ANALYSIS III | ENERGY EFFICIENT TECHNOLOGIES

MAE INFLUENCE

BACKGROUND

Mid-Atlantic Data Center 5 will be a highly green building and much more efficient than most typical data centers. In fact, this building will be one of a handful of data centers that has been certified LEED Gold in the country. Nevertheless, in the big picture, a data center still consumes a great deal of energy and continues to struggle with efficiency issues. Due to escalating energy costs, developers are constantly searching for ways to reduce their energy bills and improve their data center efficiencies.

GOAL

The goal of this analysis is to evaluate state-of-the-art electrical and mechanical technologies that could improve the energy efficiency of Mid-Atlantic Data Center 5. Through research and a thorough analysis, the expectation is to conclude that implementing a thin-film photovoltaic (PV) system and water-side economizers would create a more energy efficient building and reduce the overall energy costs for the owner in the long-run.

METHODOLOGY

Thin-Film Photovoltaic System

1. Research current solar panel systems to determine the most efficient and effective system for MADC5.
2. Analyze the solar PV system and its implementation with the building lighting system. Perform calculations to layout the system, size the wires, and size the conduits.
3. Evaluate the constructability, schedule and cost impacts of the solar PV system.
4. Form conclusions and recommendations.

Economizers

1. Research air-side and water-side economizers and determine which equipment would better suit MADC5.
2. Analyze the existing mechanical system to determine the effects of installing economizers.
3. Develop or redesign the system with the economizers.
4. Evaluate the constructability and cost impacts of improving the efficiency of the existing system.
5. Form conclusions and recommendations.

RESOURCES

- Current Events and Literature
- DuPont Fabros Technology, Inc., contacts – Faran Kaplan and Joe Ambrogio
- CCG Facilities Integration, Inc. (MEP Engineer on the project), contact – Mike Mckenna
- EYP Mission Critical Facilities/Hill Mechanical, contact – Andrew Syrios
- Carlisle Syntec, Inc. – Energy Services Department
- The Morin Company, LLC – Steve Wandishin
- Architectural Engineering 5th Year Students – Jim Gawthrop, Mech. & Courtney Yip, L/E

THIN-FILM PHOTOVOLTAIC SYSTEM | ELECTRICAL INFLUENCE

RESEARCH

Over the past few years, thin-film technology has become the most efficient solar technology available in the market. As of 2005, 19.5% efficiency was recorded with copper-indium-gallium-selenium (CIGS) photovoltaic cells by a team at the National Renewable Energy Laboratory (Copper indium gallium selenide, 2009). CIGS is a semiconductor light absorbing material that has a specific microstructure allowing the cells to be only a few micrometers thin. As expected, the CIGS thin-film technology has exploded in the solar market and has taken on several forms, including a unique cylindrical shape provided by Solyndra.

PRODUCT SELECTION

Solyndra has utilized the CIGS technology to design, manufacture, and sell cylindrical photovoltaic panels, or tubular solar panels, for low-slope rooftops. Within each panel, sized at 1m x 2m, are (40) – 1 inch diameter cylinders with CIGS thin films rolled inside the cylinders. Contrary to traditional panels (Figure 16 below), the tubular panels are mounted horizontally and laid extremely close to one another, allowing significantly more roof coverage and resulting in a higher production of electricity per rooftop per year (Products, 2009).

Figure 16 - Solyndra panels on left vs. conventional panels on the right.

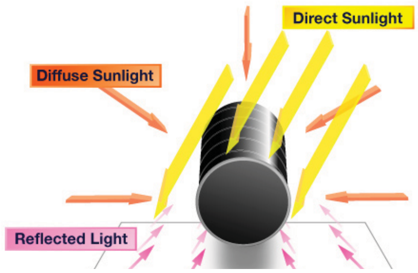


Figure 17 - Solar energy collection of each module.

According to Solyndra, optimum performance can only be achieved when the panels are horizontal to the roof surface.

One of the most unique features of the cylindrical modules is the ability to capture 360-degrees of direct and diffuse sunlight, which allows the system to remain stagnant and not have to track the sun. When combined with a white roof, which reduces building cooling loads, the panels become capable of capturing up to 20% more sunlight from the sunlight that reflects off of the white roof (Solyndra Reveals

Thin-film Solar Tubes, 2008), which in turns produces significantly more electricity per year. Figure 17 to the right depicts the various directions of sunlight that each module can collect.


