# Senior Thesis Final Report

## FDA Building One – White Oak, MD

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This Final Report of the Architectural Engineering Capstone Thesis examines FDA Building One located at the Federal Research Center in White Oak, MD. The existing design in the categories of architecture, structural, mechanical, electrical and lighting is described. Further this report explores an area of improvement in the mechanical depth in the capacity of installing photovoltaic panels as a source of renewable energy. From a construction management point of view, the storage of renewable energy in the form of thin film batteries is explored. Specifically the constructability, cost and scheduling impacts are studied. Also, the distribution of direct current power to the building's low voltage fixtures is evaluated as a part of the electrical depth. The impact of the electrical breadth studies ties back into the mechanical depth in that the impact of reduced size of pumps is assessed and general cost analysis has been conducted.

## 1.0 EXECUTIVE SUMMARY

The FDA Building One located in White Oak, MD was renovated in 2007-2008 as a part of a larger effort to consolidate FDA facilities at the Federal Research Center. The historic Naval Ordnance Building was built in 1946 and is located on the FDA's new headquarters campus outside of Washington DC. This four-story, 102,000-square-foot building was completely transformed into the Office of the Commissioner for FDA and serves as the gateway to the FDA campus. The building's historical integrity was maintained through the renovation.

The mechanical system that was designed for this building uses a variety of systems to service the different areas based on the use of the space. FDA Building One receives conditioned supply air from three air handling units (AHU's). These serve the building's perimeter offices, security pavilion, conference rooms and interior work spaces. Additional computer room AC units are used for LAN and electrical rooms.

Building One is connected to a Central Utility Plant (CUP) on the campus. The plant has a CoGen unit that provides electricity as well as chilled and hot water to buildings on the campus. The Central Utility Plant was developed in partnership with Sempra Energy Services and Honeywell under an Energy Savings Performance Contract. The efficiency and reliability of buildings running serviced by the plant justify the cost for the build out.

In an effort to reduce the load on the Central Utility Plant, an improvement opportunity was considered for Building One. A photovoltaic system that would provide up to 40% of the building's electric needs was evaluated. Cost and payback of the system were justified by taking into consideration the fuel tariff rates used for electricity generation at the CUP.

To minimize losses and smooth spikes from electricity generated from the photovoltaic system, a direct current approach was studied. As a part of the construction management breadth, constructability of embedding thin film battery into wall insulation was examined. The robust material is a cutting edge technology that conglomerates are investing in heavily. Scheduling concerns are addressed by the fact that the thin film battery comes in rolls and can be cut to suitable size in the field.

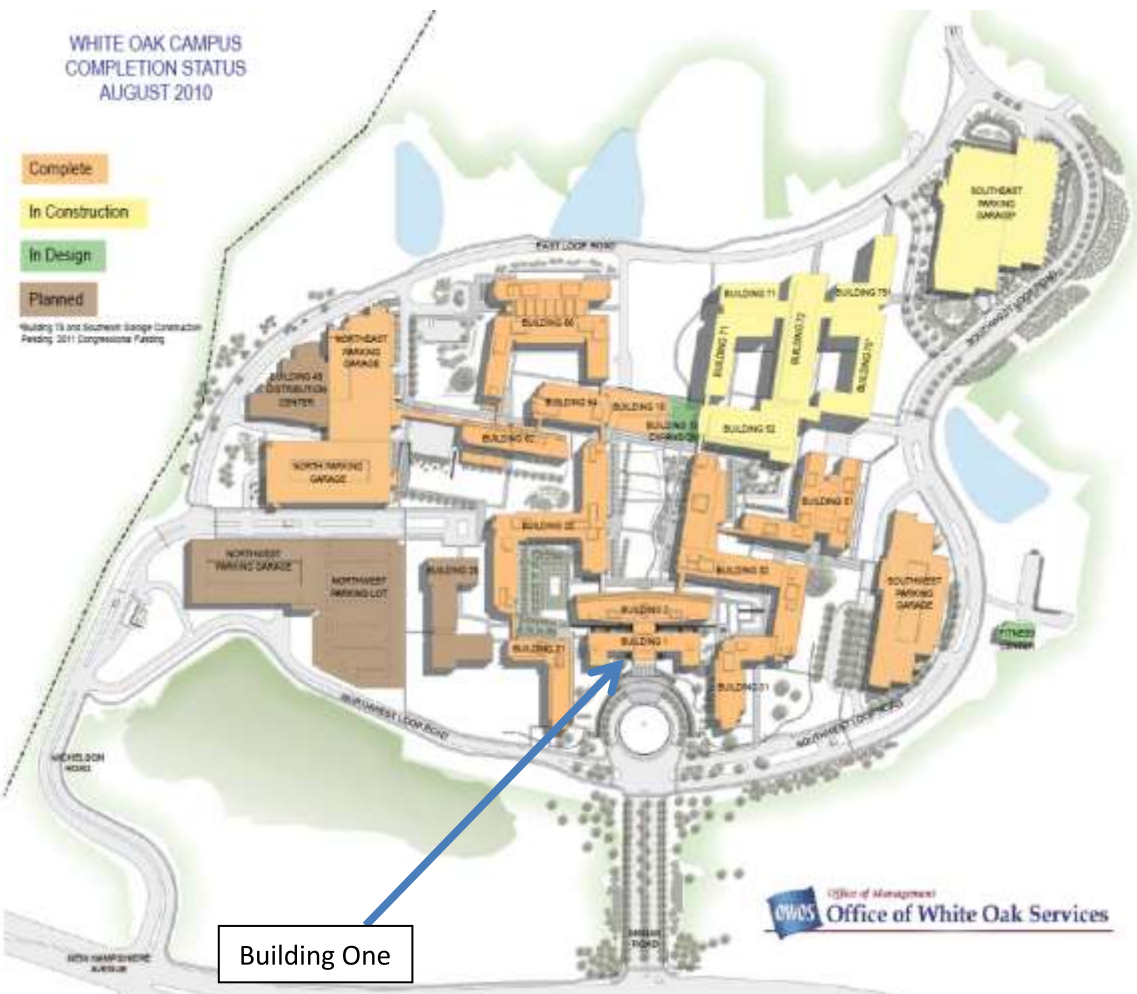
As part of the electrical breadth, DC distribution applications within the building were proposed. DC distribution would eliminate the need of an inverter and, thus inefficiencies, of converting from DC to AC from the photovoltaic system or battery backup. The flexibility and sustainability of the approach is very well developed, as are the options available for system fixtures.

The impact of DC applications in the building was tied back to the mechanical system. Exploitation of the efficiency of the system allowed for resizing the pumps that are used within Building One. If applied, upfront cost savings of up to 10% could be realized.

## 2.0 PROJECT INFORMATION

### 2.1 Background

FDA Building One is the seventh White Oak structure completed as part of the FDA's consolidation project on the White Oak, MD campus. The consolidation was strategically planned at this site due to its proximity to Washington, DC. GSA oversaw the renovation of the 102,000 square foot, four-story historic Building One - originally the headquarters of the Naval Surface Warfare Center for 52 years - to accommodate the FDA's Office of the Commissioner and related executive functions. The renovation took up $36.5-million of the $1.4-billion FDA Campus HQ Consolidation Project which also includes renovation of two other historic buildings and construction of 17 new buildings, totaling 5.3 million square feet of new laboratories and offices.  As a part of the infrastructure this also included construction of a central utility plant and parking garages for approximately 5,900 vehicles.




FDA White Oak Campus Completion Status August 2010

## 2.2 Historical Significance of FDA Campus at White Oak

In 1944, acquisition, planning and construction work began at a 712-acre wooded site located at 10903 New Hampshire Avenue, Silver Spring, MD. Someone remarked to a Navy official during early 1945 that it seemed odd to be building the new laboratory at that time: the war would probably be over before the facility could be finished. "That laboratory," remarked the Navy man, "is not being built for this war."

The Laboratory participated in all the nuclear weapons tests and was the sole repository of all nuclear weapons blast effects data for the Department of Defense. Here was developed the ceramic materials used in missile nose cones and heat shields for space craft. The wind tunnels provided model flight data for missiles and space crafts. One material discovered and developed here, NITINOL and is subsequent derivatives, is widely used medically as stints in arteries and veins. Also a mathematical model of chaos was developed here to study and control variations in heart arrhythmia. Over 2000 patents were granted to our scientists over the 50 years which attests to the technical excellence, inventiveness, and talent of our scientists and engineers.

Many of the scientists and engineers that worked here were recognized national and international experts in their fields, and were able to attract, recruit, and retain top level talent based on the technical reputation. Examples of the level of talent employed here were John Bardeen, John Atanasoff, and Joseph Webber. John Bardeen co-invented the transistor and received two Nobel Prizes. John Atanasoff invented the digital computer, and Joseph Webber co-developed the laser. Also, the level of scientific work carried on here is evidenced by the fact that John Nash, of movie fame, “Beautiful Minds,” consulted with NOL mathematicians and Albert Einstein, consulted with explosive experts.

Original Construction of FDA Building One 1944-46

This 1960s-era postcard image shows the NOL Administration Building and golf course as seen from New Hampshire Ave. After renovation for use by the FDA it still looks much the same, with "Naval Ordnance Laboratory" still carved in stone above the main entrance.

### 2.3 Project Stat's at a Glance

**Location & Site:** Food & Drug Administration
Federal Research Center – White Oak, MD

**Building Occupants:** Office of the Commissioner –
Food & Drug Administration

**Function Type:** Office Building

**Size (GSF):** 102,000 SF
**Number of Stories:** 4 Stories above Grade + Penthouse

**Project Team**

-Owner: General Services Administration

-General Contractor: Grunley Construction

-CM: Heery-Tishman

-A/E: KlingStubbins with RTKL

**Date of Construction:** 9/25/2007 – 11/15/2008

**Contract Amount:** $36,444,302

**Project Delivery Method:** Lump Sum Contract

## 2.4 Architectural Overview

The adaptation of historic Building One symbolizes the transformation of the White Oak campus from a weapons research facility to a 21st-century headquarters for the world's foremost institution safeguarding our nation's health and well-being. Serving as the centerpiece and administrative nexus of the campus, the restored building provides a new public expression for the agency while providing enhanced security. The design includes the renovation and restoration of the existing four-story building, a new multi-level link connecting the historic lobby to the adjacent atrium in the Central Shared Use building, and a new security pavilion and landscaped entry forecourt that serves as the main arrival point for the campus.
As the new home of the US Food and drug Administration Commissioner, this project represents a commitment to sustainable design principles

Flanked by two office buildings, Building One creates a formal entry forecourt. The entry drive, forecourt, and Mahan Road were re-graded to match the elevation of the courtyard area. A new circle, built to match the scale of the new forefront, replaces the original circle in front of the main entrance.
The building integrates 148 offices, nine conference rooms and several workstations and shared business areas and connects to the campus' first Central Shared Use space with access through the first floor lobby.

Original Campus Layout

New Campus Layout

The design of the building complies entirely with historic preservation with a few modern touches to the façade. Special considerations were taken into account in order to compliment the design of the existing buildings as well as match the architectural materials that were selected for the original campus facade. KlingStubbins in part with RTKL was hired to be the design team and worked directly with the State Historic Planning Office (SHPO) as well as the National Capitol Planning Commission (NCPC). Undoubtedly, a lot of effort was put into retaining the original integrity of the building. To maximize sustainability, the original brick and limestone core of the historic Building One was reused in conjunction with additional building materials containing low Volatile Organic Compounds (VOCs). To better conserve energy, the historic building envelope was thoroughly insulated and the original single-pane windows were replaced with operable, low-E steel units.

FDA Building One as seen when entering the FDA HQ Campus

## 2.5 Construction Overview

The historic renovation and additions to the FDA Building One at White Oak was similar to many of Grunley Construction's previous modernizations which required preserving the historic fabric of the building while maintaining a fully-operational Government Campus. They immediately recognized the challenges associated with this project to include maintenance of access to surrounding buildings and coordination with other contractors who were simultaneously performing construction on the campus while delivering a first-class office building suitable for the Commissioner of the FDA and GSA.

Grunley viewed the FDA Building One project as a complex project consisting of the renovation of the existing building while simultaneously modifying all four building entrances and providing a new monumental entrance. Key components include the North and South canopied entrances, a new connector to the existing Central Shared Use Building, and the new security pavilion housing the secure screening area and entrance. Immediately following Notice to Proceed (NTP), they mobilized on-site and performed the following critical activities:

-Tree protection and sediment controls,
-Set-up of project staging area and securing of site,
-Removal and storage of the historic flagpole,
-Installation of OSHA-compliant safety measures in the existing building, and
-Survey, documentation, and protection of historic building features to remain.

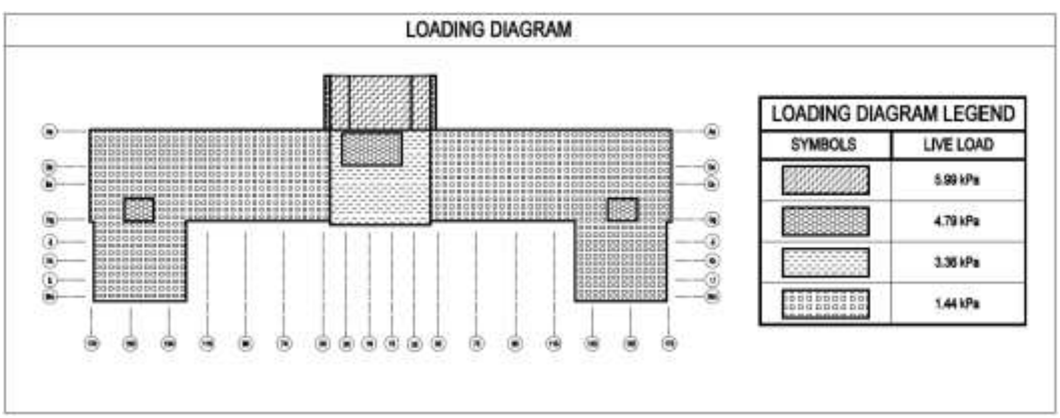
Upon completion of the initial project mobilization activities and submission of initial contract deliverables, they sequenced and executed the work in five very distinct portions consisting of the Security Pavilion addition, Atrium Connector Link construction, existing Building One renovation, façade restoration, and major site modifications and improvements. They began with excavations at the Security Pavilion and Atrium Connector Link while simultaneously starting the structural modifications of the existing building.

## 2.6 Structural Overview

The foundation consists of reinforced spread footing foundations beneath Building One with additional boring required for the area beneath the Security Pavilion and the Connector Link. The structural bays in Building One consist of 20feet in the longitudinal direction and 11 feet in the latitude direction. To a large extent structure was only reinforced to withstand seismic loads; while replacement of choice beams and areas of slab were done. The column grid presents the added benefit of allowing the use of repetitive member sizing of the interior beams taking advantage of uniformity of detailing, fabrication and erection. The framed floors are 2-1/2" NW concrete on 3" deep gauge galvanized composite steel deck.

