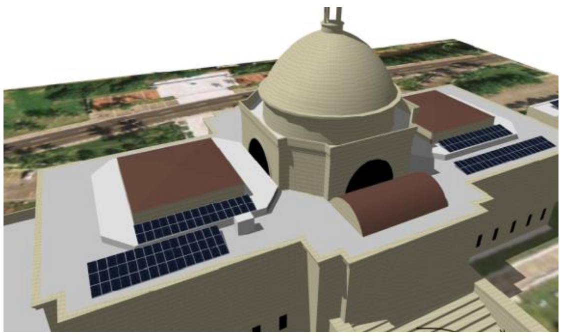


Figure 4
Perspective of the proposed pv module array

The first steps in a feasibility study for a photovoltaic system is the shading analysis.. The use of a Solmetric Suneye (shown in Figure 5) is recommended to view the solar window for the probable location of the pv array.

Figure 5
Solmetric SunEye equipment for shading analysis

Using this equipment with the corresponding latitude and longitude of the site, the arrays presented in Figures 6, 7 and 8 were obtained for the Capitol and Annexes Buildings.

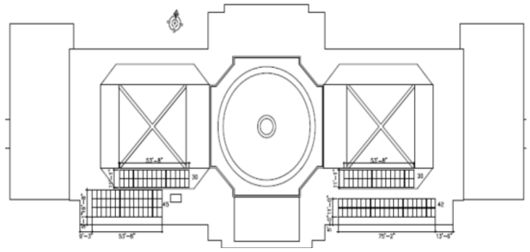


Figure 6
Capitol Building proposed pv array

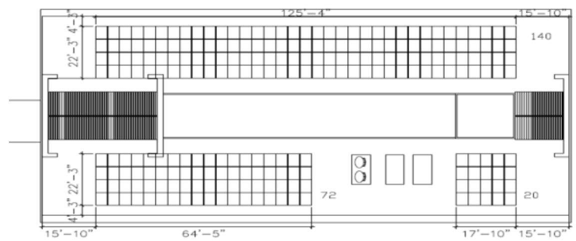


Figure 7
Senate proposed pv array

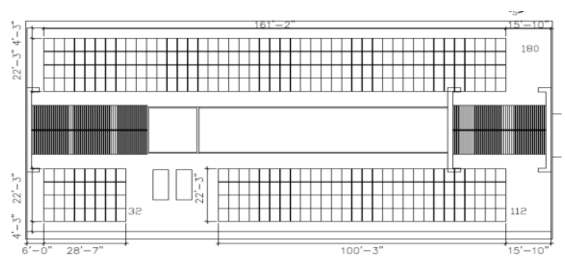


Figure 8
House proposed pv array

Estimated Kw-h Energy Production for this Area

There are three main parameters for energy calculations, other than the amount of pv modules and inverters capacity:

- Inclination: it is always recommended 18 degrees of inclination because it is the latitude of Puerto Rico and it is the best scenario for energy harvesting. At this inclination, based on the National Renewable Energy Laboratory (NREL) we obtained an average per year of 5.5 peak sun hours. At a tilt less than azimuth there is a minor derating of the energy harvesting, but insignificant, as it will be shown shortly.

- ➢ Orientation: this is the orientation of the pv modules. It is always recommended to orient the pv modules to the true south. However, due to roof layout and building orientation, it is not possible to accommodate the pv modules to the south. In that case there is going to be a minor derating of the energy harvesting, but insignificant, as it will be shown shortly.
- ➢ Efficiency: this is the derating factor used to convert from dc to ac. Here we account for mismatch of pv modules, power rating of the modules, cable losses, availability, shading, inverter efficiency, temperature derating and soiling conditions. Based on our experience and calculated efficiencies on other projects in Puerto Rico and based on average temperature, expected efficiency is within .7 to .75, as shown in Table 9.