SOLYNDRA
CONVENTIONAL

Figure 18 - Wind design for Solyndra and a conventional system.

Another significant design feature of the tubular panels is its wind performance (Products, 2009). The panels allow wind to blow through the spaces between each module, whereas traditional panels are solid and prohibit wind from passing through the panel. Please see Figure 18 above for an illustration of the two systems. As a result, there is negligible wind loads, both upward and downward, on the roof structure. In fact, the system has significant mass that can sustain up to winds of 130 mph. In addition, this elevated, open configuration optimizes performance for snow loads and other rooftop obstacles.

DESIGN ANALYSIS

Once the solar energy system was chosen, see Appendix F for product data, there were several steps to designing the system for MADC5.

1. Determine the maximum amount of panels that could fit onto the roof, which includes a main roof and a second level mezzanine roof.
    a. Main Roof = 236,000 SF
    b. Mezzanine Roof = 61,000 SF (if necessary)
    c. Panel Size = 6 ft x 3.5 ft = 21 SF

By simple calculations, leaving extra space for roof obstacles and space between panels, it was determined that the main roof could fit about 11,000 panels and the mezzanine could fit 2,800 panels.

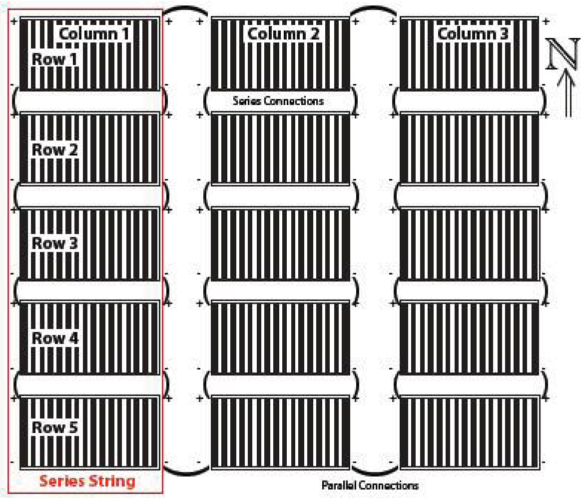


Figure 19 - Series and parallel connections for Solyndra panels

2. Determine the amount of panels in each array. See Figure 19 to the right.
    a. Connected in Series (also known as a Series String)
        i. No. of Panels =

$$\frac{\text{US NEC Rating (V)}}{\text{V}_{\text{OC}}} = \frac{600\text{ V}}{102.5\text{ V}} = 5.85 = \mathbf{5\ panels}$$

   b. Connected in Parallel (Per design guide, up to 3 strings can be placed in parallel.)
      i. $\text{No. of Strings} = \left(\frac{\text{I}_{\text{fault}}}{\text{I}_{\text{SC}}} + 1.25\right)\left(\frac{1}{2.81}\right) = \left(\frac{23\text{ A}}{2.70\text{ A}} + 1.25\right)\left(\frac{1}{2.81}\right) = 3.47 =$ $\mathbf{3\ Stings}$

3. Determine the amount of panels required to power the building lighting load of 508 kW. It is typical to use more panels to ensure that the load is met.
   a. As determined above, each sub-array consists of 15 panels (5x3). Per supplier, it is typical to place 10 sub-arrays in each array.
   b. $\text{No. of Arrays} = \frac{508\text{ kW}}{27.3\,\frac{\text{kW}}{\text{array}}} = 18.6 = \mathbf{19\ array}$
   c. $\text{No. of Panels} = (19\text{ arrays})\left(150\,\frac{\text{panels}}{\text{array}}\right) = \mathbf{2850\ panels} \ldots \mathbf{518.7\ kW\ power}$
   d. By a comparison to the allowable amount of panels, it can be determined that there is ample room for the panels to power the lighting load.
4. Determine the amount of inverters required for the system.
   a. According to the supplier, this system this size would typically use a 260kW inverter (see Appendix F for product data).
   b. $\text{No. of Inverters} = \frac{518.7\text{ kW}}{260\,\frac{\text{kW}}{\text{Inverster}}} = 1.995\text{ Inverters}$
   c. For a factor of safety, it is determined that the best option would be to use **3 inverters** to ensure that the system would function properly.
5. Determine the wire and conduit sizes of the conductors connecting the combiner boxes to the inverters.
   a. Please see Appendix F for a complete breakdown of the wire and conduit sizing.