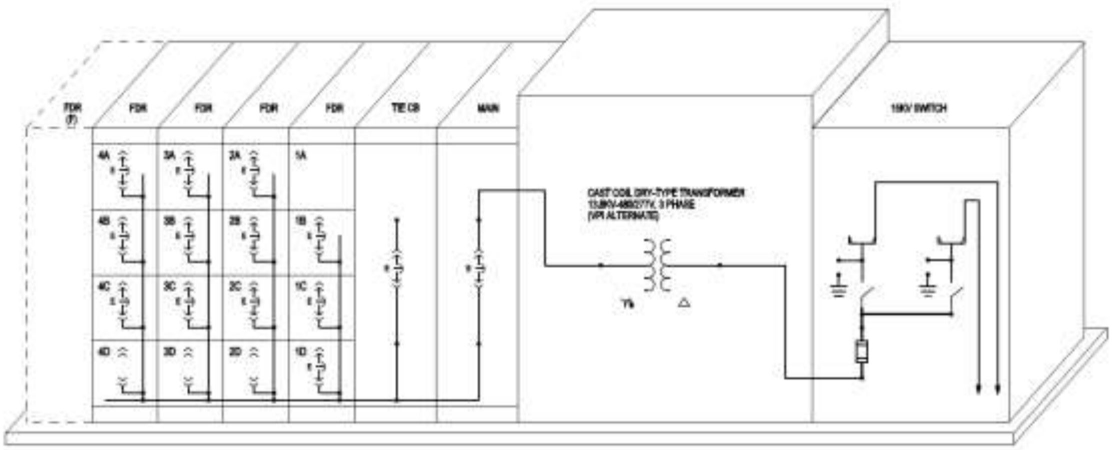
### DESIGN LOADS

| | | | | |
|---|---|---|---|---|
| 1. | SNOW LOADS | | | |
| | a. | GROUND SNOW LOAD, Pg | 1.20 kPa | |
| | b. | IMPORTANCE FACTOR, Is | 1.0 | |
| | c. | EXPOSURE FACTOR, Ce | 1.0 | |
| | d. | THERMAL FACTOR, Ct | 1.2 | |
| | e. | FLAT ROOF SNOW LOAD, Pf | 1.00 kPa | |
| | f. | MINIMUM DESIGN LOAD | 1.44 kPa | |
| 2. | DEAD AND LIVE LOADS | | DEAD | LIVE |
| | a. | BUILDING 1 | | |
| | | ROOF | 0.96 kPa | 1.44 kPa (1) |
| | | ROOF FAN ROOMS | 0.48 kPa | 4.79 kPa |
| | | OFFICE | 3.37 kPa | 3.83 kPa |
| | | STAIRS | 2.40 kPa | 4.79 kPa |
| | | LOBBY | 3.61 kPa | 4.79 kPa |
| | | TOILET ROOMS | 3.85 kPa | 3.83 kPa |
| | | COMMUNICATION & ELECT CLOSETS | 3.37 kPa | 3.83 kPa |
| | b. | SECURITY PAVILION | | |
| | | TERRACE | 6.23 kPa | 4.79 kPa |
| | | SKYLIGHT | 0.72 kPa | 1.44 kPa (1) |
| | | ROOF | 5.03 kPa | 1.44 kPa (1) |
| | c. | ATRIUM CONNECTOR | | |
| | | ROOF | 1.20 kPa | 1.44 kPa (1) |
| | | MECHANICAL ROOM | 4.31 kPa | 6.00 kPa |
| | | BRIDGE | 2.92 kPa | 4.79 kPa |



## 2.7 Electrical & Lighting Overview

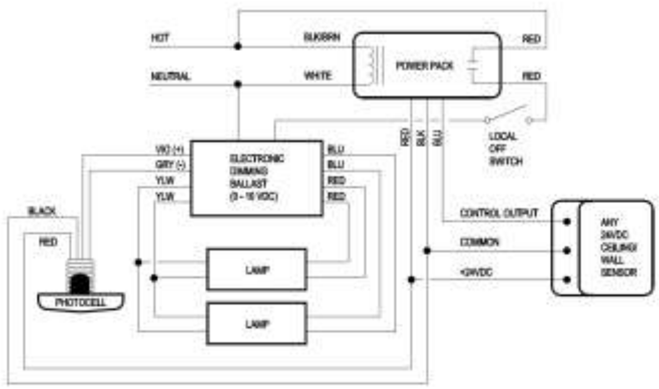
FDA Building One is connected to a Central Utility Plant which fulfills power demands for the entire FDA Campus. This was proposed and awarded in 2001-2002. The CUP is planned in phases, to meet the growing demand as the campus consolidation continues. Building One receives 13.8 kV, 3-Phase power from a dual fuel powered generator located at the central plant. There is a 13.8kV- 480/277V 3 Phase Dry Type substation transformer. Secondary switchgear includes 3200A 480/277V 3 Phase, 4 Wire Main breaker and Tie Breaker. Emergency back-up provided by uninterrupted power supply. The load interrupter switch is a 15kV Primary Duplex Switch with manual transfer.




**Load Summary**

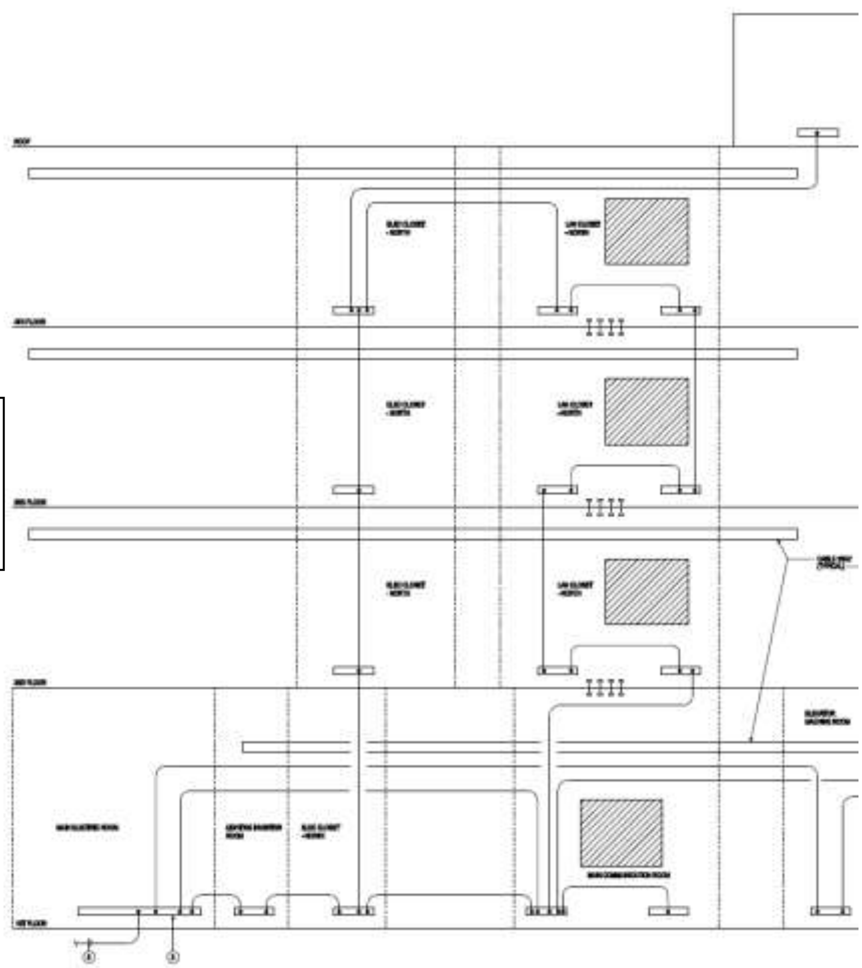
| Load Description | Connected (KVA) | Demand Factor | | Demand (KVA) | REMARKS |
|---|---|---|---|---|---|
| EM LIGHTING | 22.2 | 1.0 | | 22.2 | |
| EM/SB/C POWER | 120.6 | 0.6 | | 72.4 | |
| NORMAL LIGHTING | 76.7 | 1.0 | | 76.7 | |
| MECHANICAL EQUIPMENT | 216.3 | 0.6 | | 129.8 | |
| ELEVATORS | 99.6 | 1.0 | | 99.6 | |
| RECEPTACLES | 457.7 | 1.0 | First 10 KVA | 10.0 | |
| | | 0.5 | Remainder over 10 KVA | 223.8 | |
| Sub-Total : | 993.1 | KVA | | 634.5 | KVA |
| 25% Allowance for Future Growth : | 248.3 | KVA | | 158.6 | KVA |
| Total : | 1241.3 | KVA | | 793.1 | KVA |
| Total (480 VOLT, 3 phase AMPS) : | 1493.2 | AMPS | | 954.0 | AMPS |

Fluorescent lighting is provided throughout the building. Interestingly, along with heavy emphasis on day lighting, areas within offices and conference rooms have been installed with both photocell dimming and occupancy sensors. In private offices around the perimeter 54W T5 lamps are used with electronic dimming ballast. Throughout the corridors 26W compact fluorescent lamps are used in downlight and wall wash luminaires.




Electric & LAN Rooms are 2 to a floor with one each on the North and South end of the building.

Electric and LAN closets layout on each floor Mirrored on the south side as well



## 2.8 Telecom Overview

The FDA requested the GSA install a state-of-the-art Voice, Data, and Video cabling system. The voice, data, and video cabling system will connect the user to voice, data, and video services via installed horizontal cabling, placed in appropriately sized and classed pathways to the designated Telecommunications Room. IT infrastructure includes pathways, spaces, cabling, and termination equipment required for signal distribution for voice, data, video, cellular telephone, and grounding.

## 2.9 Security Overview

A myriad of security equipment has been installed in Building One. The only way to enter the building is through the staffed security pavilion which requires card access and ID clearance. Closed circuit TV cameras are spread throughout, installed in discrete locations. In all private offices a passive infrared motion detector as well as video intercom station is used. Magnetic and electric door locking devices are used at all exits and for access to computer rooms.

## 2.10 Fire Protection Overview

Fire Protection was an important component during the design of Building One.  A complete wet pipe sprinkler system is provided throughout the facility. Throughout office spaces a 1GPM quick response, recessed pendant fixture with chrome finish head is installed. The system for Building One ties into the system installed within the Central Shared Unit. A stead pressure of 150psi is maintained for the entire system.

# 3.0 MECHANICAL SYSTEM

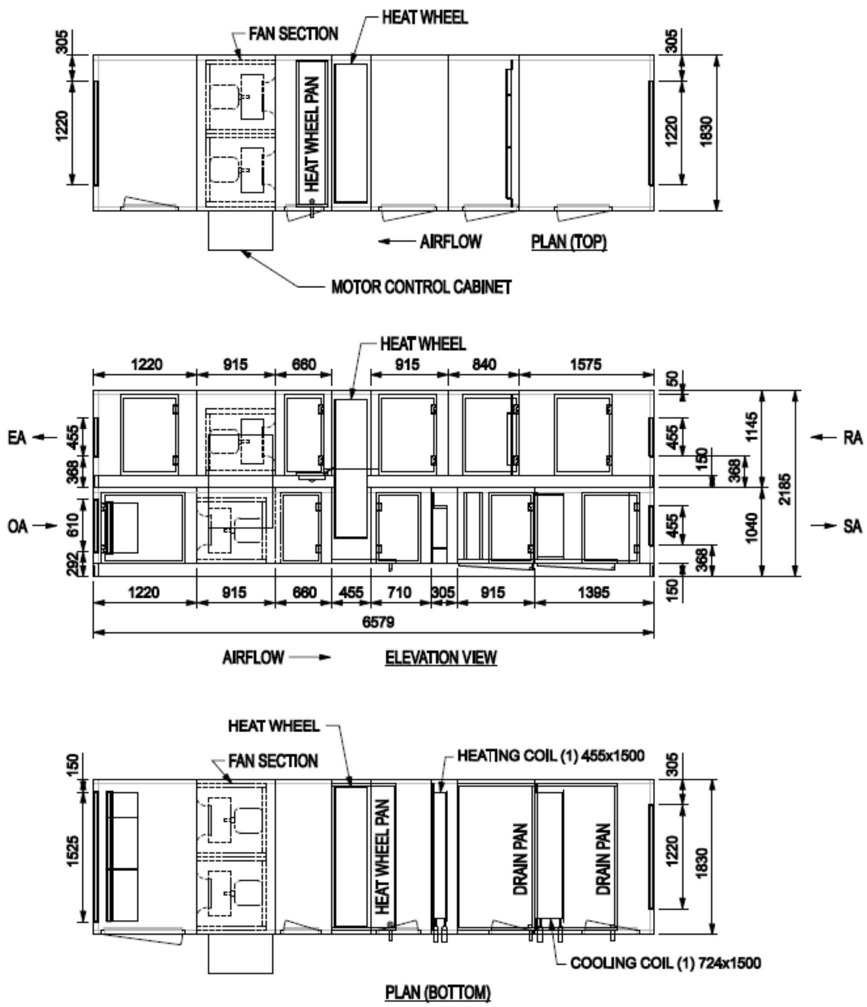
## 3.1 Building One Mechanical System

FDA Building One's renovation was designed with the goal of making it a signature project of GSA – to exemplify the focus of the organization on the sustainability movement. Extensive efforts were made to design this building to LEED standards. LEED certification will be detailed later.

The building has three air handling units. Outside Air Handling-1 and Air Handling Unit-1 are located on the penthouse floor. Air Handling Unit-2 is located in the mechanical room on the first floor of the building.

OAHU-1 is sized at 5,300 CFM, taking in 100% OA and has an Energy Recovery Wheel installed on it. This particular unit serves fan coil units in the entire building. It also serves dual duct terminal units (used in all conference rooms of the building) and variable single air terminal unit boxes with water reheat which are used in interior zones of the building.

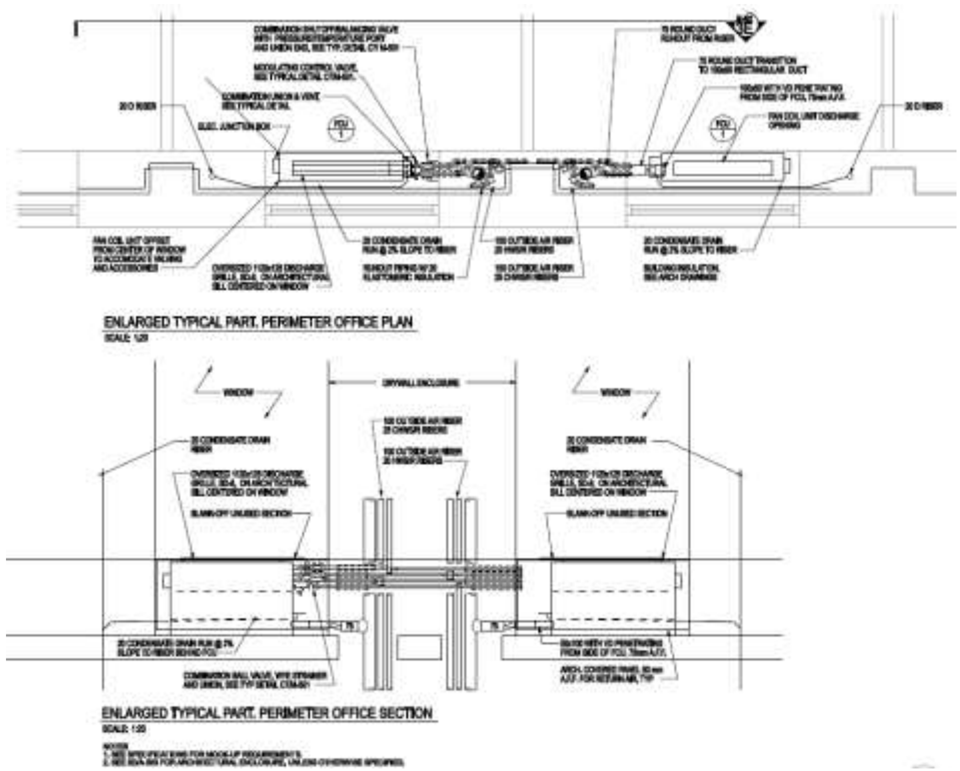
Outside Air Handling Unit Detail



Fan Coil Units are used at window locations, in the electrical rooms on every floor and the elevator machine room. It's a typical 2-pipe heating & cooling type system with 300+ CFM forced air.

