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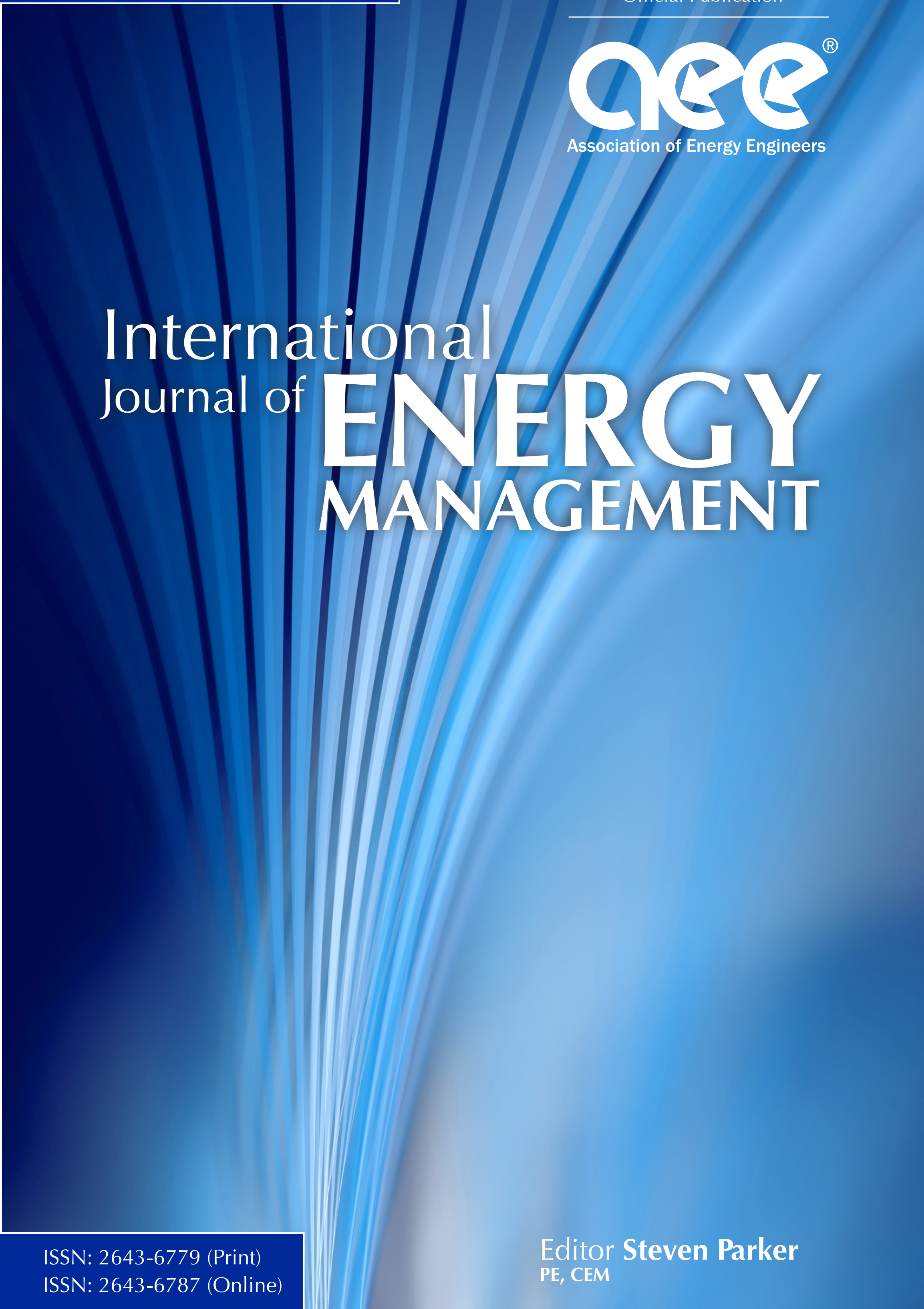

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Contents

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Editor's Desk

Invest in Yourself (part 2)

You may notice the title of my Editor's Desk in this issue is a continuation from Vol. 1, No. 4. I have a reason. Typically, before I begin to opine, I have two things in mind: where I want the message to go (a goal or objective) and where (or how) I want the message to begin. The story evolves as I think about getting from the beginning to the end.

Typically, this style works for me—at least as far as writing the Editor's Desk. My editorials are a form of stream of consciousness with a conversational style. [Note: I write technical papers very differently.] In any event, as I wrote the Editor's Desk for Vol. 1, No. 4, the story evolved differently from what I originally had in mind. Don't get me wrong, I still believe in the message, it just was not the conclusion that I had in mind when I started writing. This may be particularly amusing given the second sentence I wrote in the editorial. (Feel free to go back and review, I can wait.) So, I am going to try again.

As I also wrote in the previous Editor's Desk, it would be great if our employers would fund (time and money) continuing education requirements. After all, it takes a lot to keep current in any career: professional memberships, license and registrations fees, continuing education requirements for licensing, registrations, and certifications, as well as preparing yourself for that next step in your career (e.g., promotion). The fact is, many companies do not invest as much in their employees as they should. I understand, there just isn't always enough time or money to do what is necessary. This is why you have to be prepared to invest in yourself.