Table 21 - Quantity take-off for DC wires

DC Wires – Combiner Boxes to Inverters				
From Combiner	To Inverter	# of Arrays	Cable Size	Conduit Size
AF01	1	10	**300**	**2"**
AF02	1	10	**4/0**	**1-1/2"**
AF03	1	10	**3/0**	**1-1/2"**
AF04	1	10	**2/0**	**1-1/4"**
AF05	1	10	**1**	**1"**
AF06	1	10	**2/0**	**1-1/4"**
AF07	1	10	**4/0**	**1-1/2"**
BF01	2	10	**300**	**2"**
BF02	2	10	**250**	**2"**
BF03	2	10	**4/0**	**1-1/2"**
BF04	2	10	**2/0**	**1-1/4"**
BF05	2	10	**1/0**	**1-1/4"**
BF06	2	10	**3/0**	**1-1/2"**
BF07	2	10	**4/0**	**1-1/2"**
CF01	3	10	**350**	**2"**
CF02	3	10	**300**	**2"**
CF03	3	10	**4/0**	**1-1/2"**
CF04	3	10	**3/0**	**1-1/2"**
CF05	3	10	**2/0**	**1-1/4"**

CONSTRUCTABILITY ANALYSIS

PANEL WEIGHT & MOUNTING

As for the structural design of the system, it is lightweight and self-ballasted. Each panel weighs approximately 70 lbs (Solyndra Reveals Thin-film Solar Tubes, 2008) with a distributed rooftop load of 3.3 lbs/ ft^2 (Products, 2009). Two people can easily lift, carry, and place all the panels while one person makes the electrical connections at the array; however for a job this large it is best to have five people for installation. There are no leak-prone roof penetrations, anchoring, or ballast required to secure the system to the roof. Panels and aluminum frames are simply placed on panel mounts, allowing the panels to be placed over items less than nine inches, and then connected to each other. In comparison to traditional solar panels, the weight and mounting system of the Solyndra system is quite minimal and can be installed without having a significant effect on the existing structure. The simple installation process is depicted below in Figure 20.

Figure 20 - Installation process

WIRING

Panels are prewired for connection with each other, making the installation a fairly simple process. After the panels are mounted, the panels are connected in series and in parallel according to the given configuration. Typical wire size between panels and to the combiner box is #12 AWG. The only extra wire assembly to occur is connecting the combiner boxes to the inverters and the inverters to the panels.

UTILITY CONNECTION REQUIREMENTS

Since this is a significantly large system, it is highly necessary that the local utility company is notified about the installation and use of a solar energy system, as well as to determine if the utility company has any unique requirements. Notification would be sent prior to the installation and connection to the grid.

SAFETY

Solyndra panels, photovoltaic panels in general, are unique equipment in the sense that voltage is present whenever light is present. Therefore, power is constantly on and the panel electrical connects are live wires. It is important that all safety precautions, including local and national electric and building codes, are taken when handling and installing the panels due to the live electricity.

SCHEDULE ANALYSIS

The labor rate for this system with a five man crew is 15 panels/hour. Given there are 2,850 panels, the installation duration is 190 hours, which equates to **24 days** assuming eight-hour work days.

There are two key activities dates to keep in mind when installing the PV system, which are roof completion and Level 3 Commissioning start-up. According to the original schedule, the roof would have been complete by September 12, 2008 and Level 3 Commissioning would have begun in December 2008, creating an available time period of 2.5 months. Since the installation duration is 24 days, the system can be installed with minimal, if any, impact on the schedule.

COST ANALYSIS

FUNDING AND STATE INCENTIVES

FEDERAL

Business Energy Investment Tax Credit (ITC) (Business Energy Investment Tax Credit (ITC))

- This tax credit s is available for systems installed on or before December 31, 2016. For solar energy systems installed, the tax credit equals 30% of expenditures and there is no maximum credit limit.