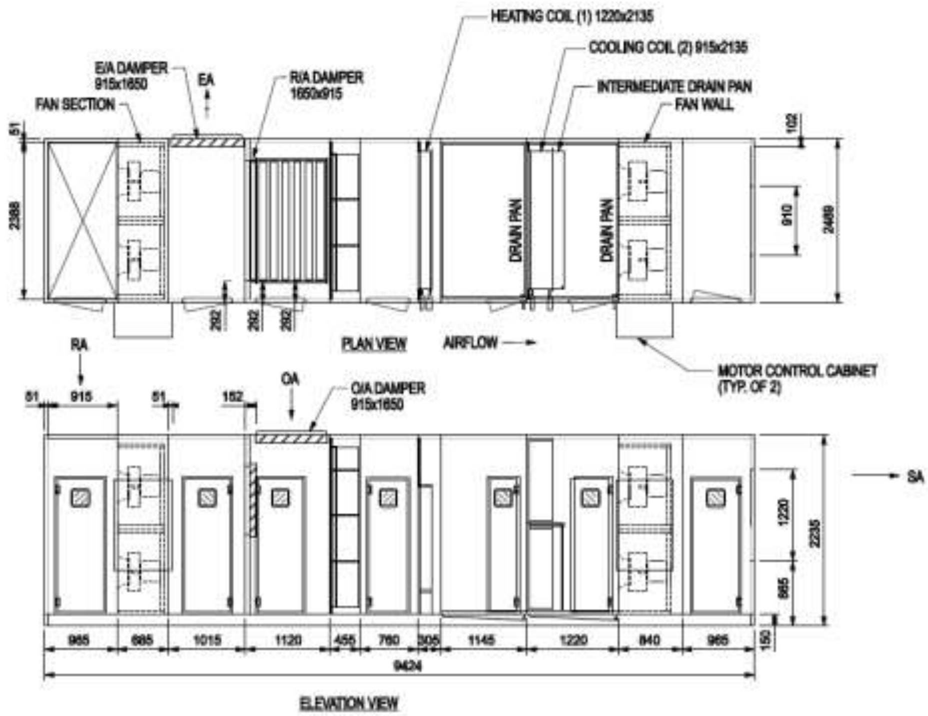
FAN COIL UNIT, SCHEDULE

| EQUIP. NO. | LOCATION | TYPE | FAN L/s (CFM) | DRIVE | EXT. Pa (S.P.) | MOTOR KW (HP) | MOTOR ELECTRIC V/PH/HZ | MOTOR RPM | COOLING CAPACITY KW (MBH) SENS. | COOLING CAPACITY KW (MBH) TOTAL | COOLING EAT DB/WB C (F) | COOLING LAT DB/WB C (F) | COOLING EWT DEG C (DEG F) | COOLING L/s (GPM) | COOLING P.D. kPa (FT. WG) | HEATING CAPACITY KW (MBH) TOTAL | HEATING EAT DB/WB C (F) | HEATING LAT DB/WB C (F) | HEATING EWT DEG C (DEG F) | HEATING L/s (GPM) | HEATING P.D. kPa (FT. WG) | FILTER QTY SIZE mm (IN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FCU-EMR | ELEV MACH RM 1ST FL | VERTICAL DUCTED | 870 (1,840) | BELT | 187 (0.75) | 0.75 (1) | 208/3/60 | 1750 | 12.5 (42.8) | 12.5 (42.8) | 24/16 (75/60) | 12/11 (53/52) | 7.2 (45) | 0.455 (6.0) | 1.18 (4.72) | - | - | - | - | - | - | (1)610x610x50 (1)(24x24x2) |
| FCU-E1S, E2N, E2S, E3N, E3S, E4N, E4S | ELEC RMS 1-4 FL | VERTICAL DUCTED | 378 (800) | DIRECT | 187 (0.75) | FRAC | 120/1/60 | 1000 | 4.30 (14.7) | 4.30 (14.7) | 26/17 (78/63) | 16/12 (61/53.4) | 7.2 (45) | 0.2 (3.2) | 1.971 (7.91) | - | - | - | - | - | - | (2)356x267x25 (2)(14x10.5x1) |
| FCU-E1N | BATTERY RM 1ST FL | VERTICAL DUCTED | 378 (800) | BELT | 187 (0.75) | FRAC | 120/1/60 | 1200 | 5.8 (19.7) | 5.8 (19.8) | 26/17 (75/63) | 11/11 (52/51) | 7.2 (45) | 0.3 (5) | 0.66 (2.63) | - | - | - | - | - | - | - |
| FCU-01 | WINDOWS TYP | VERTICAL | 143 (305) | DIRECT | 50 (0.20) | FRAC | 120/1/60 | 1310 | 1.8 (6.0) | 2.1 (7.2) | 24/17 (75/63) | 13.8/13.3 (56.8/56) | 7.2 (45) | 0.091 (1.4) | 2.7 (0.9) | 2.7 (9.3) | 22.2/12.2 (72/54) | 37.8/18.1 (100/64.5) | 93 (200) | 0.032 (0.5) | 2.7 (0.9) | (1)197x1080x25 (1)(7.75x41.75x1) |
| FCU-02 | WINDOWS SPECIAL | VERTICAL | 196 (415) | DIRECT | 50 (0.20) | FRAC | 120/1/60 | 1300 | 2.4 (8.2) | 2.9 (10.0) | 24/17 (75/63) | 13.8/13.3 (56.7/56) | 7.2 (45) | 0.126 (2.0) | 5.70 (1.9) | 4.4 (14.85) | 22.2/12.2 (72/54) | 40.6/19.1 (105/66.3) | 93 (200) | 0.063 (1.0) | 2.7 (1.1) | (1)197x1111x25 (1)(7.75x43.75x1) |




Typical Fan Coil Unit Detail

AHU-1 is sized at 19,000 CFM, taking in approximately 5,500 CFM OA. This unit delivers conditioned air to dual duct terminal units and constant single air terminal unit boxes that are used for perimeter zones. This unit also serves some variable boxes, similar to OAHU-1.
Both of these units are installed with VFDs and deliver air through plenums, in addition to having pre-heat coils.

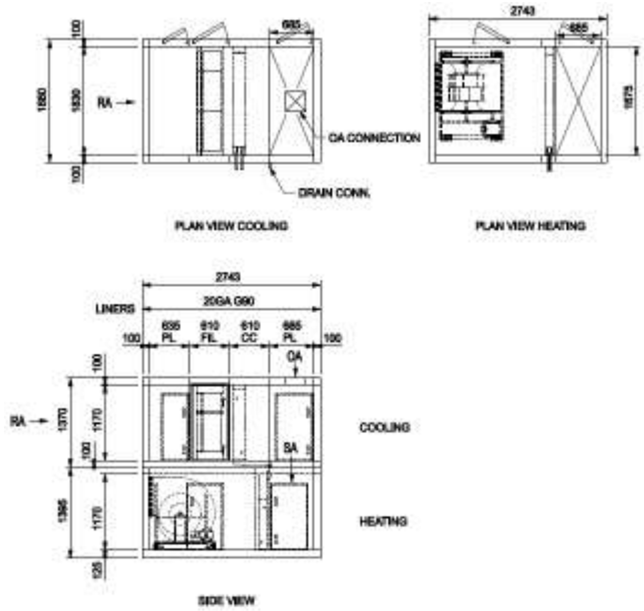



Air Handling Unit-1 Detail

| MAXIMUM DISCHARGE SOUND DATA FOR AHU-1 AND OAHU-1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FREQUENCY | 63 HZ | 125 HZ | 250 HZ | 500 HZ | 1000 HZ | 2000 HZ | 4000 HZ | 8000 HZ |
| SOUND POWER LEVEL (dB) SUPPLY | 82 | 79 | 82 | 77 | 72 | 71 | 68 | 62 |

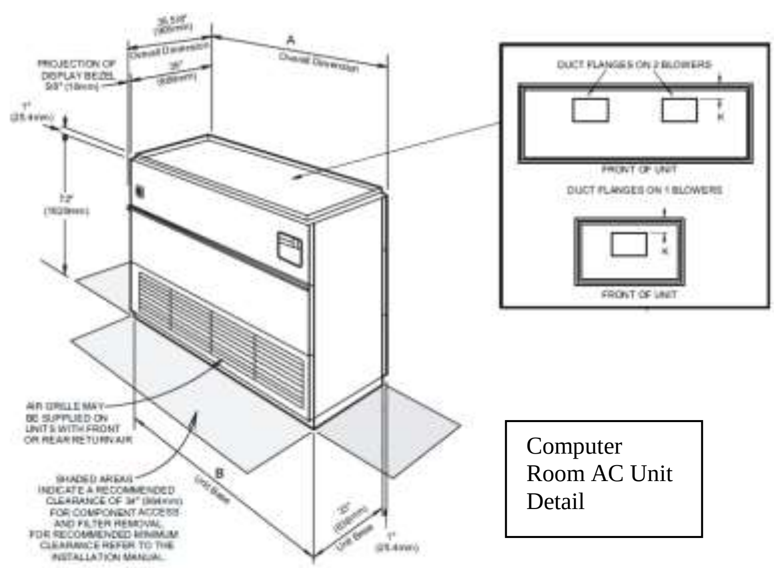
NOTES:
1. ALL SOUND POWER LEVELS ARE dB re: $10^{-12}$ W

AHU-2 is sized at 7,350 CFM, taking in the minimum amount of OA at 400 CFM and its further OA needs are supplemented by the OAHU-1. AHU-2 serves solely the security pavilion at the main entrance of the building. This unit is kept at constant volume and therefore has no return fan. This unit differs from the other two, in that it has a re-heat coil.

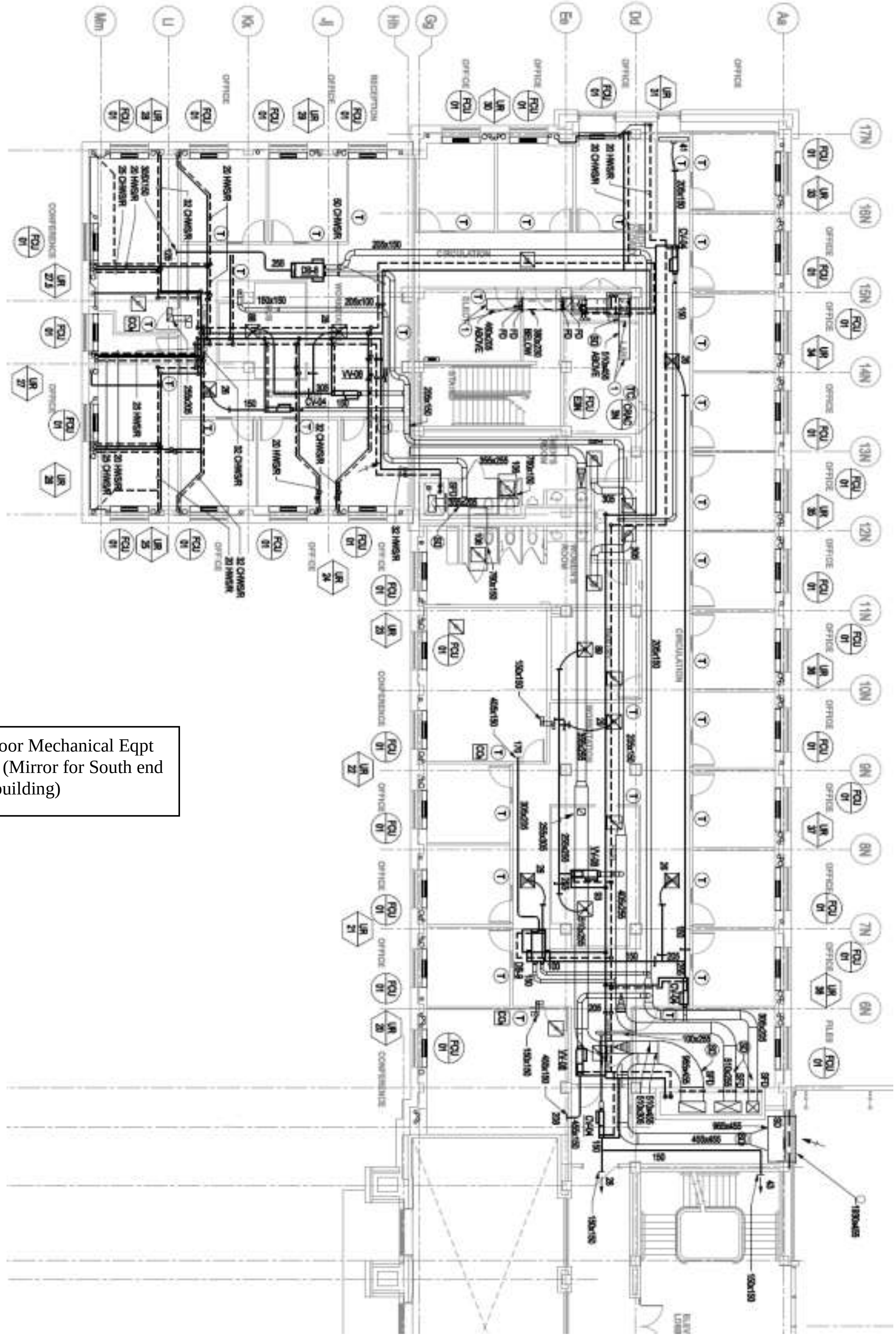



Air Handling Unit-2 Detail

There are a couple of spaces that are not serviced by the air handling units. Those spaces are the electrical, telecom and LAN rooms on every floor. These spaces are serviced by computer room air conditioning units. All units are vertically ducted, which makes sense as the system takes advantage of natural convection direction. The electrical room on the first floor of the building uses a 5,250 CFM unit that providing air at 61 degrees F. The LAN rooms on all four floors used systems sized at 2,800 CFM providing air at 55 degrees F. The telecom room on the first floor also provides 55 degree air and is sized at 6,050 CFM.




Computer Room AC Unit Detail



Half Floor Mechanical Eqpt Layout (Mirror for South end of the building)

The building doesn't contain any chillers or boilers. It receives 39F chilled water and 200F hot water from a central plant. For domestic water temperature control a plate and frame heat exchanger has been installed. The chilled water and hot water pumps have standby's assigned for redundancy.