Everyone understands (or they should) that to maintain your career, you need to set and achieve goals, accomplish deliverables, and support your organization and stakeholders. However, to advance your career, it is likely to require more. Investing in yourself makes sense and may be a requirement.

Investing in yourself can take many forms. You may have to fund your own formal training courses to maintain certifications. You may have to fund your own participation in a conference to attend presentations or even give presentations yourself. I have done all of these things. Over the course of my career, I know I have invested significant capital. I have the receipts to prove it. While there were tax benefits to making some of these investments in myself, it really paid off as I saw my career develop and grow and my salary alongside it. Like any investment, there is some risk and not everything provides a visible return. In the long term; however, the gains outweighed the costs.

I have mentioned many times before, that writing and publishing articles is an excellent way to learn something new (learn more through teaching), it is also an excellent form of visibility, which can then lead toward other growth opportunities.

In the current *gig economy*, one item to consider, for those of you who feel they are well versed in certain topics, is to develop a stand-alone training seminar. This could be as brief as a half-day training session, or longer, (1-day or 2-day) depending on the level of detail you want to address. There is no doubt that you will learn a lot developing a seminar. [As an example, my state licensing board grants 10 hours of professional development for every 1 hour of seminar developed and provided.] More so than published articles, technical seminars provide excellent visibility, as well as a form of compensation. Teaching seminars is also a great form of marketing, which can lead to future business opportunities.

So, over these past two issues of Editor's Desk, I have addressed investing in yourself in the forms of reading articles, buying books, attending seminars and conferences. These thoughts then give rise to the idea of writing articles, developing seminars, maybe even writing books. All of which are excellent forms of personal and professional development, visibility and career growth. Combined with the gig economy, there is also the opportunity for financial growth as well.

The Association of Energy Engineers is interested in offering new seminars to its members. This opportunity will require a significant investment in yourself, but the long-term payoff can be worthwhile. I do not want to lead anyone on, developing a new seminar, even a short one, requires a considerable amount of time. As I mentioned before, you will never learn more than by teaching. Think you may have what it takes? If so, AEE may be interested in your proposal. If you are interested in this opportunity, I recommend contacting Teresa Piazza, training director, at AEE (teresa@aeecenter.org). Teresa can provide more information on proposal guidelines.

Investing in yourself is a wise investment. I hope all your investments return well.

Steven Parker, PE, CEM
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Impact of Movable Solar Shades on Energy, Daylighting and Indoor Thermal Performance

Jian Yao

ABSTRACT

Solar shading plays an important role in improving energy performance and indoor thermal comfort. This article gave an investigation into the building energy saving, daylighting and indoor thermal performance improvements by using solar shading in hot summer and cold winter zones of China. The results showed that a significant energy savings (about 50%) can be achieved as well as daylighting performance (an improvement by 53.4%). Moreover, the indoor comfort time can be increased by 22.8% and the extremely uncomfortable time can be reduced by 51.6%. It is recommended that the importance and effectiveness of using movable solar shading devices be described in future revisions of the building energy design standard.

INTRODUCTION

Energy consumption by buildings in the world has become a major issue due to growing concern about greenhouse gas emissions [1]. Reducing building energy consumption but still maintaining a comfortable indoor thermal condition is a challenge facing building designers. Many energy efficiency measures can be adopted to diminish energy demands for space cooling and heating, such as wall insulation [2, 3], natural ventilation [4] and green roof [5], etc. For hot summer and cold winter zones of China, the need for solar shading to block unwanted solar radiation to reduce indoor temperature is intense. Thus, solar shading devices play a significant role in improving indoor thermal condition as well as energy performance. A lot of research has been carried out on solar shades. For example, Bellia's research showed that the global annual energy savings related to the use of suitable shading devices has been evaluated between 8% for Milan (the coldest climate) and 20% (for Palermo, the warmest one) [6]. A similar study conducted by Littlefair (et al.) showed that the benefits of shading are latitude dependent; in Scotland, installation of external shading gave an energy penalty of between 1% and 9% [7]. Some researchers studied the daylighting performance of automated roller shades and they found that the useful daylight illuminance index can be maximized for specific window-to-wall ratios and that depends on the glazing properties and fabric properties for each orientation [8]. Significant improvements in indoor thermal performance have also been reported by researchers in South Korea [9], France [10] and USA [11]. However, these research efforts only focus on one aspect of energy, daylighting and indoor thermal performance. These research findings are not applicable to hot summer and cold winter zones of China due to climatic difference. Thus, the influence of solar shading on energy, daylighting and indoor thermal performance improvements in hot summer and cold winter zones of China was studied in this research.

METHODOLOLY

Filed Measurement

This research focuses on a 22-story office building in Ningbo city in China. This is a glazing wall building and it experienced poor indoor thermal conditions in summer. Thus, the building owner decided to add movable solar shades to block excessive solar radiation in summer. Then this building was retrofitted with internal movable solar shades in 2013. Figure 1 shows the picture of the building and solar shades used in an office. To have a comprehensive comparison, indoor thermal condition, daylighting performance and energy saving ratio were investigated before and after using solar shades. Field measurement was conducted to evaluate the indoor thermal and daylighting performance as follows.