STATE

Local Option Property Tax Exemption for Solar (Local Option Property Tax Exemption for Solar)

- In the state of Virginia, any residential, commercial, or industrial property with solar energy equipment can be exempt or partially exempt from any county, city, or town property taxes. Solar energy equipment is defined as equipment that is "designed and used primarily for the purpose of providing for the collection and use of incident solar energy for water heating, space heating or cooling or other application which would otherwise require a conventional source of energy."

EQUIPMENT COST

The thin-film photovoltaic system includes the following items:

Table 22 - Cost breakdown of Solyndra system

Description	Cost
System	$3,316,700
Panels (2,850)	
Wiring from Panels to Combiner Boxes	
Combiner Boxes	
Inverter	
Labor	
Monitoring System	$22,900
20-yr Warranty for Inverter/System	$62,000
Permitting	$5,000
Electrical Installation (Conduit & Labor for Combiner Box to Grid)	$320,400
TOTAL INSTALLATION COST	**$3,727,000**
Installation Cost $/W	**$7.19**
Incentives	
Business Energy Investment Tax (30%)	$1,118,100
Local Option Property Tax Exemption for Solar	$0.00
Post Incentive Installation Cost	**$2,608,900**
Installation Cost $/W	**$5.03**

**Costs obtained through discussions with Solyndra installer.*

ENERGY SAVINGS

Table 23 below provides a summary of the energy savings attributed to the Solyndra photovoltaic system.

Table 23 – Solyndra energy savings calculations

PV Avg. Power Output (kWh/yr)	Electricity Cost ($/kWh)	Total Savings	Savings (lbs of CO_2/yr)
687,796	0.068	$46,770	962,914
With Future Proposed Carbon Tax			
687,796	0.1762	$121,190	962,914

- The average power output
- 1.4 lbs of CO_2/kWh (Referenced in Lori Farley's Thesis Report 2008)
- The current electricity rate, as provided by the owner, is $0.068/kWh. However, in order to show an even greater potential savings, an analysis was completed involving the proposed carbon tax on energy. The idea of the carbon tax is to place an environmental tax on carbon dioxide and greenhouse gas emissions. Implementing this tax is a means of slowing the climate change by reducing such emissions and forcing energy companies to produce cleaner energy. It is estimated that a tax between $0.1027-$0.1137/kWh will be placed on electricity produced by coal (for an average of $0.1082) (Carbon Tax, 2009).

PAYBACK

In the case of the Solyndra system the total cost for purchasing and installing is $2,608,900 and the total savings provided by the system is $46,770. Dividing these numbers produces a payback period of **55.8 years**, which is quite unreasonable from a cost perspective for a data center.

As mentioned in the energy savings section above, it is highly probable that a carbon tax will be instituted in the near future. By implementing the carbon tax, the saving for the photovoltaic system increases to $121,190. Such a savings decreases the payback period to **21.5 years**, which is still unreasonable.

ECONOMIZERS | MECHANICAL INFLUENCE

RESEARCH

Economizers are a type of mechanical mechanism that aid in reducing energy consumption by recycling energy produced within a system or utilizing outdoor environment temperature differences (Fontecchio, 2008). In the more recent years, economizers have become more commonly utilized within mechanical systems of data centers on either the chillers or computer room air handling units (CRAHs) due to the ability to save a substantial amount in operating costs.

The typical design of economizers for data centers includes several filters located within the ductwork that connects the outdoor environment to the indoor environment. In order to ensure proper operation of economizers, it is necessary to have good controls, valves, dampers, and maintenance procedures (Economizer, 2009), as well as necessary to monitor the outdoor air conditions to maintain appropriate humidity levels. Otherwise, without proper operation and monitoring, the true savings of the economizers could not be reached.

There are several types of economizers used in the industry; however, data centers typically operate with either air-side economizers and/or water-side economizers. The following sections provide further detail on both the air-side and water-side economizers.

Air-Side Economizers

The idea of air-side economizers is to more efficiently prevent overheating of a building space using 100% recirculated air. The cool outdoor air is directly circulated in the building space, while the warm return air is rejected to the outdoors. Figure 21 below provides a diagram of an air-side economizer (Intel Air Side Economization Study, 2008). This process is most efficient when the outdoor air temperature is sufficiently cool and the amount of enthalpy in the air can be reasonably controlled, thus not necessary to additionally condition the air. Mild climates, such as San Francisco, are the optimal geographic region to utilize the economizers and achieve the best reduction in HVAC energy costs. However, temperate climates, such as Chicago, New York City, and Washington, D.C., can also be positively impacted by the economizers.