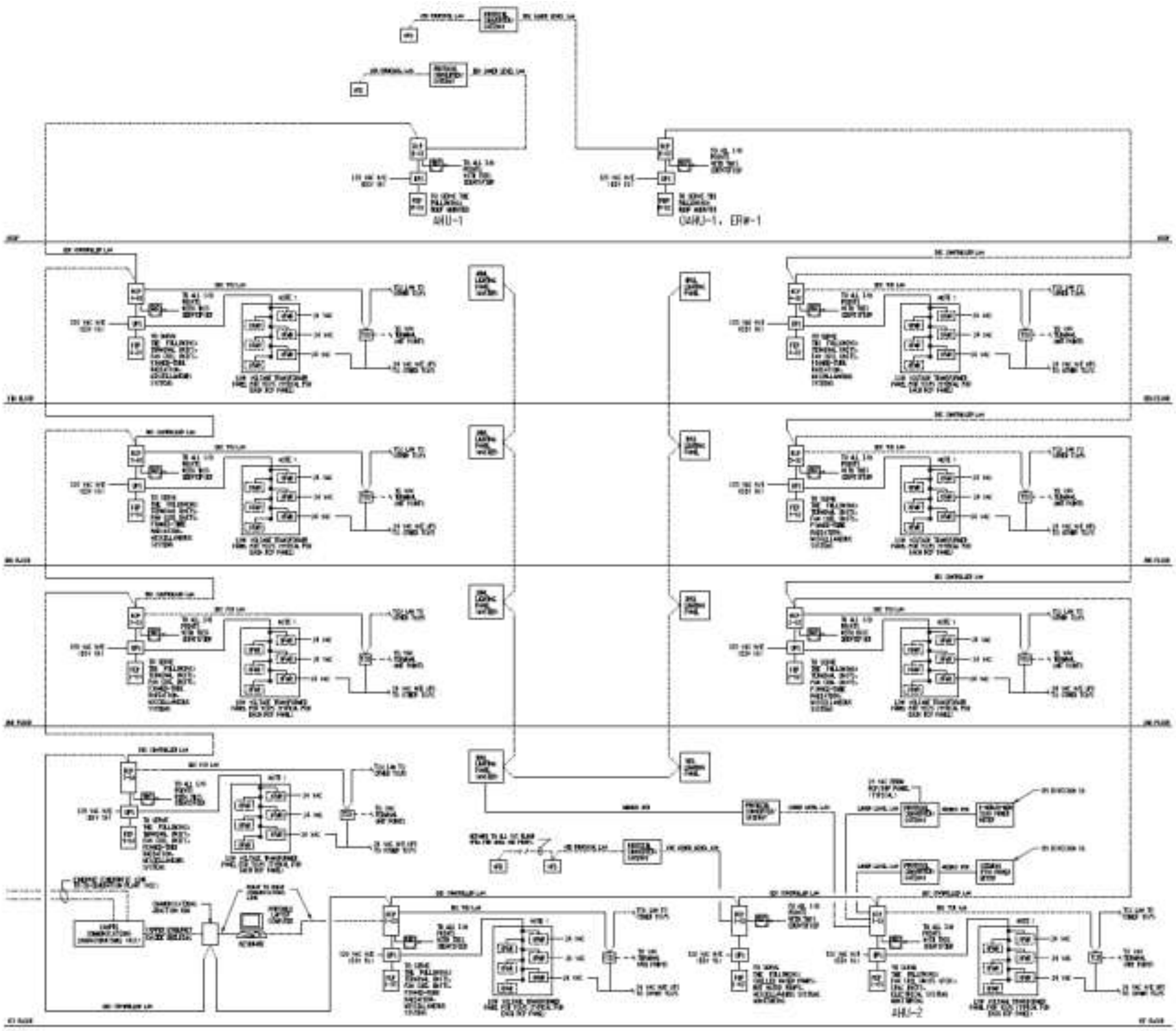
**PUMP SCHEDULE**

| | | | | | PUMP | | | | | | MOTOR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | TOTAL | MIN. | MAX. | SIZE | | | | | BASIS | |
| EQUIP. NO. | LOCATION | SERVICE | TYPE | PUMPED LIQUID | L/s | HEAD KPA | EFF. % | INPUT KW | SUCTION | DISCHARGE | KW | RPM | ELECTRIC V/PH/HZ | OF DESIGN | REMARKS |
| CHWP-1, 2 | PUMP ROOM | CH PRIMARY | END SUCTION | WATER | 19 | 390 | 70 | 14.8 | 400 | 75 | 15 | 1750 | 460/3/60 | BELL&GOSSETT SERIES 1510 | VFD, ACTIVE |
| CHWP-3 | PUMP ROOM | CH PRIMARY | END SUCTION | WATER | 19 | 390 | 70 | 14.8 | 400 | 75 | 15 | 1750 | 460/3/60 | BELL&GOSSETT SERIES 1510 | VFD, STANDBY |
| HWP-1, 2 | PUMP ROOM | HEATING HOT WATER | END SUCTION | WATER | 5.1 | 255 | 57 | 3.4 | 50 | 40 | 3.7 | 1750 | 460/3/60 | BELL&GOSSETT SERIES 1510 | VFD, ACTIVE |
| HWP-3 | PUMP ROOM | HEATING HOT WATER | END SUCTION | WATER | 5.1 | 255 | 57 | 3.4 | 50 | 40 | 3.7 | 1750 | 460/3/60 | BELL&GOSSETT SERIES 1510 | VFD, STANDBY |
| CP-1 | SEE PLAN | CONDENSATE PUMP | END SUCTION | WATER | 0.026 | 60 | - | 0.1 | - | 9.5 | - | - | 120/1/60 | LGPC VCMA-20UL | |

**PLATE AND FRAME HEAT EXCHANGER SCHEDULE**

| | | | HOT WATER SIDE | | | | COLD WATER SIDE | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| EQUIP. NO. | LOCATION | SERVICE | LPS | EWT (DEG C) | LWT (DEG C) | MAX P.D. (KPA) | LPS | EWT (DEG C) | LWT (DEG C) | MAX P.D. (KPA) |
| HX-1 | FIRST FLOOR PUMP ROOM | DOMESTIC HOT WATER | 1.58 | 93.3 | 60 | 23.23 | 0.85 | 4.4 | 60 | 12.82 |

## Building One Control Operations



## 3.2 Central Utility Plant

This facility as mentioned before is a part of the larger campus which is serviced by a Central Utility Plant and campus electric and hydronic distribution system. This is part of an energy saving strategy, in conjunction with reliability concerns, to provide the entire campus with 13.8kV 3-Phase electricity, 200F hot water and 39F chilled water. The utility plant is able to monitor loads amongst the various buildings and size up or down the supply based on the demand loads. In this manner, the utility plant itself can function with utmost efficiency, allow for reliability and extreme load scenarios.

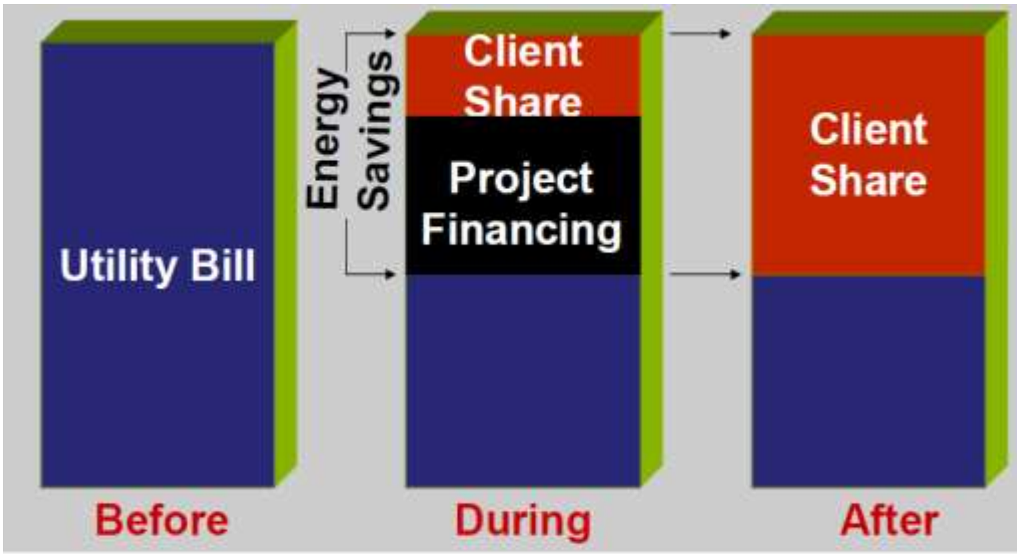

The Central Utility Plant was developed in partnership with Sempra Energy Services and Honeywell under an Energy Savings Performance Contract (ESPC). The plant buildout is staged to match the multi-year campus development. The project is currently expanding to almost 20 MW of cogeneration, including a 5.6 MW dual fuel engine and three 4.5 MW natural gas combustion turbines. Other project features include two 1130-ton absorption chillers, two 1130-ton and three 1980-ton electric chillers and three 10 MMBtu/hr hot water boilers. The ESPCs also include integrated plant controls and building automation systems. The $71 M installed system cost is estimated to save $5.8 M in annual energy cost savings and $6.5 M in annual reduced O&M costs when all of the supported Campus buildings are completed. The total plant efficiency is at 70% currently.



**Historic Preservation:**

The energy plant includes beneficial reuse of an historic structure on the White Oak campus, an added benefit of this project.

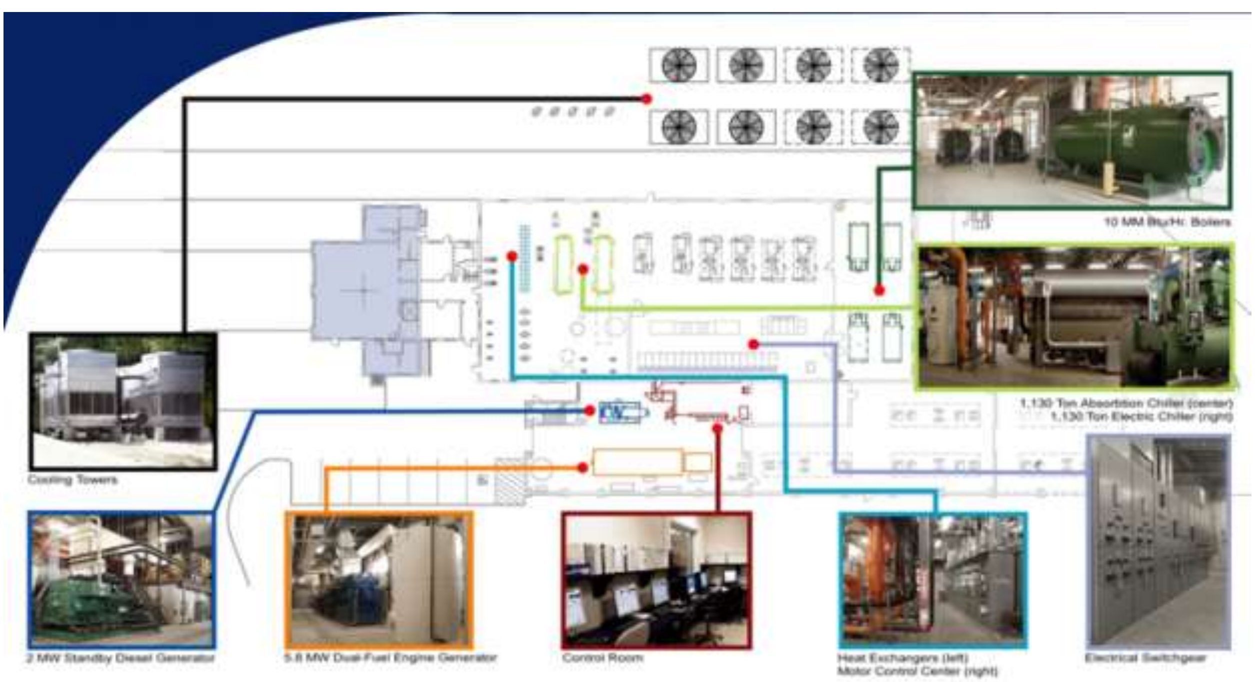
The financial approach and justification of developing a Central Utility Plant as a part of the FDA Consolidation Project.




Energy Conservation Measures include:

- Central Plant Improvements (40%),
- Operations & Maintenance (40%),
-Lighting & Glazing, VFDs on Pumps, Demand controlled ventilation and night setbacks (17%)

Central Utility Plant Equipment Layout



## 3.3 LEED Analysis

The Leadership in Energy and Environmental Design (LEED®) was created by the United States Green Building Council (USGBC) in order to help both building owners and design teams realize the importance of energy efficient and environmentally friendly construction practices.

FDA Building One received a LEED Gold Certification for Major Renovations. The Gold designation is the second-highest level of certification. It is the first renovation project in the GSA National Capital Region to achieve the distinction. The project, which employed the guidance of Sustainable Design Consulting during the LEED process, was a challenge to turn a weapons research facility, into an eco-friendly administrative hub for the White Oak campus. The property won the designation for having a transportation management plan, utilizing green, off-the-grid power, creating a highly reflective roof and recycling the existing structural frame as well as the brick/limestone veneer.

In evaluation, 49 LEED credit points were earned and it is worth noting that this is the first renovation project in the GSA National Capitol Region to achieve a LEED Gold Certification. As the new home of the US Food and Drug Administration Commissioner, this project represents a commitment to sustainable design principles, including:

-Reduction in the demand for raw materials through the reuse of the existing core and shell and public area finishes, including the restoration of the original brick and limestone exterior.

TABLE 1. – MINIMUM CONTENT STANDARDS FOR RECOVERED MATERIALS IN BUILDING INSULATION PRODUCTS

| Product | Material | Postconsumer Content (%) | Total Recovered Material Content (%) |
|---|---|---|---|
| Structural Fiberboard | Recovered Material | - | 80-100 |
| Laminated Paperboard | Postconsumer Paper | 100 | 100 |
| Rock Wool Insulation | Slag | -- | 75 |
| Fiberglass Insulation | Glass Cullet | -- | 20-25 |
| Cellulose Loose-Fill and Spray On | Postconsumer Paper | 75 | 75 |
| Perlite Composite Board Insulation | Postconsumer Paper | 23 | 23 |
| Plastic rigid foam, polyisocyanurate/ Polyurethane: Rigid Foam Insulation | Recovered Material | - | 9 |
| Foam-in-Place Insulation | Recovered Material | -- | 5 |
| Glass Fiber Reinforced Insulation | Recovered Material | -- | 6 |
| Phenolic Rigid Foam Insulation | Recovered Material | -- | 5 |
| Floor Tiles (heavy duty/ commercial use) | Rubber<br>Plastic | 90-100<br>- | -<br>90-100 |
| Patio Blocks | Rubber or Rubber Blends<br>Plastic or Plastic Blends | 90-100<br>- | -<br>90-100 |

Example of sustainability efforts, recovered material usage as specified in the RFP

-Use of low VOC (Volatile Organic Compound) materials throughout the building.

-Replacement of original single pane steel windows with operable, insulated low-E steel units that are interconnected with the building HVAC system.

-Use of a new high SRI (Solar Reflectance Index) roof to mitigate heat islands.

-Use of native plantings and low-water demand plants throughout the project.

-Use of a shuttle bus service from nearby transit hubs and incorporation of preferred and dedicated parking for bicycles, hybrid vehicles, and car / van pools.

Especially noteworthy is that Building One achieved 35.8% energy cost savings below the ASHRAE 90.1 baseline resulting in a maximum ten (10) points available for the LEED category of Optimizing Energy Performance. Contributing strategies include:

-Integrating the HVAC design with the cogeneration central utility plant

-Utilizing natural ventilating, recovering exhaust / relief air energy through an enthalpy wheel

-Insulating the historic building envelope

-Reducing lighting energy through daylight/occupation dimming controls

-Using outdoor air economizers

-Controlling outdoor air quantities through CO2 demand control ventilation

## Sustainability Challenges

**Asbestos-Laden Windows:** On Building 1, the plan had been to restore the windows; however, during the abatement testing phase, workers found that the window glazing and caulk contained asbestos. To remediate the asbestos-laden glazing and caulk and keep those windows would have exhausted the budget. It took a year before all the agencies involved agreed that the windows could be replaced, with similar windows.

The design team went back to the original manufacturer, Hope's Windows, Inc., still in business, to see if they could reproduce the original window design. Working with both the construction management team and the design team, Hope's personnel came up with several designs that mimicked the existing windows. Once the window designs were approved by the historic preservation entities, GSA moved forward with replacement of approximately 276 existing windows. Following this approval, the construction management field team began working with the general contractor and with Hope's to schedule production so the windows could be manufactured, shipped and installed in time for the Commissioner's offices to open on time.

**Fish Spawn:** One of the biggest challenges affecting construction on the entire campus and not just Building 1 was a stream running near the project boundaries. Because this stream is a contributory to Paint Branch Stream, which is protected as "Waters of the U.S.," no construction activities are allowed between October and May within the stream buffer zone due to the sensitivity of native fish that spawn during that time. To build a new six-lane entry road, which was crucial to the development of the entire site, the team had to divert part of that stream, and to do so they had to go to the Maryland Department of the Environment (MDE) for a variance.

Approval of this variance came with the stipulation that it would only be good for a maximum of 14 calendar days. The CM team worked with the general contractor and the utility contractor to develop a material delivery and construction schedule that would meet the stipulations of MDE's variance approval. The team spent two months building a diversion for the stream, used the diversion for just two days during the off-season (which met the stipulation), and then returned the stream to its normal banks.