Indoor Thermal Comfort

Many factors affect indoor thermal comfort such as room temperature, relative humidity, air velocity, etc. When the indoor thermal comfort was evaluated, predicted mean vote (PMV) and predicted percent dissatisfied (PPD) were widely adopted as the principal index, which was established by Fanger in 1970 [12]. PMV-PPD index can be calculated using Equations 1 and 2.

$$\mathrm{PMV} = F\,(T_a, \phi, T_r, V, M, I_r) \qquad \text{(Eq 1)}$$

$$\begin{aligned}\mathrm{PMV} = {} & (0.028 + 0.3033e^{-0.036M}) \text{ x } (M - W) \\ & - 3.05\,[5.733 - 0.000699\,(M - W) - Pa] \\ & - 0.42\,[(M - W) - 58.15] - 0.0173\,M\,(5.867 - Pa) - 0.0014\,M\,(34 - T_a) \\ & - (3.96 \text{ x } 10^{8}) \text{ x } fcl\,[T_{cl} + 273)^4 - (T_r + 273)^4] - fcl \text{ x } h_c\,(T_{cl} - T_a)\end{aligned}$$

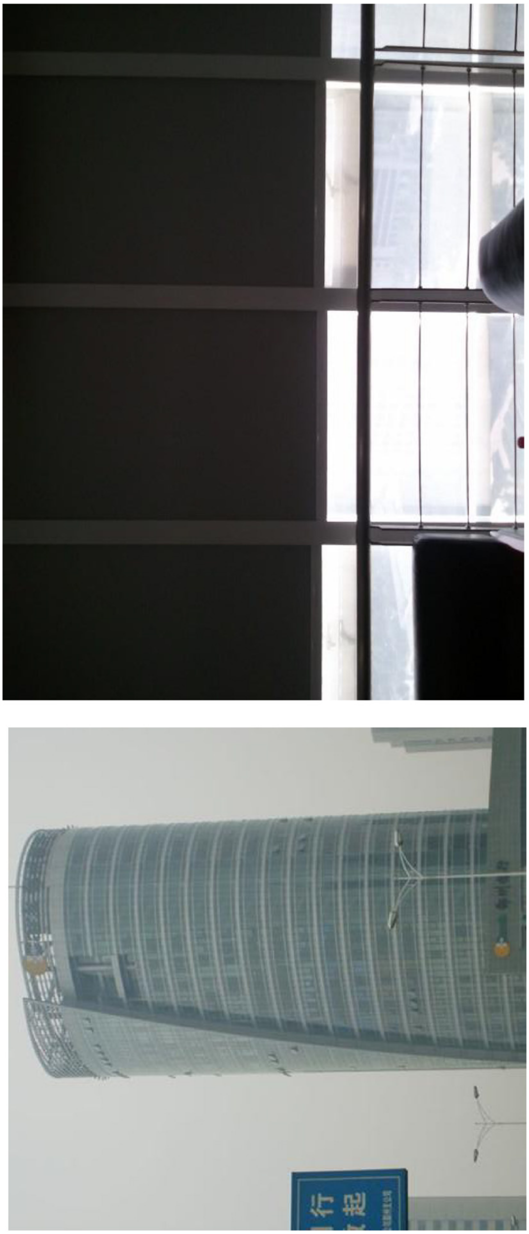


Figure 1. (a) The Retrofitted Building and (b) Solar Shade Used in an Office in this Building

Then PPD can be expressed as a function of PMV using Equation 2.

$$PPD = 100 - 95\exp[-(0.03353\ PMV^4 + 0.2179\ PMV^2)] \qquad \text{(Eq 2)}$$

The relationship between PMV and thermal sensation is depicted in Table 1.

Table 1. Thermal Sensation vs. PMV-PPD

PMV	Thermal sensation	PPD (%)
+3	Hot	100
+2	Warm	75
+1	Slightly warm	25
0	Neutral	5
-1	Slightly cool	25
-2	Cool	75
-3	Cold	100

In China, PMV between -1 and 1 is corresponding to an indoor thermal condition between slight warm and slight cool with a PPD value of 25%. It can be considered a comfortable region for indoor occupants. According to Equation 1, manual calculation of PMV index was time consuming and thus field measurement was conducted by using the equipment MICROTHERM, as shown in Figure 2, which was designed to test the PMV index. The test was carried out from Jun. 2013 to May. 2014 (a whole year) with a time internal of 1 hour. The measurement was conducted in two identical office rooms one with solar shades in use and the other without. These two rooms were not occupied in this year and thus no HVAC systems served for the two rooms.

The movable solar shades were controlled each day by the building owner to comply with regular adjustment behavior of occupants (as shown in Table 2). The aim of occupants' control in summer is to block excessive solar radiation while keeping enough daylight (during he daytime) and enabling natural ventilation to decrease indoor temperatures (during the nighttime). The use of solar shades in winter is to warm indoor space in daytime and reduce heat loss in nighttime.