➢ Table 9

➢ Calculator for DC and AC derate factor

➢

Calculator for Overall DC to AC Derate Factor

Component Derate Factors	Component Derate Values	Range of Acceptable Values
PV module nameplate DC rating	0.98	0.80 - 1.05
Inverter and Transformer	.97	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	.95	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	.92	0.00 - 1.00
Sun-tracking	1.00	0.95 - 1.00
~~Age~~ Replaced by Temp. Derating	.92	0.70 - 1.00
Overall DC to AC derate factor	**0.708**	

Calculate Derate Factor

The software used for estimating energy production on the United States, including Puerto Rico, is free software developed by NREL where it has the average peak sun hours of the site at different inclination, orientation and efficiencies to convert from dc to ac. This software is called PV Watts and it's recommended by the Association of Energy Engineers (AEE). Tables 11 and 12 were developed using on PV Watts. They show the estimated annual energy production for the maximum pv system of 168 KW is 212,302 kw-h. and an estimated/probable savings of 5.3% of the approximated annual energy consumption of 4,015,000 kw-h. This means about $63,838.50/yr in savings.

➢ Table 10

Calculator for DC and AC derate factor

PV Watts — AC Energy & Cost Savings — Cautions for Interpreting the Results

Capitol Building and Annexes: Possible maximum of 168 KW PV System

Station Identification	
City:	San_Juan
State:	Puerto_Rico
Latitude:	18.43° N
Longitude:	66.00° W
Elevation:	19 m
PV System Specifications	
DC Rating:	168.0 kW
DC to AC Derate Factor:	0.710
AC Rating:	119.3 kW
Array Type:	Fixed Tilt
Array Tilt:	6.0°
Array Azimuth:	173.0°
Energy Specifications	
Cost of Electricity:	22.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.62	15407	3389.54
2	5.18	15629	3438.38
3	5.90	19720	4338.40
4	6.05	19650	4323.00
5	5.79	19129	4208.38
6	6.02	19472	4283.84
7	6.11	20247	4454.34
8	5.95	19637	4320.14
9	5.77	18394	4046.68
10	5.11	16889	3715.58
11	4.43	14137	3110.14
12	4.25	13990	3077.80
Year	5.43	212302	46706.44

If the scenario would have a 50 KW pv system, then the estimated energy production of the system can be 63,185 Kw-h, an estimated yearly savings of 1.6%. This means about $18,955.50/yr in savings.

➢ Table 11

Calculator for DC and AC derate factor

PV Watts — AC Energy & Cost Savings — Cautions for Interpreting the Results

Capitol Building and Annexes: 50 KW PV System

Station Identification	
City:	San_Juan
State:	Puerto_Rico
Latitude:	18.43° N
Longitude:	66.00° W
Elevation:	19 m
PV System Specifications	
DC Rating:	50.0 kW
DC to AC Derate Factor:	0.710
AC Rating:	35.5 kW
Array Type:	Fixed Tilt
Array Tilt:	6.0°
Array Azimuth:	173.0°
Energy Specifications	
Cost of Electricity:	22.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.62	4585	1008.70
2	5.18	4652	1023.44
3	5.90	5869	1291.18
4	6.05	5848	1286.56
5	5.79	5693	1252.46
6	6.02	5795	1274.90
7	6.11	6026	1325.72
8	5.95	5844	1285.68
9	5.77	5475	1204.50
10	5.11	5026	1105.72
11	4.43	4208	925.76
12	4.25	4164	916.08
Year	5.43	63185	13900.70

CONCLUSION

The implementation of the full lighting retrofit and replacement of DX units will provide the following financial benefits:

- Annual Savings $292,071.41
- Estimated Capital Costs $874,671.25
- Single Payback 2.99 years

Based on this feasibility study, it is possible for the Capitol of Puerto Rico to install a pv system of 168 KW distributed in the main building and the two annex.

- Annual Savings $63,838.50
- Estimated Capital Costs $500,000.00 (AFI will provide the pv modules)
- Single Payback years 7.83 years

The benefits are not only in energy costs savings, but also reducing the dependency of oil and avoiding hundreds tons of CO_2 going into atmosphere.

FUTURE WORKS

After the completion of the pv project you can access the web page; ***http://live.deckmonitoring.com/?id=puerto_rico_state_capitol***

This page will provide the following information:

- Total Energy Generated in terms of 60 watts bulb used on daily basis.
- Total CO_2 Offset in terms of tree saved
- Total Energy Generated in terms of tons of CO_2 saved
- Total Energy Generated in terms of gallons of gas saved

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