LEED Checklist Tabulation

| | | | | |
|---|---|---|---|---|
| 9 | 3 | 2 | **Sustainable Sites** | **14** Points |
| 2 | 2 | 1 | **Water Efficiency** | **5** Points |
| 12 | 1 | 2 | **Energy & Atmosphere** | **17** Points |
| 4 | 2 | 7 | **Materials & Resources** | **13** Points |
| 14 | 0 | 1 | **Indoor Environmental Quality** | **15** Points |
| 2 | 0 | 3 | **Innovation & Design Process** | **5** Points |
| 43 | 8 | 16 | **Project Totals** | **69** Points |

# 4.0 Mechanical Depth: Photovoltaic System

The campus is still expanding to include all FDA employees from various sites. For this reason more buildings on campus are being constructed and the Central Utility Plant is continuously undergoing expansion to meet demand. Since the building itself has achieved great mechanical system efficiency and extensive sustainability measures were taken, it was difficult to propose a redesign or improvement that would be logical and beneficial.

Integrating photovoltaic panels on the roof of the building was a decision that would be explored. Newly constructed buildings on campus have implemented photovoltaic panels and there was no reason not to explore their impact on the current energy usage of the building.

## 4.1 PV Sizing

Several tools were used to conduct this study. NREL – PV Watts was a program that helped with sizing of the system. This program is backed by the DOE and is thus, credible in a sea of programs/tools available.

SolarPro is another program which is used by vendors for initial estimates of PV systems. A known vendor, with whom a rapport has been established, directed me to this tool and it has proved to be extremely helpful.

Even though Building One receives its electricity from the CUP, it is generated by purchased natural gas and diesel. The rates of these fuels as well as the tariff structure of purchased electricity from PEPCO in the White Oak, MD area for a commercial building has helped to make the case for a PV consideration.

In the following sections, data as collected from the aforementioned tools is outlined.

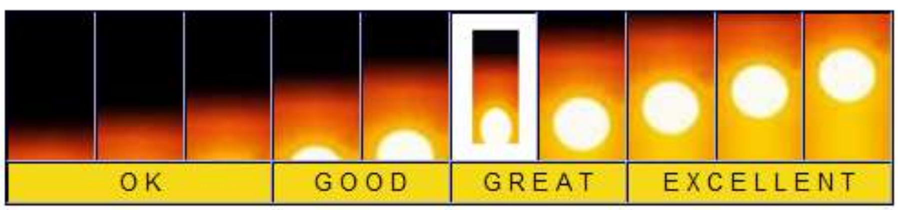
| Station Identification | |
|---|---|
| City: | Baltimore |
| State: | Maryland |
| Latitude: | 39.18° N |
| Longitude: | 76.67° W |
| Elevation: | 47 m |
| PV System Specifications | |
| DC Rating: | 350.0 kW |
| DC to AC Derate Factor: | 0.820 |
| AC Rating: | 287.0 kW |
| Array Type: | 1-Axis Tracking |
| Array Tilt: | 39.2° |
| Array Azimuth: | 180.0° |
| Energy Specifications | |
| Cost of Electricity: | 14.0 ¢/kWh |

| Results | | | |
|---|---|---|---|
| Month | Solar Radiation ($kWh/m^2/day$) | AC Energy (kWh) | Energy Value ($) |
| 1 | 4.02 | 37027 | 5183.78 |
| 2 | 5.27 | 43636 | 6109.04 |
| 3 | 5.89 | 51954 | 7273.56 |
| 4 | 6.48 | 54414 | 7617.96 |
| 5 | 6.64 | 55845 | 7818.30 |
| 6 | 7.35 | 57512 | 8051.68 |
| 7 | 7.20 | 57775 | 8088.50 |
| 8 | 6.83 | 54822 | 7675.08 |
| 9 | 6.16 | 48414 | 6777.96 |
| 10 | 5.95 | 50228 | 7031.92 |
| 11 | 4.19 | 35920 | 5028.80 |
| 12 | 3.25 | 29314 | 4103.96 |
| Year | 5.77 | 576861 | 80760.54 |

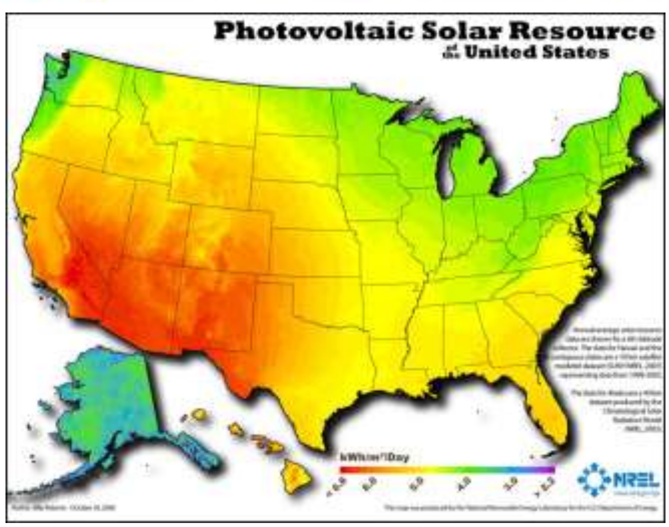
Assumptions made – No losses from Inverter (discussed later), No losses for AC wiring (also discussed later), $0.14/kWh as per PEPCO tariff rate, 1-axis tracking, and 350KW system to meet needs for ~40% of building electric usage.

Summer Solstice (Sample) Output

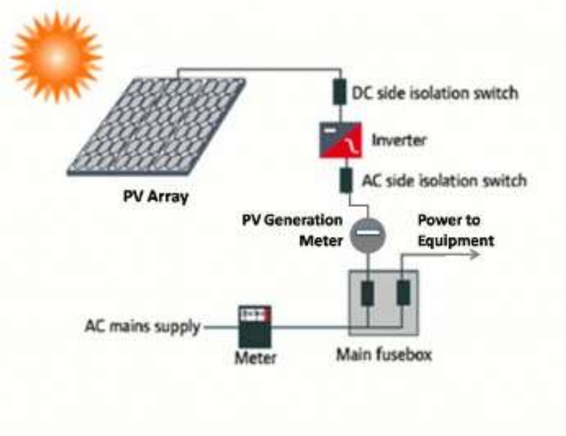
| Month | Date | Hour | Watts |
|---|---|---|---|
| 6 | 21 | 600 | 14474 |
| 6 | 21 | 700 | 74547 |
| 6 | 21 | 800 | 121266 |
| 6 | 21 | 900 | 154502 |
| 6 | 21 | 1000 | 158670 |
| 6 | 21 | 1100 | 162029 |
| 6 | 21 | 1200 | 170935 |
| 6 | 21 | 1300 | 169649 |
| 6 | 21 | 1400 | 166913 |
| 6 | 21 | 1500 | 157660 |
| 6 | 21 | 1600 | 145748 |
| 6 | 21 | 1700 | 104691 |
| 6 | 21 | 1800 | 1012 |
| 6 | 21 | 1900 | 15 |

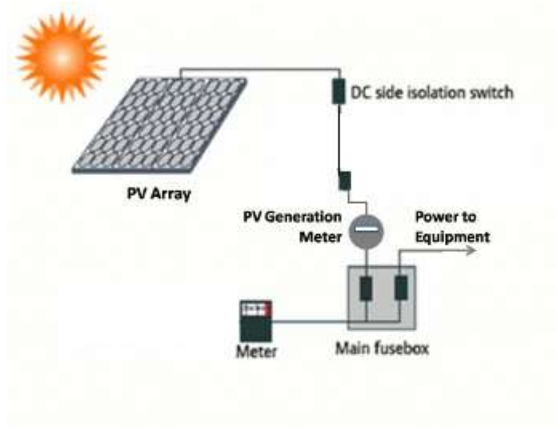



The solar rating of your area is Great for adopting a solar system. (4.80 kWh/m^2 per day).



An intended deviation from traditional PV systems: implement direct current within the building to avoid DC to AC inefficiencies. All information shown reflects this intended design difference.

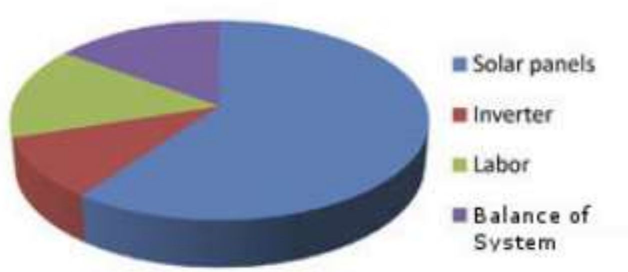



Layout of system with traditional DC to AC inverter (left)
PV system with intended DC distribution application (right)

## 4.2 PV Cost Information

| | Assumed Cost, per Watt DC | |
|---|---|---|
| **Item** | **System Size < 2kW** | **System Size ≥ 2kW** |
| Assumed Total | $9 per watt DC (+/- 20%) | $8 per watt DC (+/- 20%) |




About 60% of the cost to install a solar-electric (PV) system goes to the solar photovoltaic (PV) panels, 10% to an inverter, 15% to direct labor, and 15% to the "balance of system" (BOS) costs.

But in the case of not requiring an inverter, 10% cost can be saved in the estimation of the system.

| SAVINGS & BENEFITS | |
|---|---|
| **First-year Utility Savings:** | **$62,160** |
| **Average Monthly Utility Savings:** *over 25-year expected life of system* | **$8,694** |
| **Average Annual Utility Savings:** *over 25-year expected life of system* | **$104,333** |
| **25-year Utility Savings:** | **$2,608,333** |
| **Return on Investment (ROI):** | **241%** |
| **Internal Rate of Return (IRR):** | **21.5%** |
| **Net Present Value (NPV):** | **$1,427,083** |
| **Profitability Index:** | **2.2** |
| **Greenhouse Gas (CO2) Saved:** *over 25-year system life* | **9,102 tons** **18,204,000 auto miles** |

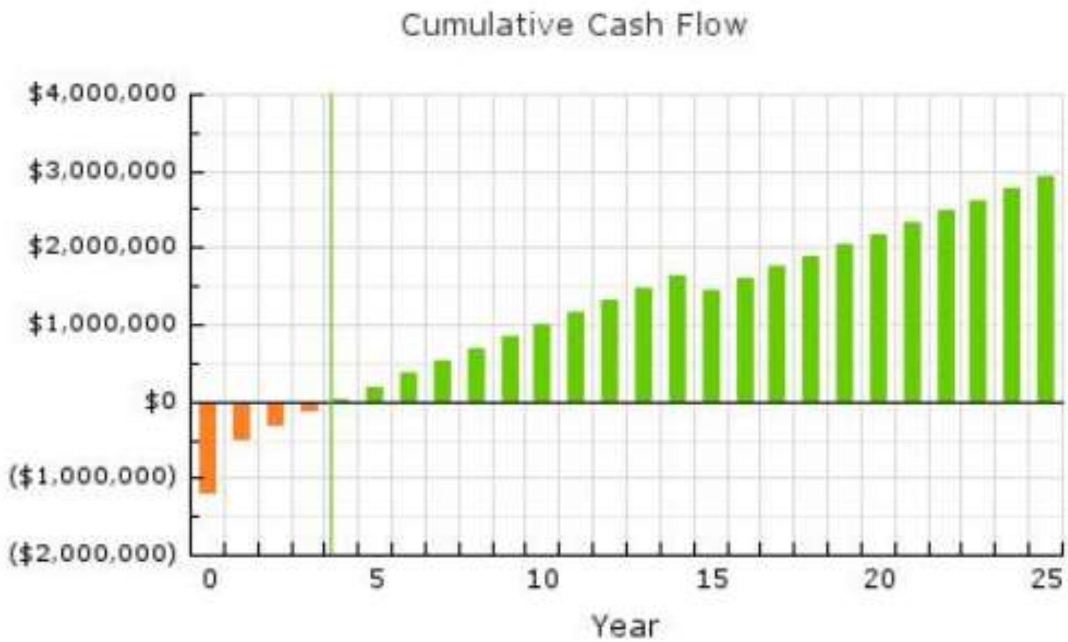
Further Assumptions as built into the SolarPro software

| Factor | Assumption |
|---|---|
| Solar resources | Assumed solar availability: As per Solar Radiance chart |
| Soiling or contamination of the PV panels | Clean, washed frequently: 100% design sunlight transmission |
| Temperature | 25C, calm wind |
| System configuration (battery or non-battery) | Non-battery |
| Orientation to the sun | tilted at your latitude, full sun |
| Shading | None |
| PV Energy delivered as % of manufacturer's rating | 95% |
| Soiling, wiring & power point tracking losses | 9% (91% delivered) |
| Inverter Efficiency | 90% |
| Total Energy Delivered | 95% x 91% x 90% = 78% |

Efficiency of the delivered energy increases slightly without the inverter: 95% x 91% = 86.5%

| ESTIMATED SYSTEM COST | |
|---|---|
| **Assumed Installation Gross Cost:**<br>"Gross Cost" is the cost before any rebates, incentives, tax credits, etc. are applied. See the Cost Notes, below! | **$1,748,700**<br><br>assuming $5 per watt DC |
| **FINANCIAL INCENTIVES** | |
| Financial incentives shown are totals across all years. So, if an incentive spans multiple years then the value shown is the total of all years. For details, please refer to the table below "Cash Flow by Year and Cumulative Across Years" | |
| Maryland Public Srvc Comm - $ 0.36 per kWh SREC purchase » link | $ 2,192,232 |
| MD Clean Energy Production Tax Credit » link | $ 18,864 |
| Montgomery County - Clean Energy Rewards Program » link | $ 50,000 |
| Federal Tax Credit (30% of Gross Cost at Installation) » link | $ 524,610 |
| Modified Accelerated Cost Recovery System (MACRS) Depreciation (5 yr) » link | **YES** |
| **ESTIMATED NET COST:** | **$ -1,037,006** |
| **ESTIMATED NET COST AT INSTALLATION:** | **$ 1,224,090** |

## CASH FLOW


Cumulative Cash Flow
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
($1,000,000)
($2,000,000)
0
5
10
15
20
25
Year

For the first eleven years, the cash flow is shown including tax credits and Maryland's SREC purchase rate.

| Year of Operation: | at Install | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Gross Cost | ($1,748,700) | | | | | |
| Maryland Public Srvc Comm - $ 0.36 per kWh SREC purchase | $0 | $151,831 | $144,225 | $137,000 | $130,137 | $123,618 |
| MD Clean Energy Production Tax Credit | $0 | $3,774 | $3,773 | $3,773 | $3,772 | $3,772 |
| Montgomery County - Clean Energy Rewards Program | $0 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Federal Tax Credit (30% of Gross Cost at Installation) | $524,610 | $0 | $0 | $0 | $0 | $0 |
| Tax savings from MACRS Depreciation | $0 | $497,942 | $0 | $0 | $0 | $0 |
| Utility Savings | $0 | $42,899 | $44,520 | $46,203 | $47,950 | $49,762 |
| ANNUAL CASH FLOW | $-1,224,090 | $698,446 | $194,518 | $188,976 | $183,859 | $179,152 |
| Cumulative Cash Flow | $-1,224,090 | $-525,644 | $-331,126 | $-142,150 | **$41,709 Breakeven** | $220,861 |

| Year of Operation: | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|
| Gross Cost | | | | | | |
| Maryland Public Srvc Comm - $ 0.36 per kWh SREC purchase | $117,425 | $111,543 | $105,955 | $100,647 | $95,605 | $90,816 |
| MD Clean Energy Production Tax Credit | $0 | $0 | $0 | $0 | $0 | $0 |
| Montgomery County - Clean Energy Rewards Program | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Federal Tax Credit (30% of Gross Cost at Installation) | $0 | $0 | $0 | $0 | $0 | $0 |
| Tax savings from MACRS Depreciation | $0 | $0 | $0 | $0 | $0 | $0 |
| Utility Savings | $51,643 | $53,595 | $55,621 | $57,724 | $59,906 | $62,170 |
| ANNUAL CASH FLOW | $171,068 | $167,138 | $163,576 | $160,371 | $157,511 | $154,986 |
| Cumulative Cash Flow | $391,929 | $559,067 | $722,643 | $883,014 | $1,040,525 | $1,195,511 |

As noted, after year 4 the system has paid for itself through various methods. This does include heavy tax credits which can be claimed within the first year and continuous power purchasing incentives provided by various agencies from the county government, state and federally.