Daylighting Performance

The positive impact of solar shades when they are deployed for reducing direct solar radiation in summer may lead to a negative influence on daylight-

Figure 2. MICROTHERM for PMV Measurement

Table 2. Movable Solar Shading Control Strategy

Season	Time	Shading Sate
Summer (Jun 1 – Sep 30)	Daytime (8:00 – 18:00)	Shade 2/3 of window area
	Nighttime (19:00 – 7:00)	Fully open
Winter (Oct 1 – May 31)	Daytime (8:00 – 18:00)	Fully open
	Nighttime (19:00 – 7:00)	Fully closed

ing. Therefore, the daylight illuminance was also measured and recorded by using JTG01, as shown in Figure 3. The test was carried out during Jun 1 and Sep 30, 2013 and the light sensors were placed at occupant' s sitting position near external windows (0.5 m off the external walls and 0.8 m above the floor). Previous research shows that useful daylight illuminance (UDI) is a good index for daylight quality evaluation. Thus, this index is used in this article with the

Figure 3. JTG01 for Daylight Illumimance Measurement

daylight illuminance ranging from 300 to 2000 lux. A lower or higher UDI (UDI > 2000, too bright or UDI < 300, too dark) may lead to a poor daylight quality for indoor occupants [11].

Since the movable solar shades were deployed at a position that covered 2/3 of the window area during the summer and were fully opened during the winter daytime, the daylight illuminance for Shade is equal to Noshade during the winter and the following daylighting performance analysis will be focused on the summer condition.

Computer Simulation for Energy Performance

The energy consumption data of the building are not available, and thus the building energy performance simulation was adopted to have a comparison of the energy improvement before and after using solar shades. The setting of building enveloped and HVAC, etc. comply with the real building, as shown in Table 3. The solar transmittance of this shade (0.1) has been determined by field measurement and the movable solar shades control strategy is described in Table 2.

For simplicity, a 4 × 4 × 3-m office room (see Figure 4) was modeled in EnergyPlus [13] to conduct energy performance simulation and the south facade was considered in this article. The energy performance can be compared from three aspects: cooling, heating and total energy consumption. Here the energy saving percentage will be used to evaluate the performance improvement.

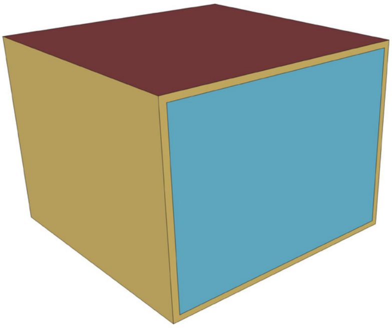
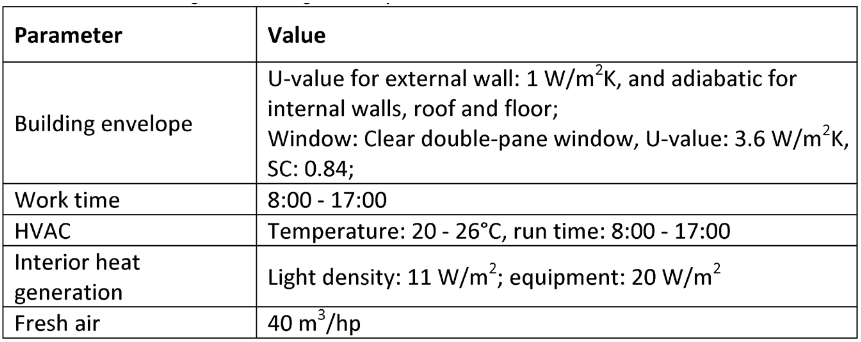


Figure 4. Building Model

Table 3. The setting of building enveloped and HVAC, etc.



Parameter	Value
Building envelope	U-value for external wall: 1 W/m^{2}K, and adiabatic for internal walls, roof and floor; Window: Clear double-pane window, U-value: 3.6 W/m^{2}K, SC: 0.84;
Work time	8:00 - 17:00
HVAC	Temperature: 20 - 26°C, run time: 8:00 - 17:00
Interior heat generation	Light density: 11 W/m^2; equipment: 20 W/m^2
Fresh air	40 m^3/hp

RESULTS

PMV

PMV values during annual work time for the south offices are shown in Figure 5. There is an obvious difference between two measures during summertime and the Noshade case (without solar shading) has a much higher PMV value than the Shade case (using solar shading). While for the winter season, this difference is minor. This is because solar shading plays a significant role in