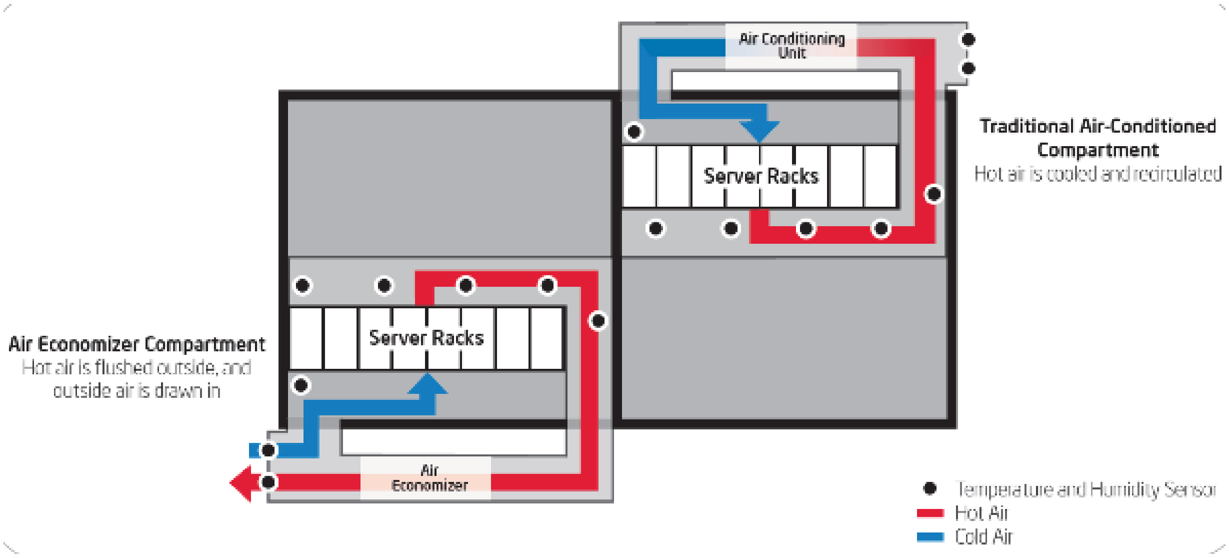


Figure 21 - Air side economizer

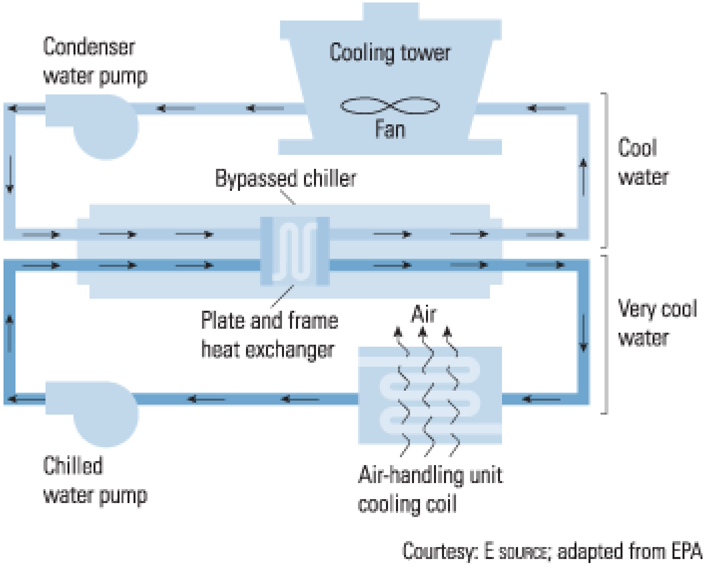
There are several disadvantages to using air-side economizers. First, in comparison to a conventional cooling system, the economizers require additional outdoor air louvers, return duct, and exhaust duct. All of these items require a significant amount of space, especially the louvers, and cost. Second, the controls of this mechanism tend to be quite complex. Lastly, since the economizers have a direct impact on the computer rooms, there is little room for error with the design. (David R. Pickut, 2008)

WATER-SIDE ECONOMIZERS

Water-side economizers, placed on chillers, allow cooling towers to produce chilled water when weather conditions permit. Opposing air-side economizers, this process is most efficient in temperate climates, such as Chicago, New York City, and Washington, D.C., and somewhat efficient in mild climates, such as San Francisco.