## 4.3 PV Panel Selection

After having spoken to a few reputable vendors in the Maryland area, for guidance regarding this project, a particular manufacturer was narrowed. This was due in part to the unique features and forward-thinking technology. SunPower Corp was the selected manufacturer, beyond that a particular panel was suggested for application in the Building One project.

The SunPower T5 roof tile is the world's first photovoltaic (PV) roof product to combine the solar panel, frame, and mounting system into a single pre-engineered unit. Each Non-penetrating T5 roof tile positions the highest efficiency SunPower solar panels at a 5-degree tilt for greatest energy production, making the T5 the most powerful SunPower solution for area-constrained or weight-constrained flat rooftops.

## Installation

The T5 Solar Roof Tiles interlock for secure, rapid installation and maximum power output. Smooth-edged, durable and lightweight polymer material designed for a 30-year life protects the roof and eliminates the need for electrical grounding. The patented design resists high winds and corrosion and is flexible to adapt to virtually any flat or low-slope roof.

## Benefits

**The Most Energy per Rooftop**

The T5 Solar Roof Tile produces more energy in an area-constrained or weight-constrained space than any other roof tile solar panel system on the market today.

**Easy to Install with All-in-One Design**

Solar panel, frame, and mounting system are integrated into one unit for rapid installation. No grounding or roof-penetration needed.

**Roof-Preserving**

The T5 assembly is compatible with all roof membranes. A smooth, lightweight design, combined with a non-penetrating installation protects your roof and preserves roof warranties.

**Long Lasting Durability**

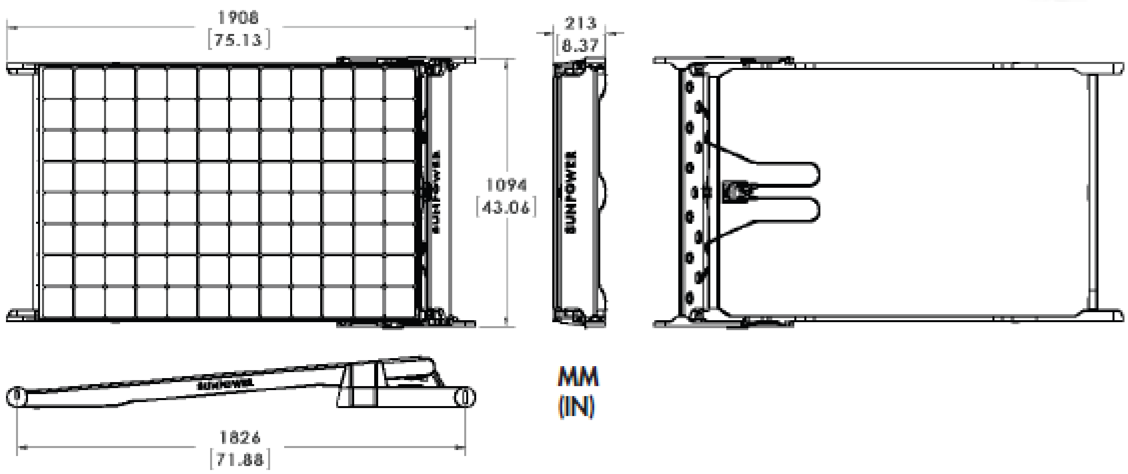
An aerodynamic, self-ballasted design resists high winds and water runoff. Strong, glass-filled polymer material offers long-term durability.

SunPower T5 Solar Roof Tiles are available with the SunPower E19 Series panels, including the 320-watt solar panel. SunPower E19 Series panels are the planet's most powerful, delivering the most possible electricity over the lifetime of your system. The E19 Series integrates SunPower premium technology with the highest efficiency solar cells and a patented, anti-reflective coating to optimize sunlight absorption.

T5 assembly as used for Agilent Offices (top)

Fast and east snap-together-assembly (right)

### Technical Details




25,000SF roof / 22.7 SF per panel = 1100 Panels

Up to 14.5W/SF x 25,000 SF = 362 KW Capacity based on panel size and roof capacity

Rate for installation as per Aztec Solar Power = $5/Watt installed

Therefore: 350,000 W x $5/W = $1,750,000

Cost is within $2,000,000 as approximated by software tool listed above. Therefore simple payback is confirmed to be within 5 years.

The flexibility is an enormous advantage. The product is durable and low maintenance. At most twice a year, direction of panels can be adjusted to optimize performance.

| Electrical Data<br>Measured at Standard Test Conditions (STC): Irradiance 1000W/m², AM 1.5, and cell temperature 25° C | | | |
|---|---|---|---|
| Peak Power * | $P_{max}$ | 305 W (±5%) | 318 W (+5% / -3%) |
| Rated Voltage | $V_{mpp}$ | 54.7 V | 54.7 V |
| Rated Current | $I_{mpp}$ | 5.58 A | 5.82 A |
| Open Circuit Voltage | $V_{oc}$ | 64.2 V | 64.7 V |
| Short Circuit Current | $I_{sc}$ | 5.96 A | 6.20 A |
| Maximum System Voltage | UL | 600 V | |
| Temperature Coefficients | Power<br>Voltage ($V_{oc}$)<br>Current ($I_{sc}$) | -0.38% / K<br>-176.6 mV / K<br>3.5 mA / K | |
| NOCT | | 45° C +/-2° C | |
| Series Fuse Rating | | 15 A | |

| Mechanical Data | |
|---|---|
| Solar Laminate | SunPower™ 305 Solar Laminate, or<br>SunPower 318 Solar Laminate |
| Solar Cells | 96 SunPower all-back contact monocrystalline |
| Front Glass | SunPower 305 Solar Laminate:<br>High transmission tempered glass<br>SunPower 318 Solar Laminate:<br>High transmission tempered glass with anti-reflective (AR) coating |
| Junction Box | IP-65 rated with 3 bypass diodes, 32 x 155 x 128 (mm) |
| Output Cables | 1000 mm length cables / MultiContact (MC4) connectors |
| Frame | Polymer material with fiber reinforcement, PPE+PS |
| Tile Weight | 47 lbs (21.3 kg) |
| Roof Coverage | 85% N–S |

| Tested Operating Conditions | |
|---|---|
| Temperature | -40° F to +185° F (-40° C to +85° C) |
| Max load | 50 psf 245kg/m² (2400 Pa) front and back – e.g. wind |
| Impact Resistance | Hail 1 in (25 mm) at 52mph (23 m/s) |

*Other laminates may be available upon request

| Warranties and Certifications | |
|---|---|
| Warranty | 25-year limited power warranty<br>10-year limited product warranty |
| Certifications | CSA listed (Tested to UL 1703), Class C Fire Rating |
| Built in the USA. Complies with the "Buy American" clause of The American Recovery and Reinvestment Act of 2009. | |

## Context of Cost

Approximately 12,000 MMBTU are consumed by the building.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Total BTUs | 12,118,000,000 | | | | | | | | |
| Total KWH | 1,300,000 | | | | | | | | |
| | | | | | | | | | |
| | | **Natural Gas** | | | | | | | |
| | | | | | | | | | |
| | | | 1,211,800 | Therms | | | | | |
| | | | | | | | | | |
| | | | 10,000 | 1st 10K Therms | | 0.198 | $/therm | $ 1,980.00 | |
| | | | | | | | | | |
| | | | 1,201,800 | Remainder | | 0.095 | $/therm | $114,171.00 | |
| | | | | | | | | | |
| | | | | | | | | $116,151.00 | per year in cost |
| | | | | | | | | $ 9,679.25 | per month |
| | | | | | | | | | |
| | | **Electricity** | | | | | | | |
| | | | 12,118 | MMBTU | | 14.66 | $/MilBTU | $177,649.88 | per year in cost |
| | | OR | | | | | | $ 14,804.16 | per month |
| | | | | | | | | | |
| | | | 1,300,000 | kWh | | 0.14 | $/kWh | $182,000.00 | per year |

If $8,000/month can be saved from the utility cost to the FDA, the photovoltaic array is absolutely worth the initial cost. This is also demonstrated by the payback shown earlier.

# 5.0 Renewable Energy Storage: Thin Film Battery

## 5.1 Thin Film Battery Technology

This technology is being developed by various R&D groups. One such company is Paper Battery Co.

The company's innovation is the architecture of a structural sheet that becomes a power plane. The architecture is a massively parallel array of independent cells and has stress management and fault-tolerance built into its design. The technology is agnostic to either super-capacitor, lithium battery or hybrid storage technology.

By combining weight bearing and energy storage in one structural sheet, a systemic approach to energy management is possible, with power accessible at the point of use throughout the accessible surface area of the device. For the first time, energy management stakeholders include architects, designers, mechanical or civil engineers and system integrators, who can specify and buy a structural material that provides local power access.

The company has filed its own patents on the (PowerWrapper) technology platform and also holds worldwide exclusive rights to the broad background patent filed by Rensselaer Polytechnic Institute.

The PowerWrapper sheets are fault tolerant, fully integrated freestanding devices, and can be mechanically tuned to serve as casing material, or composites that provide all the power functions without needing replacement for the life of the device. The PowerWrapper's packaging efficiency with multi-layered sheets can achieve 2X higher energy density than commercial can super-capacitors and will have higher voltage in a compact volume (e.g. up to 24V in < 1.5mm thin sheet). No other flexible and scalable thin sheet-like electrostatic storage product is available today. The PowerWrapper platform opens new market applications with its unique structurally-integrated cost model and performance.

The first generation sheet device incorporates super-capacitor technology in a massively parallel array of cells for long cycle life. Packing efficiencies give 2X higher energy capacity compared to existing rigid devices at high voltages. This fault tolerant sheet is print-formed, has tunable mechanical properties and can be cut to fit, with custom shapes including patterned holes in a multi-layered device. Roll to roll printing gives high volume, low cost production.

The PowerWrapper is made by print-forming complex, fully functional, components like electrodes and a porous separator in situ, using techniques compatible with high volume roll to roll printing methods. However, unlike most other printed devices, the PowerWrapper is not built around any starting web or paper sheet. The entire integrated device is print-formed from particles, resulting in unprecedented design control to tune the mechanical and storage properties of the sheet to the desired application. Designed to be 'cut to fit,' the unit device can be shaped and sized specifically to the power storage and shape desired including patterned holes. These processes thus enable addressable power cells or entire power planes to be built based on OEM specifications.

PowerWrapper depicted to be lined on the roof of a building

Other opportunities include integration with flexible photovoltaic sheets to provide intermittent power pulses, smooth the output and improve low light functioning in niche applications.

The GEN2 PowerWrapper is sold as a premium building sheeting material (e.g. integrated with and replacing high end insulation) amortizing costs into mortgages or remodel equity loans. Adoption is driven by market forces and new business models, not bound by utility regulatory cost models. Networks of this scalable storage with no footprint are now available to customers and utilities for multiple applications, like avoidance of peak demand charges and enabling fast-charging of EVs with local direct DC power. Societal externalities, integration of renewable energy, cost savings and energy transaction revenue streams will drive the selection of a PowerWrapper™ premium sheeting material.

Key technology:

• Scalable, thin (<1mm) conformable and print-formed sheets that can be integrated and co-packaged with end-products

• High cycle rate (high peak power), high voltage (3-48V) in thin form factor, high energy density (up to 23 W-hr/$m^2$)

• Fault and damage-tolerant scalable sheet that can be custom patterned ("cut to fit")

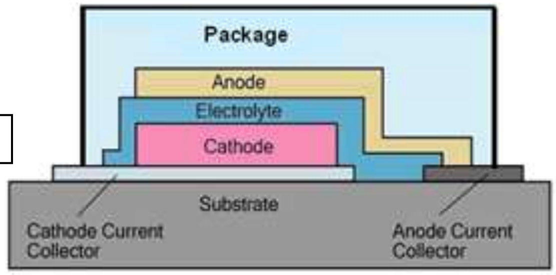
• Long cycle life (>>30,000 cycles) with high round trip efficiency of storage (>98%)

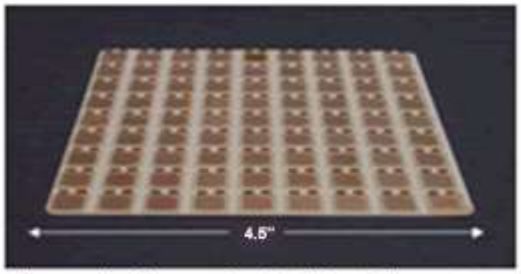
**Competitors**: Traditional batteries cannot scale without increasing bulk; have a short cycle life (< 3,000); Thin film batteries are complementary with lower power capabilities; rigid devices do not compete in the selected applications

The manufacturing process for thin film batteries includes:

- Film deposition
- Packaging
- Testing
- Dicing

Anatomy of battery

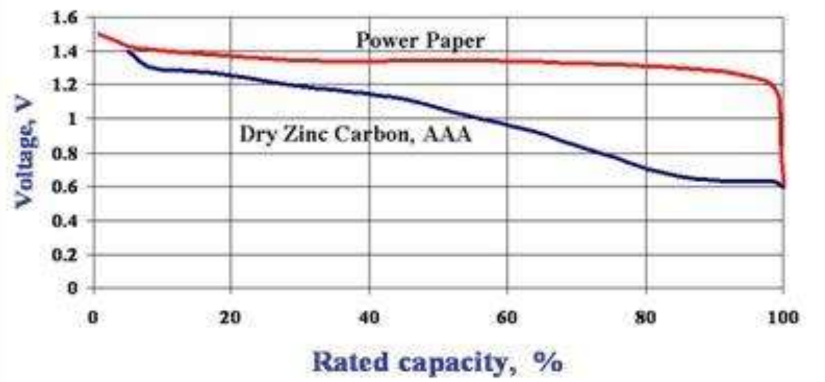



Photograph of a completed 4.5" x 4.5" ceramic wafer with 81 hermetically sealed batteries ready for dicing.

Example of product

The photograph shows one wafer with 81 batteries after packaging and before dicing. Typically batteries are custom designed to match the requirements of specific applications. The batteries in the photograph are based on a generic design with relatively large contact pads for easy electrical connection and are intended for evaluation by potential customers. Specifications and test data for batteries are constantly changing due to improvements in technology.

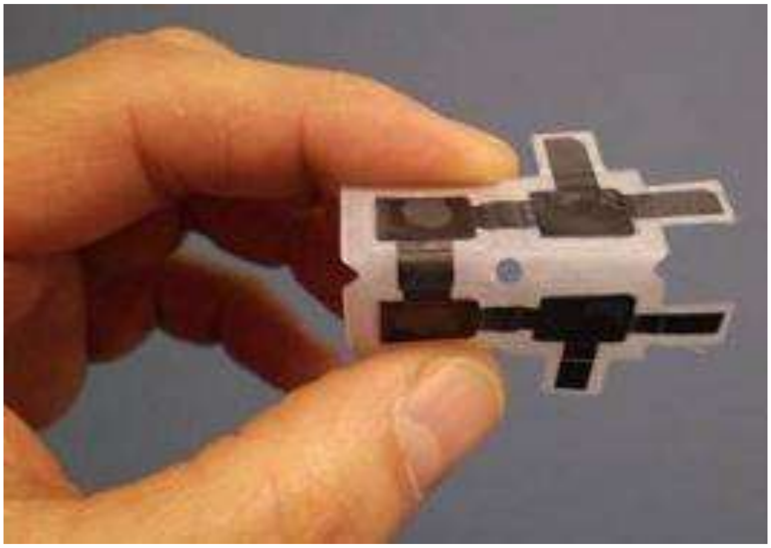



Typical discharge curve for the Power Paper standard cell compared to a commercially available metal casing cell with similar chemistry. Both cells were discharged under typical operation load

An example of properties as published by a company that is already mass producing the product for small scale uses:

| | |
|---|---|
| Primary cell (multiple cell battery packs are possible) | 1.5V |
| Typical thickness (total) | 0.7 mm |
| Bending radius | 2.5cm (1 inch) |
| Nominal continuous current density (per active area) | 0.1 mA/cm 2 |
| Nominal capacity (per active area) | 4.5 mAh/cm 2 |
| Nominal internal resistance (1kHz impedance) | 50 Ohm max |
| Temperature operating range | -20°C to +60°C |
| Environmentally friendly | No heavy metal components such as Mercury, Cadmium or Lead |

| Power Paper Model | STD-3 Regular | STD-3 Premium | STD-20 |
|---|---|---|---|
| Outline Dimensions | 39mm x 39mm | 39mm x 39mm | 39mm x 26mm |
| Nominal Voltage | 1.5 V | 1.5 V | 1.5 V |
| Nominal Continuous Current | 0.5 mA | 0.5 mA | 0.2 mA |
| Nominal Capacity | 18 mAh | 30 mAh | 13 mAh |
| Nominal Internal Impedance at 1 kHz | 50 Ohm | 15 Ohm | 30 Ohm |
| Nominal Peak Pulse Discharge Current | | 15 mA [1 msec] | |



Power Paper as used in medical devices – one if its many applications

Regarding the viability of the product, many large companies are investing in the technology. Power Paper, an Infinity Group portfolio company, and GE Global Research, the technology development arm for the General Electric Company announced that the companies have signed an agreement to jointly develop self-powered OLED lighting devices. Using low-cost, high volume manufacturing processes, these devices could be deployed in a wide variety of environments from military ships to night-time jogging vests. The collaboration is supported by an Israel-U.S. Bi-national Industrial Research and Development Foundation (BIRD Foundation) program.