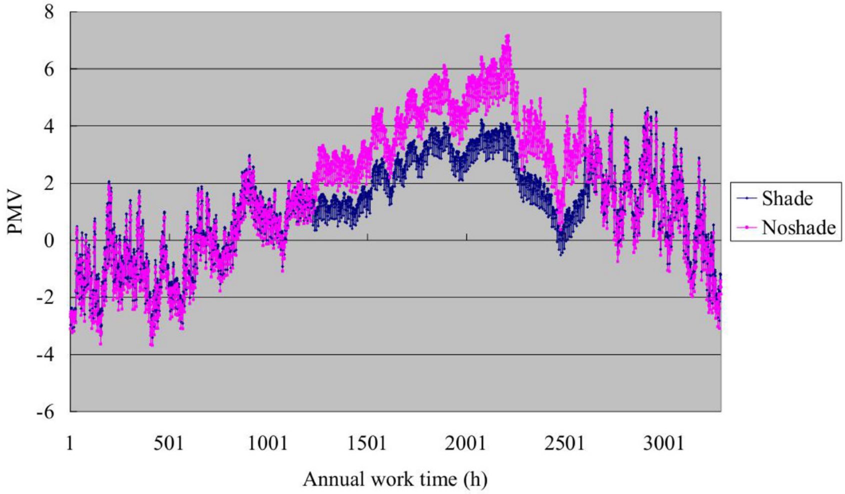


Figure 5. PMV Values During Annual Work Time for South Offices

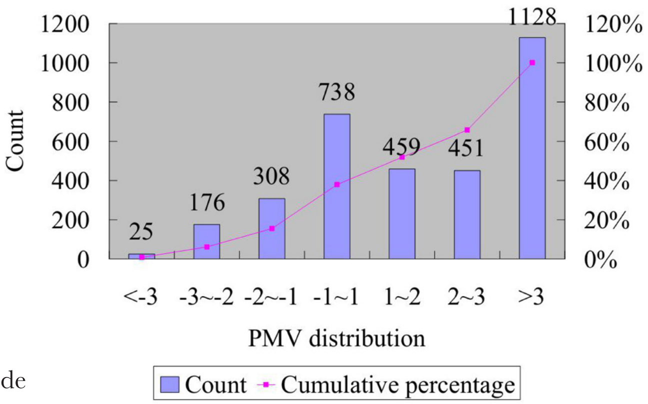
blocking solar radiation in summer and thus reduces indoor temperature and PMV values. The biggest reduction of PMV value reaches about 3, indicating a very significant improvement in indoor thermal comfort.

PMV Distribution

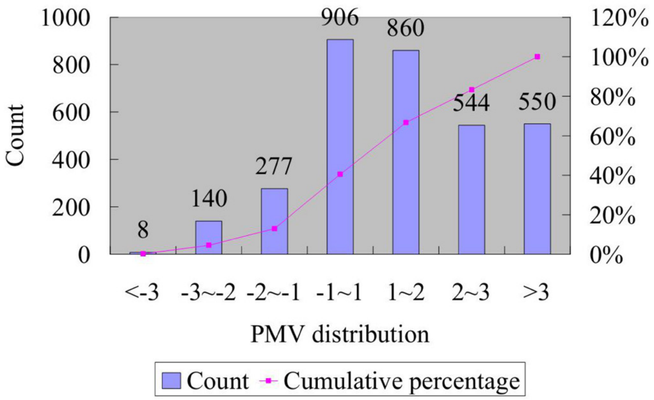
PMV distribution for south offices before and after using solar shading is illustrated in Figure 6. The indoor thermal comfort time ($-1 < PMV < 1$, $PPD < 25\%$) is increased by 168 h, equivalent to a 22.8% enhancement. Moreover, the extreme discomfort time ($PMV > 3$ or $PMV < -3$, $PPD = 100\%$) has been improved more significantly with a reduction of 51.6%. This is because the south window is exposed to solar radiation for a long time, and thus the summer passive cooling effect by solar shading is more significant.

Daylighting Performance

The daylight illuminance for Noshade and Shade during summer work time is illustrated in Figure 7. It can be seen that Noshade has a much higher daylight illuminance than Shade, with almost half hours higher than 10000 lux. The average values for the two measures are both higher than 300 lux (7301 lux for Noshade and 952 lux for Shade), indicating an overall adequate daylight illuminance. However, Noshade apparently has too much daylight with an average daylight illuminance value higher than 2000 lux. Furthermore, UDI index is compared for the two measures and it also shows that the UDI is 842 h (69% of summer work hours) for Shade, while it is only 190 h (15.6% of



(a) Noshade



(b) Shade

Figure 6. PMV Distribution for South Offices

summer work hours) for Noshade. This means that movable solar shades have a significant improvement (53.4%) in daylighting performance compared to windows without solar shading.

Energy Performance

To compare the energy performance after using solar shading, the energy saving index was calculated, which can be expressed as follows:

$$ES = [(E_b - E_{shading})/(E_b)] \text{ x } 100\% \qquad \text{(Eq 3)}$$

where ES means energy saving ratio, E_b indicates energy demand before using solar shading, and $E_{shading}$ is energy demand after using solar shading.