Figure 22 - Plate-and-frame heat exchanger

Currently, the most common type of this economizer is the plate-and-frame heat exchanger; see Figure 22 (Plate & Frame Heat Exchangers, 2008) to the right. This type of economizer pre-cools the chilled water prior to flowing into the chiller's evaporator. As long as the outdoor wet-bulb temperature is at least 10°F less than the design return chilled water, there will be a heat transfer from the return chilled water to the condenser water loop from the cooling tower. Therefore, the chiller loading and energy consumption can be reduced as a result of lowering the temperature of the water entering the evaporator. Further, if the wet-bulb temperature decreases low enough, the cooling tower could solely serve the cooling load while the chillers are turned off. Please see Figure 23 below for a diagram of this system. (Heating and Cooling, 2008)



Courtesy: E SOURCE; adapted from EPA

Figure 23 - Water side economizer system

Comparable to an air-side economizer, there are several disadvantages to a water-side economizer. First, this device requires an additional heat exchanger, piping valves, and controls which take up additional space and cost. Further, adding a heat exchanger increases pumping costs due to the added pressure loss. Second, the controls tend to be complex in comparison to a conventional system. Last, water-side economizers can be quite tricky and difficult to operate when the weather conditions are sub-freezing and/or freezing temperatures. (David R. Pickut, 2008)

COMPARISON AND SELECTION

In comparison, air-side and water-side economizers are quite similar in regard to their advantages and disadvantages. Most importantly, in terms of proper climates, both systems could be utilized on MADC5, with water-side being slightly more ideal. However, the most significant difference involves the need for louvers for air-side economizers. Due to the extremely large size of MADC5, the size of louvers required to operate air-side economizers would be too large for the building. On the other hand, in order to utilize water-side economizers, the only requirement would be to purchase plate-and-frame heat exchangers for each of the chillers, a total of eight per phase.

As a result, after talking with several mechanical engineers and evaluating the two devices, it was determined that water-side economizers would best suit MADC5.

CONSTRUCTABILITY ANALYSIS

Fortunately, it is not a difficult task to implement water-side economizers with the existing mechanical design since the economizers can attach to the existing headers with the chillers. One economizer per chiller would be installed in a parallel arrangement to allow the use of either the economizer or chiller at a lower kW depending on the conditions. In order to complete the installation, there is additional material required for connecting and routing pipes, however this does not require a significant amount of extra time, therefore not extending the project schedule. The following page, Figure 24, illustrates a simple schematic drawing of one of the two chiller plants with the water-side economizers.