GE is globally recognized as a pioneer in the electric lighting industry and continues to lead the way in bringing new, innovative lighting technologies to market. Power Paper develops and licenses micro-power clean technology based on an innovative paper-thin, flexible, safe, environment-friendly, printable battery.

John Ouseph, GE Commercial & Industrial Business Programs Manager at GE said, “Our goal is to design lighting products that are less intrusive, have greater flexibility and can be easily installed or modified based on changes in the application. We will build a product that costs less, consumes less energy with improved reliability and resists vibration and shock. Mobile, remote-powered light strips are a natural extension of GE’s lighting portfolio, and Power Paper is uniquely positioned to supply thin film, flexible batteries for this application.”

Under the terms of the agreement, the collaboration will combine Power Paper’s novel thin film batteries and GE’s industry leading Organic Light Emitting Diode (OLED) technology. The goal of the GE-Power Paper- BIRD project is to develop a first generation of self-powered OLED lighting products and identify next generation technologies with enhanced capabilities. The length of the program is 12 months. The general illumination market is estimated at $2.5 billion.

## 5.2 CM Breadth: Constructability, Cost, Scheduling Impact

The intended use of this product is to store renewable energy as generated from the photovoltaic panels on the roof of the building. This would smooth out voltage spikes that may be caused from the PV's. This would also tie very well into a DC distribution model as mentioned earlier.

The question arises as to how feasible it would be to install this into the building fabric. The properties of the product do not add anything to the R-value of the building. Since the thin film battery is available in rolls, it can be easily transported to the site. The seamless installation at the time of applying building insulation would make most logical sense. The ability to imbed this product eliminates the need to the allocate space for batteries within the building.

Before renovation, with surfaces being stripped

Interior at completion

## Battery Sizing Detail

| | | | | |
|---|---|---|---|---|
| 1 | **Daily Units of Electricity Consumed** | | 3600000 | Wh/day |
| | | | | |
| 2 | **Daily amp-hour requirement.** | | 150000 | Ah/ day |
| | | | | |
| 3 | **Number of days of autonomy** | CUP Backup | 1 | Days |
| | | | | |
| 4 | **Multiply the amp-hour requirement by the number of days. This is the amount of amps-hours your system will need to store.** | | 150000 | Ah/day |
| | | | | |
| 5 | **Depth of discharge for the battery. This provides a safety factor to avoid over-discharging.** | Expecting to discharge 80% max at a time | 0.8 | |
| | | | | |
| 6 | **Divide line 4 by line 5** | | 187500 | Ah/day |
| | | | | |
| 7 | **Ambient Temperature Multiplier** | 50F | 1.19 | |
| | | | | |
| 8 | **Multiply line 6 by line 7. This calculation ensures that the battery bank will have enough capacity to overcome cold weather effects. This number represents the total battery capacity needed.** | | 223125 | Ah |
| | | | | |
| 9 | **Amp-hour rating for the battery chosen** | | 4.5 | Ah |
| | | | | |
| 10 | **Divide the total battery capacity (8) by the battery amp-hour rating (9) and round off to the next highest number. This is the number of the batteries wired in parallel required.** | | 49583 | Units |
| | | | | |
| 11 | **Divide the nominal system voltage (12V, 24V, or 48V) by the battery voltage and round off to the next highest number. This is the number of batteries wired in series.** | | 16 | Units |
| | | | | |
| 12 | **Multiply line 10 by 11 gives the total number of units required** | | 793,333 | Units |

The scheduling for the project was done by dividing the renovation into five separate portions. This allowed for multiple trades to work on various portions of the building at the same and an adequate amount of float to be built in to the schedule.

The float time allowed for each wall stud assembly and drywall installation is 13-22 days for each wing (North, South) per floor. This would allow more than enough time for to line the insulation with the thin film battery before closing in the walls.

An example of this item within the schedule is shown:

| Activity ID | Activity Description | Rem Dur | Early Start | Early Finish | Total Float | Tar ES | Tar EF | Var EF |
|---|---|---|---|---|---|---|---|---|
| CN4390 | ROUGH-IN MECHANICAL SYSTEMS SOUTH | 1 | 11MAR08A | 13JUN08 | 1 | 11MAR08A | 06JUN08 | -5 |
| CN2120 | ROUGH-IN WALLS NORTH | 1 | 13MAR08A | 20JUN08 | 2 | 13MAR08A | 18JUL08 | 19 |
| CN4080 | ROUGH-IN ELECTRICAL NORTH | 1 | 13MAR08A | 19JUN08 | 1 | 13MAR08A | 12JUN08 | -5 |
| CN4290 | ROUGH-IN F/A AND SPRINKLER CENTRAL | 2 | 14MAR08A | 24JUN08 | 8 | 14MAR08A | 17JUN08 | -5 |
| CN4440 | INSTALL METAL STUD FRAMING SOUTH | 1 | 14MAR08A | 26JUN08 | 13 | 14MAR08A | 18JUL08 | 15 |
| CN3140 | INSTALL/FINISH DRYWALL NORTH | 1 | 20MAR08A | 06JUN08 | 23 | 20MAR08A | 23JUL08 | 32 |
| CN3460 | INSTALL/FINISH DRYWALL SOUTH | 1 | 20MAR08A | 23JUN08 | 22 | 20MAR08A | 20AUG08 | 41 |
| CN4280 | ROUGH-IN ELECTRICAL CENTRAL | 2 | 24MAR08A | 23JUN08 | 9 | 24MAR08A | 16JUN08 | -5 |
| CN2330 | ROUGH-IN F/A AND SPRINKLER CENTRAL | 2 | 01APR08A | 16JUN08 | -24 | 01APR08A | 09JUN08 | -5 |
| CN2130 | INSTALL/FINISH DRYWALL NORTH | 2 | 02APR08A | 24JUN08 | 2 | 02APR08A | 22JUL08 | 19 |
| CN1070 | ROUGH-IN ELECTRICAL NORTH | 6 | 07APR08A | 23JUN08 | 9 | 07APR08A | 16JUN08 | -5 |
| CN1080 | ROUGH-IN F/A AND SPRINKLER NORTH | 4 | 07APR08A | 19JUN08 | 9 | 07APR08A | 12JUN08 | -5 |
| CN1120 | ROUGH-IN ELECTRICAL CENTRAL | 3 | 07APR08A | 26JUN08 | 9 | 07APR08A | 03JUL08 | 5 |
| CN1160 | ROUGH-IN ELECTRICAL SOUTH | 8 | 07APR08A | 17JUN08 | 20 | 07APR08A | 10JUN08 | -5 |
| CN1170 | ROUGH-IN F/A AND SPRINKLER SOUTH | 4 | 07APR08A | 11JUN08 | 20 | 07APR08A | 04JUN08 | -5 |
| CN1190 | INSTALL METAL STUD FRAMING NORTH | 5 | 07APR08A | 12JUN08 | 20 | 07APR08A | 02JUL08 | 14 |
| CN1210 | ROUGH-IN WALLS NORTH | 1 | 07APR08A | 23JUN08 | 16 | 07APR08A | 08JUL08 | 10 |
| CN2320 | ROUGH-IN ELECTRICAL CENTRAL | 4 | 15APR08A | 18JUN08 | -24 | 15APR08A | 11JUN08 | -5 |
| CN1050 | ROUGH-IN MECHANICAL SYSTEMS NORTH | 5 | 23APR08A | 20JUN08 | 1 | 23APR08A | 13JUN08 | -5 |
| CN4140 | INSTALL/FINISH DRYWALL NORTH | 3 | 25APR08A | 26JUN08 | 16 | 25APR08A | 23JUL08 | 18 |
| CN7810 | INSTALL STRUCTURAL STEEL | 4 | 25APR08A | 12JUN08 | 16 | 25APR08A | 11JUN08 | -1 |
| CN1100 | ROUGH-IN MECHANICAL SYSTEMS CENTRAL | 6 | 05MAY08A | 30JUN08 | 1 | 05MAY08A | 09JUL08 | 6 |
| CN1130 | ROUGH-IN F/A AND SPRINKLER CENTRAL | 5 | 05MAY08A | 26JUN08 | 9 | 05MAY08A | 08JUL08 | 7 |
| CN7820 | POUR/PATCH FLOOR OPENING | 2 | 12MAY08A | 16JUN08 | 16 | 12MAY08A | 18JUN08 | 2 |

## Detailed Cost Comparison

To compare the cost of the thin film battery to a conventional battery, as generally used in a similar application:

As shown above, total AH required by battery is 223,125.

Thin film battery has been priced according to capacity @ $0.35/unit each unit being a function of capacity/area. For the storage capacity required, the cost of the thin film battery is approximately:

793,000 Units x $0.35 = $277,000

This cost can be offset by the savings from the avoidance of buying an inverter for the photovoltaic system.

Also, due to the fact that this can be imbedded into the insulation, the cost of it can be amortized into the building total.

Commercially Installed Battery as recommended by PV vendor:

| | |
|---|---|
| Each battery gives: | 180 Ah |
| To meet size requirements: | 223,125 / 180 = 1240 batteries required |
| Cost per unit: | $150 |
| Total Cost: | $150 x 1240 = $186,000 |

Granted this initial cost is significantly lower than the initial cost of the paper battery, the drawbacks of this antiquated technology are many; most obvious being, the frequency of replacement being multiple times (assuming at least 3 times, on the conservative side) more than the thin film battery over the life of the PV system.

It can be argued that the lifetime cost of **the conventional battery is $558,000 vs. $277,000 of the thin film battery**.

# 6.0 ELECTRICAL BREADTH: DIRECT CURRENT DISTRIBUTION

## 6.1 Background

Using DC distribution within the building seemed like a great option to explore. This was due to the fact that its known that PV systems have inefficiencies built –in and then take another hit to their efficiency as it supplies power to the end user. To combat this, and eliminate the last blow to the efficiency, it was proposed to study the alternative of a DC distribution system within the building. This was not to be considered as an alternative after completion of the renovation but to be considered as an initial design consideration. To retrofit a building with a DC system can be costly, so to keep the feasibility in a positive light a DC system is being considered as part of the original renovation intentions.

In a Typical Commercial Building, Much is Already DC-Based

– Electronic ballasts and drivers for LED Solid State lighting

– Energy management & control systems

– Adjustable speed drives for HVAC & pumping

– Computer and Information Technology Equipment

– Portable and personal electronics

…The Majority of End-User Equipment

Inefficient Power Conversions are needed from the Building's Fixed AC Infrastructure to Power These DC Devices…

It should be noted that the DC system of the building can work in two different ways. It can draw current directly from stored electricity, or at the time of charging may draw directly from the photovoltaic system. As a backup, the electricity supplied from the Central Utility Plant is also readily available with the use of AC to DC step-up inverter.

## 6.2 DC MicroGrid

A system coined as the “DC microgrid” is becoming a new standard for commercial interiors

• Safe, low voltage 24V DC power at the device interface

– Distributed through ceiling (initially), walls, floor and furniture systems

– Suspension system as power bus, “plug and play” to LV DC devices

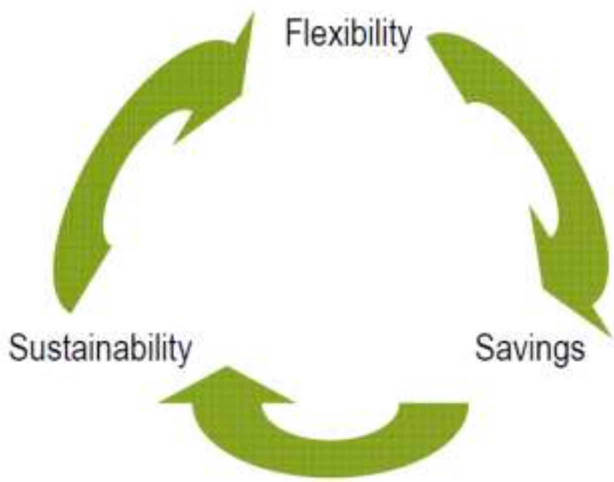
• Enables selective & scalable use – still connected to building AC & national power grid

• Optional use of locally generated and renewable DC power - solar, wind, fuel cell, etc.

• Enhanced controls help manage load demand and decrease energy usage/cost

• Safe Class 2 structured cable wiring at the user interface, UL-Listed & NEC compliant

• Easily installed by customary trades




**Flexibility**

• Direct access to, and easy use of, safe low voltage DC power

• Easy-to-install/move devices, installed by customary trades, maintained by facility staff

• Backward & forward technology compatibility without changing infrastructure

• Easy repurposing and reconfiguration of interior spaces – no rewiring

**Sustainability**

• Permits re-use of system devices

• Promotes design of simpler devices (no DC-AC conversions)

• Promotes use of on-site alternative energy with significant efficiency benefits

• Facilitates better energy efficiency through individual, addressable wireless controls

**Cost Savings**

• Reduces installation and reconfiguration costs

• Reduces upgrading and fixed asset costs

• Optimizes electrical energy use

**Safety**

• Low voltage DC Eliminates startle, reduces spark and fire hazard

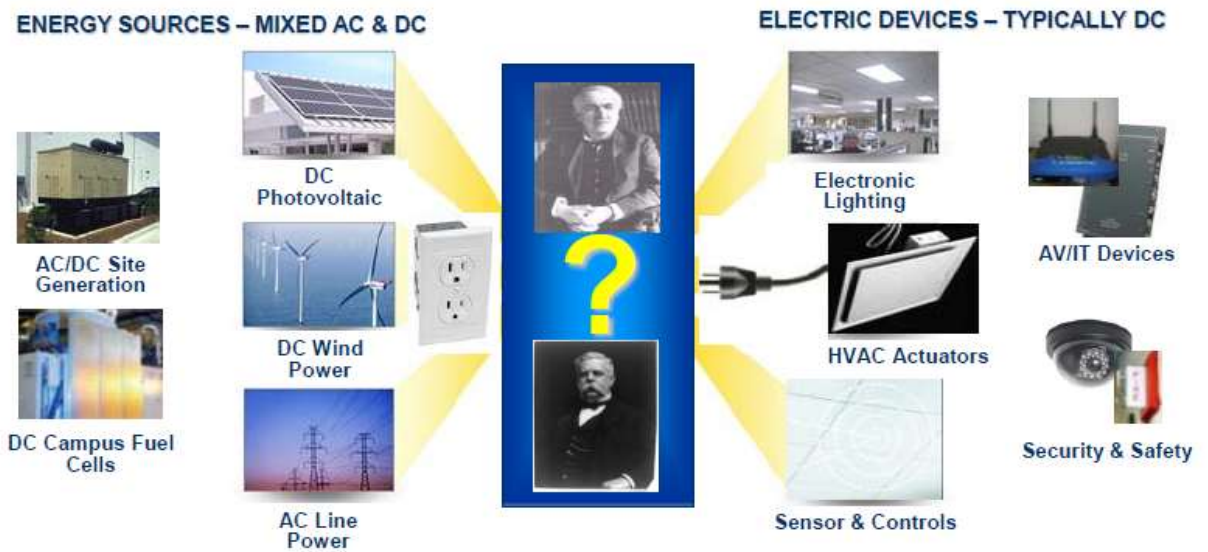
Further, some new power distribution platforms are made available. For example: A powered ceiling grid will distribute safe, low voltage DC power to lighting fixtures, sensors and other electrical devices located in or near the ceiling.