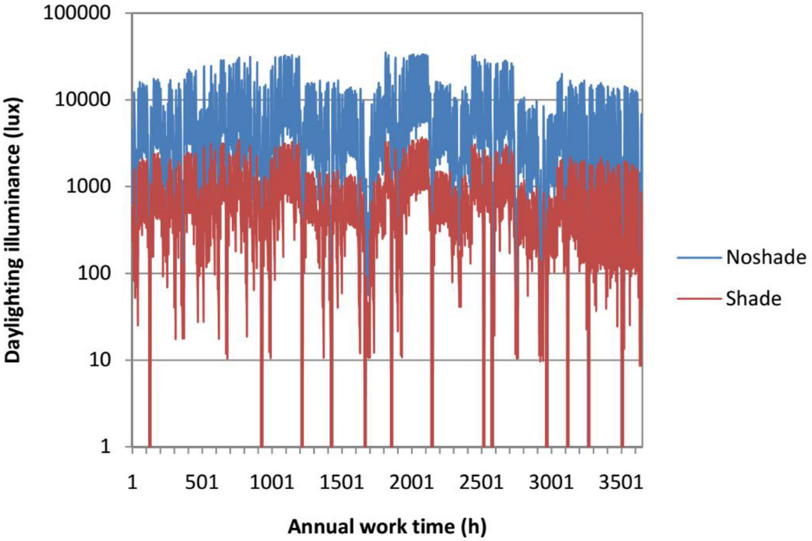


Figure 7.
Daylight Illuminance for Noshade and Shade During Annual Work Time

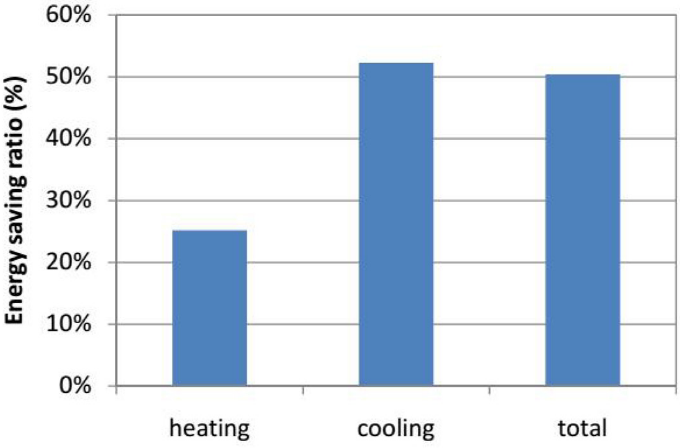


Figure 8. Energy saving performance after using solar shades

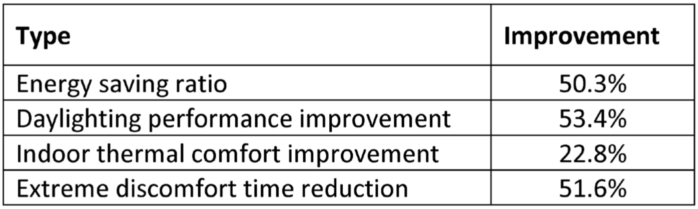
Figure 8 shows the energy saving performance after using solar shades. It can be seen that solar shades have a significant energy saving percentage in terms of cooling energy, which reaches more than 52.4%, while its value for heating energy is only about 25.2%. This is because solar shades block a lot of solar radiation in summer and thus the cooling energy can be reduced substantially. The relatively small energy saving ratio mainly results from its increased window heat insulation in winter conditions. For the total energy performance, it reaches 50.3%, indicating that this measure has a high energy saving potential in this climate region.

DISCUSSION

To have a clear comparison of solar shades vs. base case (without solar shading), the daylighting, energy performance and indoor thermal comfort improvements have been listed in Table 4. It can be seen that not only the energy performance of solar shading is significant, but it can effectively improve indoor thermal conditions by increasing comfort time and reducing extreme discomfort time. Why does movable solar shading have such a significant improvement performance? This is because the weather condition in Ningbo city requires effective measures to block solar heat gains in summer when both outdoor temperature and solar radiation reach their highest values, as shown in Figure 9. Meanwhile, solar radiation is needed to warm indoor space in winter when outdoor temperature is as low as about 2°C. Therefore, fixed solar shading devices such as overhang or low-E windows cannot accomplish these two functions and are not optimal options for buildings. On the other hand, movable solar shading devices have advantages compared to fixed ones and can be widely used in this area for building energy efficiency and indoor thermal comfort.

However, the energy design standard for building energy efficiency in this area of China focuses on wall, roof and windows insulation and the heat conduction of these parts is not allowed higher than a specific value (e.g., 1.0 W/m^2K for walls). It does not ask designers to use movable solar shading for large glazing buildings. Thus, designers usually consider increasing wall or roof insulation layers when the design does not meet the standard's requirement. This will increase initial costs significantly because the energy saving potential of adding insulation layers is marginal for large window-to-wall ratio buildings. Therefore, it is suggested that importance and effectiveness of using movable solar shading devices will be described in future revised building energy design standard for this climate region.

Table 4. Energy, Daylighting and Indoor Comfort Improvements After Using Solar Shading



Type	Improvement
Energy saving ratio	50.3%
Daylighting performance improvement	53.4%
Indoor thermal comfort improvement	22.8%
Extreme discomfort time reduction	51.6%

CONCLUSIONS

This article investigated the energy, daylighting and indoor thermal performance improvements by using solar shading in hot summer and cold winter zones of China. Indoor thermal performance and daylighting performance were measured and energy saving ratio was calculated. The results showed that the energy saving can be reached by 50.3% and the daylighting performance is improved by 53.4%. For indoor thermal condition, a much lower PMV value can be achieved after using solar shading than the bare window case, the comfort time can be increased by 22.8%, and the extremely uncomfortable time can be reduced by 51.60%. However, the existing energy design standard for building energy efficiency in this area of China focuses on the U-values of wall, roof and windows rather than window shading performance. Therefore, it is suggested that the importance and effectiveness of using movable solar shading devices be described in future revisions of the building energy design standard for this climate region.