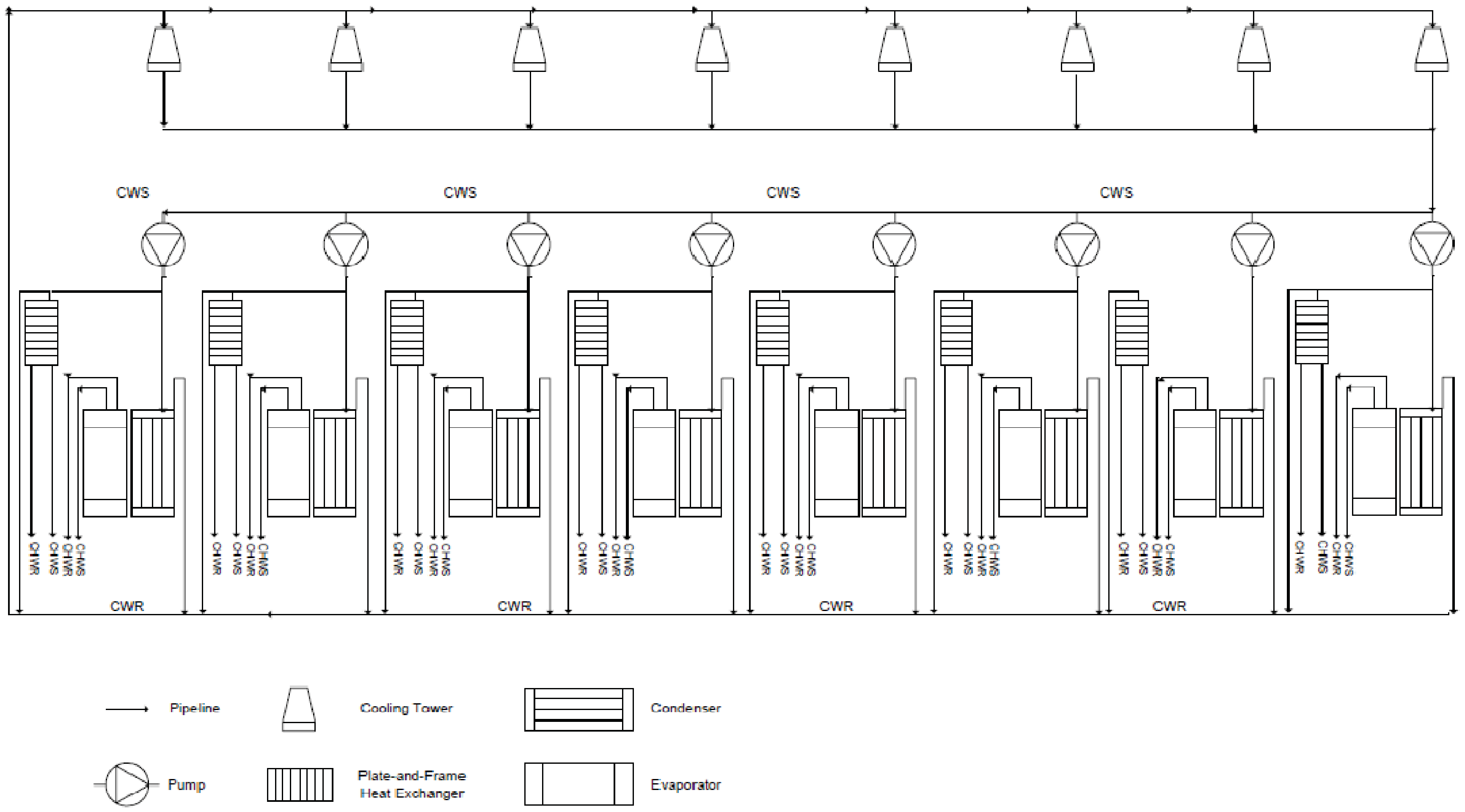


Figure 24 - Schematic of Chiller Plant with water side economizers

COST ANALYSIS

EQUIPMENT SELECTION AND COST

In order to properly size the water-side economizer, or plate-and-frame heat exchanger, it was required to analyze the given parameters for the chilled water pumps and cooling towers. The following performance data assisted with this process:

Table 24 - Water side economizer product data

	Hot Side	Cold Side
Flow Rate (gpm)	2160	3240
Inlet Temperature (°F)	58	43
Outlet Temperature (°F)	46	50.99
Pressure Drop (psi)	3.54	7.78

As a result of analyzing the above data and consulting Steve Wandishin at The Morin Company, LLC, it was determined that the optimal heat exchanger is a Tranter SUPERCHANGER® Plate and Frame Heat Exchanger (cut sheet can be found in Appendix F). The SUPERCHANGER® allows for the separation of hot and cold fluid by a plate which provides the most effect means to transfer heat from one fluid to the other. Fluid travels throughout the devise in a counter-current direction enabling the hot liquid to become cooler and the cold liquid to become warmer, as shown in Figure 25 on the left.

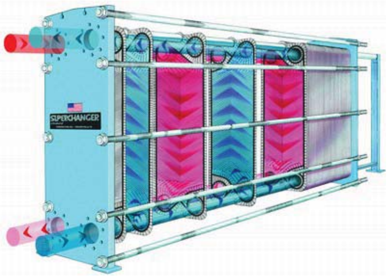


Figure 25 - Tranter SUPERCHANGER® Plate and Frame Heat Exchanger

Each SUPERCHANGER® costs approximately $47,000, plus any additional costs for connection and routing materials. Since there are sixteen chillers for the entire building, it is recommended to ultimately purchase sixteen heat exchangers. However, as the owner has determined to build out Phase 1 of MADC5, it would only be necessary to purchase eight heat exchangers for a total cost of **$376,000**.