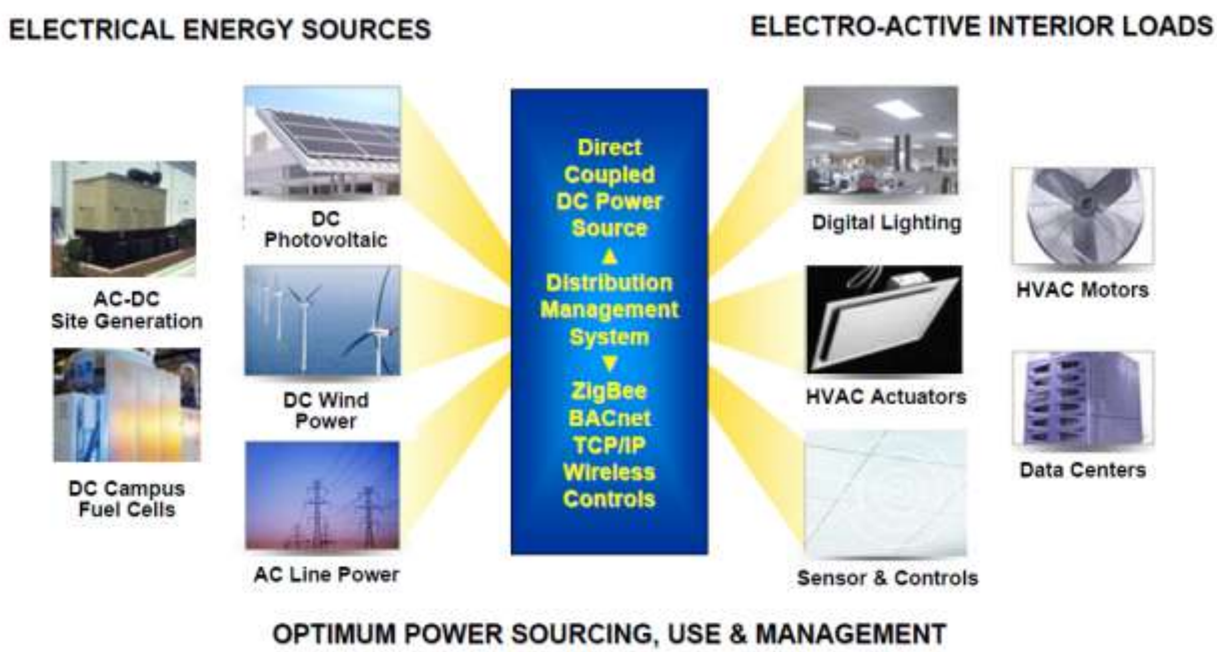
– Repurpose and reconfigure without rewiring

– Simple plug and play modularity

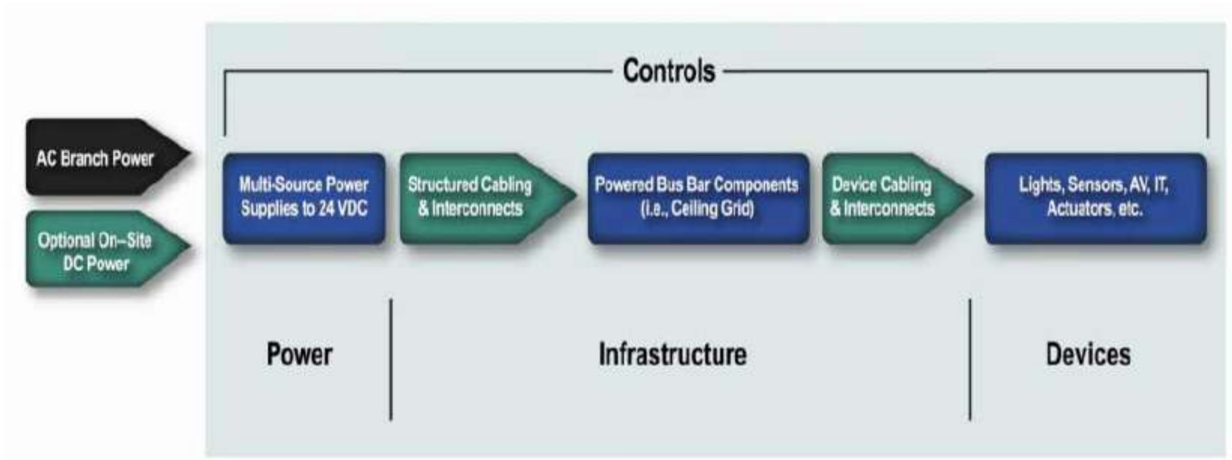
– Enables use of native DC on-site renewable energy (like wind & solar)

– Helps accelerate use of solid-state LED lighting and other power efficient electro-active devices

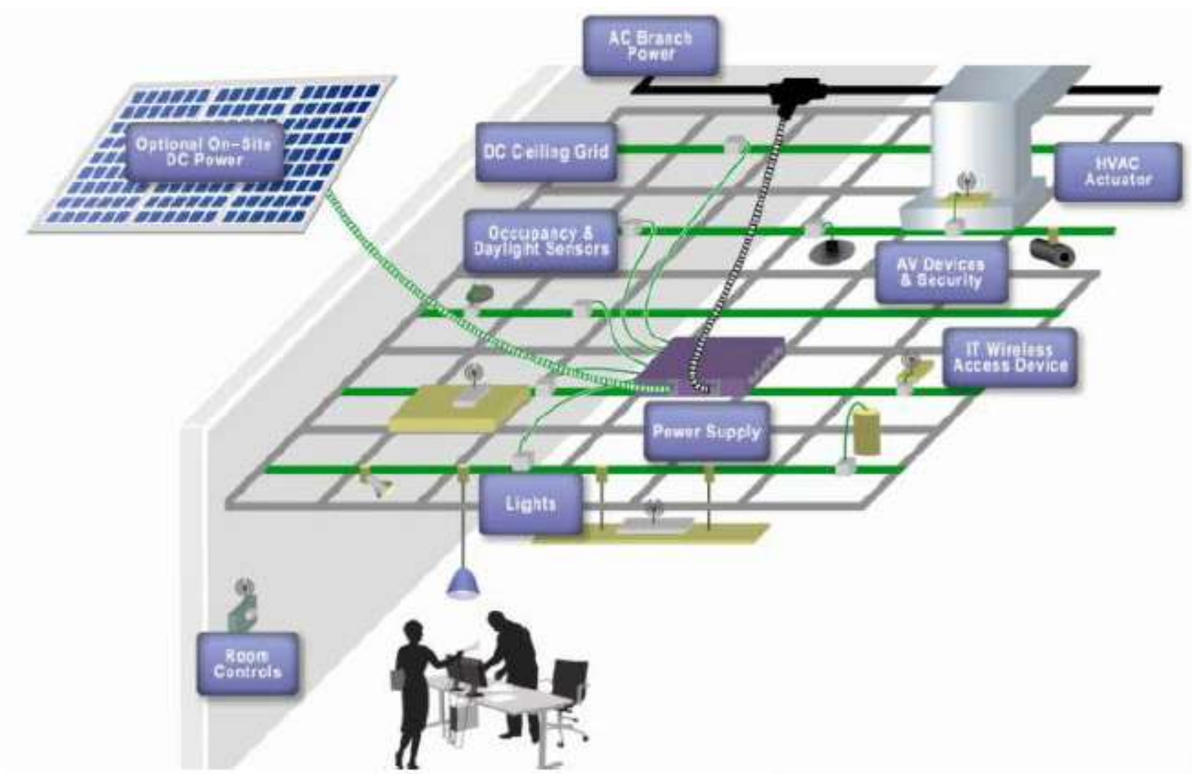

ENERGY SOURCES – MIXED AC & DC
ELECTRIC DEVICES – TYPICALLY DC
AC/DC Site Generation
DC Campus Fuel Cells
DC Photovoltaic
DC Wind Power
AC Line Power
?
Electronic Lighting
HVAC Actuators
Sensor & Controls
AV/IT Devices
Security & Safety


ELECTRICAL ENERGY SOURCES
ELECTRO-ACTIVE INTERIOR LOADS
AC-DC Site Generation
DC Campus Fuel Cells
DC Photovoltaic
DC Wind Power
AC Line Power
Direct Coupled DC Power Source
Distribution Management System
ZigBee
BACnet
TCP/IP
Wireless
Controls
Digital Lighting
HVAC Actuators
Sensor & Controls
HVAC Motors
Data Centers
OPTIMUM POWER SOURCING, USE & MANAGEMENT

Controls play a key role in a successful DC distribution system.




The way this system can be laid out and the myriad of equipment running off of it:



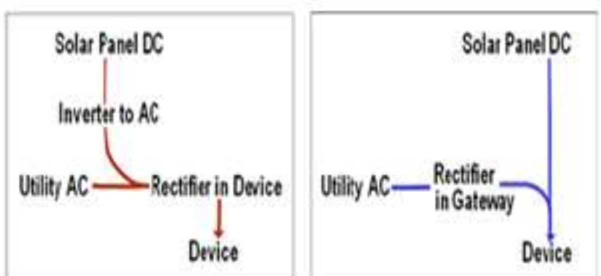
Integrate solar, wind, fuel cell and more on a common distribution bus

- Simplified direct use of DC power generated in its native form
- Safe 24Vdc at the user's plug and play level
- Eliminate multiple DC-AC and AC to DC power conversion losses

Relating more specifically to this project, the connection of the PV system with storage and distribution is as such:

Typical Solar Power System:

~89% efficiency, solar panel to device.




Direct Coupling System:

~99% efficiency, solar panel to device

### 6.3 Case Study

A case study makes for the best argument, especially when it comes from a leading council – the USGBC.

## US Green Building Council Headquarters

- Continuous high light reflectivity acoustical ceilings
- DC multi-channel power servers – utility AC Primary
  - Solar supplemental planned for later
- Fluorescent light fixtures – with DC ballasts
- Wired controls, touch-panel interface
- Daylight, occupancy and dimming functions
- LEED Platinum for Commercial Interiors

Architect Rod Letonja of Envision Design:

"The infrastructure is in place for USGBC to add solar... Solar panels will be able power all the lights in the conference rooms with DC energy distributed through the ceiling grid."

## 6.4 Mechanical Impact of DC Distribution

DC powered pumps use direct current from motor or solar power to move fluid in a variety of ways. Motorized pumps operate on 6, 12, 24, or 32 volts of DC power and use hand-operated, electric, pneumatic, or hydraulic motors. Solar-powered DC pumps use photovoltaic (PV) panels with solar cells that produce direct current when exposed to sunlight. Many DC powered pumps use centrifugal force or positive displacement to move fluids.

A variety of special DC powered pumps are available. Drum pumps are designed to transport or dispense the contents of drums, pails, or tanks. Macerator pumps empty holding tanks for sewage and typically include a bronze cutter to grind waste down to a small particle size. Sump pumps fit in compartments and remove unwanted water build-up that threatens to encroach on living or equipment space. Bilge or ballast pumps are used onboard boats and ships to remove water from the bilge or to lower or remove water for ballast. Micro pumps use a flexible structure to help move fluids in miniaturized systems and circulation pumps keep media circulating through distribution or process systems. Sampling pumps remove small amounts of media for analysis. Magnetic drive pumps use a magnetic or electromagnetic drive and are suited for laboratory, production line, chemical processing, general transfer utility, and original equipment manufacturer applications.

DC powered pumps are available with a variety of specifications and features. Devices vary in terms of maximum discharge flow, minimum discharge pressure, inlet size, and discharge size. Adjustable speed pumps can operate at speeds selected by an operator while continuous duty pumps maintain performance specifications at 100% duty cycle. Run dry pumps can operate without pumped fluid or external lubrication for an extended period of time. Some DC powered pumps are corrosion-resistant, explosion-proof, or meet strict guidelines established for sanitary process applications. Others are configured to pump sticky or stringy materials, include an integral grinding mechanism, or have centerline suction or discharge. DC powered pumps can move media either vertically or horizontally, depending on the direction of the pump stator / rotary assembly. Level control devices turn pumps on and off automatically, depending on the level of the media.

Comparing pumps that have been installed in the building already with DC pumps available of similar specifications has been interesting. A lot more variety is available than originally expected. On average head loss and over efficiency of these pumps is about 15% more than those of standard AC pumps. This allows for sizing down the pumps that are required by Building One. Smaller size translates to monetary savings. However, a direct apples-to-apples comparison shows only a cost saving of approximately 8-10%. For this project, savings approximates to $70,000 up front. Research also shows that some products may require longer lead times.

### 6.5 Cost

Cost and Utility impact as related to the lighting systems within FDA Building One.

| | |
|---|---|
| Lighting Fixtures & Lamps (F&D) | $658,345 |
| Lighting Fixtures & Lamps (L) | $154,159 |
| Low Voltage Lighting Control | $23,050 |
| | |
| | $835,554 |
| | |
| | |
| DC Systems (+25% of cost) | $1,044,443 |
| | |
| Increased Initial Cost | $208,889 |
| | |
| | |
| Orginial Utility Cost | $120,000 |
| | |
| Efficiency 11% greater than original | $106,800 |
| Annual Saving | $13,200 |
| | |
| Simple Payback (yrs) | 16 |

Although, as mentioned above DC distribution can be used in more than just lighting systems, lack of financial data for the FDA Building One project made it difficult to conduct adequate financial feasibility. However this gives an idea of the cost related with a DC system. It will most likely need to be a mindset shift by engineers. As with any emerging technology, adoption brings down cost quite a bit. It'd be awesome if Building One were able to follow in step with USGBC Headquarters.

# 7.0 CONCLUSION

## 7.1 Final Recommendations

Through this entire process, I've learned quite a bit about FDA, Building One, emerging technologies and building systems. The final word on each of the areas that I've studied is as such: Photovoltaics are a great option, especially with the payback rate that's available due to the tax credits and local incentives. It's important to note that the upfront cost will still be hefty. Also, the implementation of a DC distribution system in the building is more than just a novel idea. I feel that its advantages far outweigh the initial hesitation of cost. It's useless to have inefficiencies built into our building systems, at a time when we pay a premium for energy cost and have a wild environmental impact. Although 16 year payback is definitely a deterrent for something like the lighting system, I feel that the architect could choose from a lower cost fixture within the realm of DC products. As for the thin film battery, I feel that it's a novel idea. At this immediate stage, its application may be a stretch. But don't doubt the capability; don't sleep on the technology. The pure cost may be justified simply by the elimination of the inverter. The adoption is still a hard sell to a building owner.


## 7.2 Acknowledgements

-My parents, especially my mom, without whom none of my efforts would matter.
-AE Faculty. Despite my shortcomings, they haven't given up on me.
-Good friends are as rare as Two Dollar Bills. Value them.
-Colleagues, Engineers, PM's that helped me tremendously with this project.
-Music, TED Talks and Inspirational articles are great company for long nights in the lab

With fond memory of my Grandfather
RIP Papa
(March 19, 1930 – January 24, 2011)