Acknowledgement

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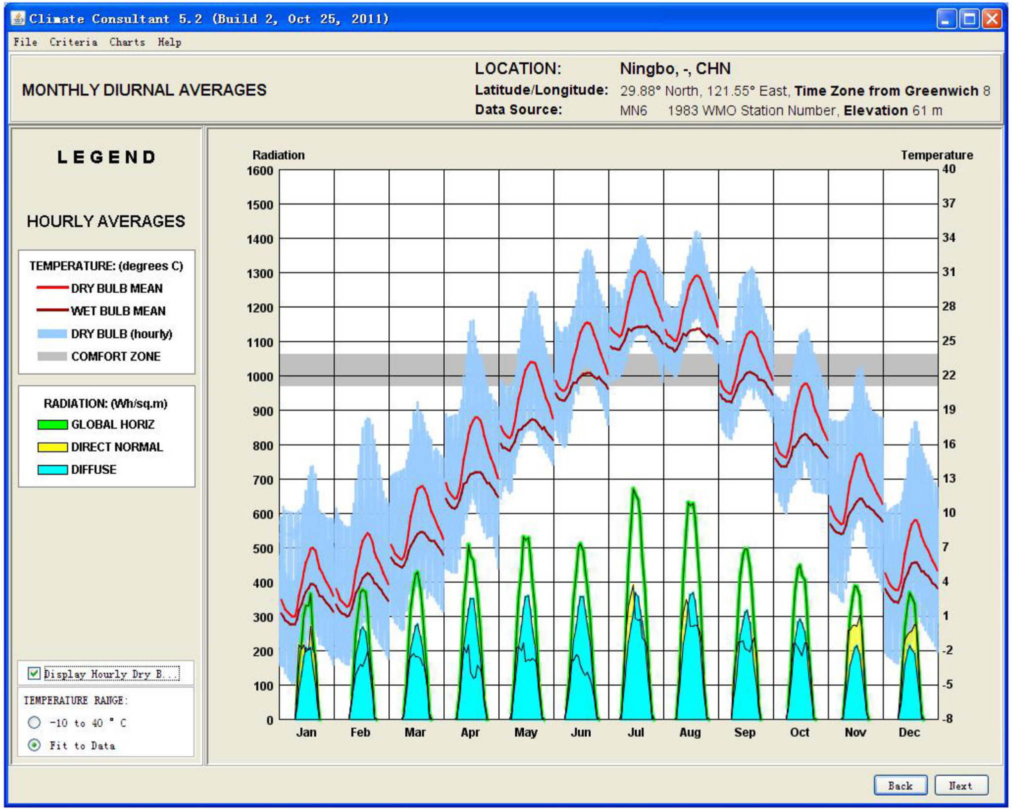

Climate Consultant 5.2 (Build 2, Oct 25, 2011)

MONTHLY DIURNAL AVERAGES

LOCATION: Ningbo, -, CHN
Latitude/Longitude: 29.88° North, 121.55° East, Time Zone from Greenwich 8
Data Source: MN6 1983 WMO Station Number, Elevation 61 m

☑ Display Hourly Dry B...

TEMPERATURE RANGE:
○ -10 to 40 °C
● Fit to Data

Figure 9. Weather Condition in Ningbo City

family houses. *Energy and Buildings*, 42, pp. 1995-1998, 2010.

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◆

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Jian Yao is an associate professor at the department of architecture of Ningbo University. Dr. Yao has many years of experience in studying solar shading performance, daylighting and occupant behavior. Jian Yao may be contacted at nagtive@163.com

Establishing Energy Performance Targets For a Crude Producing Facility—Methodology and Case Study

Muhammad Abbas, P.E., CEM, LEED AP BD+C

ABSTRACT

Establishing challenging, realistic and measurable targets for energy key performance indicators (KPIs) for a crude producing facility requires a systematic approach to forecast energy consumption required to meet planned production. In this paper, the author shares his experience in developing and applying linear regression models to forecast energy demand and determine the energy intensity (EI) KPI targets. The relationship between planned production and associated total energy consumption is not linear, and requires evaluation of all influencing variables. The energy consumption of a crude producing plant depends upon several factors such as feed quality, water cut, plant utilization, products' quality, age of facility, and energy systems' efficiencies. To forecast the overall energy consumption, regression equations were first developed for power and steam demand using last 2 years' hourly data, and then required primary energy was calculated. The final step involved determination of EI by dividing forecasted energy with the planned production.