ENERGY SAVINGS

According to Michael Kjelgaard, P.E., author of <u>Engineering Weather Data</u>, the energy savings attributed to implementing water-side economizers can be determined by the following formula (Kjelgaard, 2001):

Savings = Cooling Load * Cooling Plant Efficiency * Electricity Cost * Load Hours

**Savings value does not include tower fan and pumping cost. In addition, the cooling load is assumed to be running at 100%.*

Please see Table 24 below for a summary of the energy savings attributed to water-side economizers.

Wet Bulb Temp.	Cooling Load (tons)	Cooling Plant Efficiency (kWh/ton)	Electricity Cost ($/kWh)	Load Hours (h)	Savings per Chiller	Total Savings	Savings (lbs of CO_2/Plant)
24°F	840	0.5	0.068	803	$22,934	$183,472	4,704
With Future Proposed Carbon Tax (+$0.1082 (Carbon Tax, 2009)***)***							
24°F	840	0.5	0.1762	803	$59,425	$475,400	4,704

Figure 26 - Water side economizer energy savings data

- For the cooling plant efficiency, since a majority of the savings is directly related to the chillers, the efficiency rating was based on the chiller efficiency of 0.5.
- The current electricity rate, as provided by the owner, is $0.068/kWh. As mentioned in the solar energy system analysis, the carbon tax would be $0.1082.
- Load hours are the number of hours per year when the outside air temperature is below a user defined “economizer on” temperature. When the temperature is below the defined value, the cold outdoor air would be utilized to cool the water as opposed to using mechanically chilled water from the chillers, thus saving electricity costs. For the MADC5 data center, energy savings will be calculated for a wet bulb temperature of 24°F, which is the typical operating temperature. Please see Appendix F for all of the weather data provided by the mechanical engineer.
- 1.4 lbs of CO_2/kWh (Referenced in Lori Farley’s Thesis Report 2008)

Payback

The most important aspect, especially to the owner, of installing a newer, efficient technology is to evaluate the payback period of the device. In the case of the water-side economizer the total cost for purchasing and installing eight is $376,000 whereas the total savings provided by the economizers is $183,472. Dividing these numbers produces a payback period of **2.05 years**, which is quite reasonable.

As mentioned in the energy savings section above, it is highly probable that a carbon tax will be instituted in the near future along with a steady increase in energy costs. By implementing the carbon tax, the saving for eight chillers escalates to $475,400. Such a savings decreases the payback period to only **0.79 years (9.5 months)**.

Conclusions and Recommendations

Thin-Film Photovoltaic System

The push for environmentally-friendly energy sources has created an ever growing market for solar energy systems. Since it is such a new technology and constantly redesigned and improved, the installation cost per Watt is quite high. As a result, the energy savings are much less than owners would hope, creating an extreme payback period. However, solar energy systems are not about the short-term investment, but rather the long-term and how it can help save the environment.

Based on the above analysis, it has been determined that the owner of the project would have to play the deciding role on whether to implement the thin-film photovoltaic system. Data centers are ever-changing buildings and designs that have a relatively short lifespan before being overhauled for something bigger and better. Therefore, due to the volatility of the building and the 55.8 year payback, it would not be a wise investment for the owner. However, in the case of sustainability and protecting the environment, neither time nor money is unreasonable.

WATER-SIDE ECONOMIZER

Implementing water-side economizers are not particularly enticing in today's energy environment due to such low energy costs. In the long-run, economizers provide greater mechanical efficiency and will eventually pay off for themselves, in approximately 2 years as illustrated above. However, with the constantly increasing electricity rates and proposed environmental taxes on existing energy sources producing carbon dioxide emissions, it seems quite logical to utilize economizers within a mechanical design.

Therefore, based on this analysis of constructability and cost, as well as research on escalating energy costs and taxes, it is recommended that water-side economizers be implemented in MADC5. The mechanical devices will ultimately pay for themselves within only 9.5 months to 2 years, which is more than worth the initial investment.