INTRODUCTION

The energy intensity (EI) or specific energy consumption measures how efficiently a facility is consuming energy to meet its production targets. The facility level EI targets are used for corporate business plans as well as to monitor the impact of energy efficiency efforts. Monitoring and reporting of EI is part of the facility's energy management system that is developed and implemented as per ISO 50001 [1]. Hence, accurate energy forecasting is of paramount importance in establishing the realistic performance targets. Traditionally, facility-based EI targets for the upcoming year were calculated by reducing the previous year's actual EI by a fixed percentage. This approach had its own limitations because a facility's ability to continuously reduce its EI year-over-year is impacted by the factors such as feed quality, percentage water cut, equipment efficiencies etc. This led the authors to explore alternate energy demand forecasting solutions including linear regression analysis. In the following case study, linear regression analysis was developed for a crude producing facility and applied to estimate EI KPI targets. The main reason for choosing the linear regression was the availability of continuous data for dependent variable, and successfully obtaining the adequate fit by checking the residual plots [2].

METHODOLOGY

The flowchart in Figure 1 depicts the key steps to develop regression model and equations. A block diagram of the plant was created first, laying out all the input and output streams including feed, products, power, fuel gas and steam. All streams and associated PI-tags were listed in columns in a Microsoft Excel© sheet by grouping similar type of streams and sub-streams together. In the next step, hourly data for each stream was extracted from the PI system. Once the data was downloaded, a data filtration process was applied to eliminate the Excel sheet rows containing missing or suspected erroneous data.

After completing the data filtration step, the independent and dependent variables were identified. The predictors (independent variables) that were associated with important amount of variation in dependent variable were retained; those that contributed little were rejected [3]. Power and steam consumption are the dependent variables while feed or product streams are independent variables. The energy consumption was further classified into demand side and supply side energy. Demand-side energy included electrical power and steam consumed, while supply-side energy comprised fuel gas consumed by the boilers to generate steam, fuel gas consumed by the power plant to produce electricity, and any direct fuel gas supplied to fired-heaters. Various tools are available to determine the coefficients of regression model equations to find the best fit for the data. The true regression function represents the expected relationship between the target and the predictor variables, which is unknown [4]. In this case study, Microsoft Excel Solver was used to determine the coefficients of the regression equations. The equations were developed for different combinations of independent variables to find the best-fit to minimize error between the regression model results and the last 2 years' actual power, steam and fuel gas demand data. The regression equations with an error of less than 5% were achieved when compared against the last 2 years actual data. The same equations were applied to forecast the EI target for the upcoming years. The developed regression model equations will be applicable to the facility as

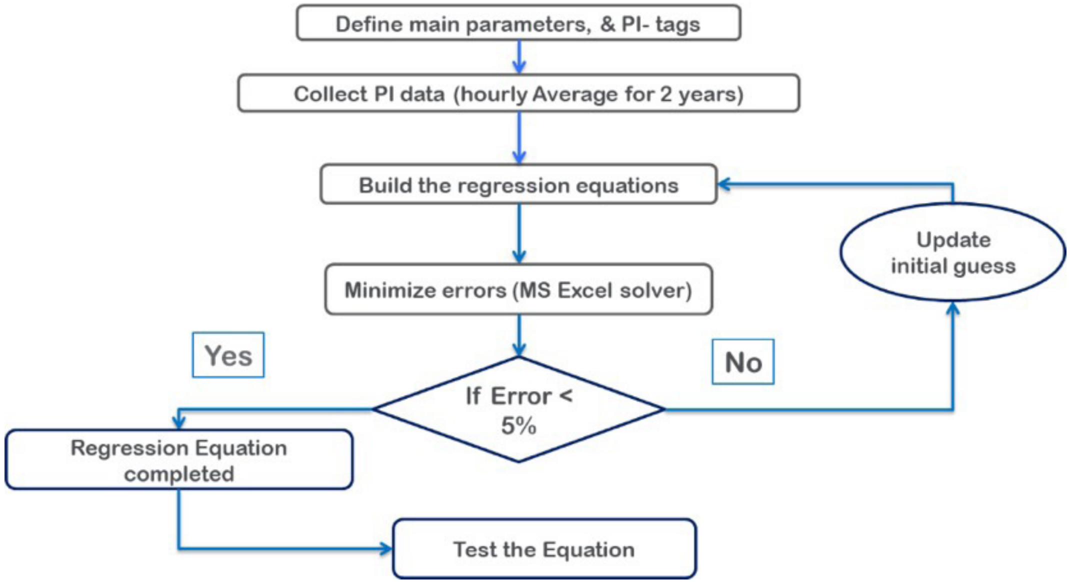

Figure 1. Linear Regression Analysis Process Flow Chart

long as the input and output streams and operating parameters described above remain same.

CASE STUDY

The facility used for this case study is producing dry crude oil, condensate and sour gas as its products and uses electric power and fuel gas as its energy input. Figure 2 provides an overview of the feed, products and energy streams. The facility generates electricity and steam by two cogeneration units. The high pressure (HP) steam generated from HRSGs (heat recovery steam generators) passes through STGs (steam turbine generators) to produce additional power. Medium pressure (MP) steam is then extracted through MP header. Additional MP steam is also produced from boilers, which is then used for crude stabilization.

As explained earlier, the regression model has two steps; demand side energy and supply side energy. It is highly important to differentiate between them to establish the regression equations for demand-side first and then calculate the supply-side energy.

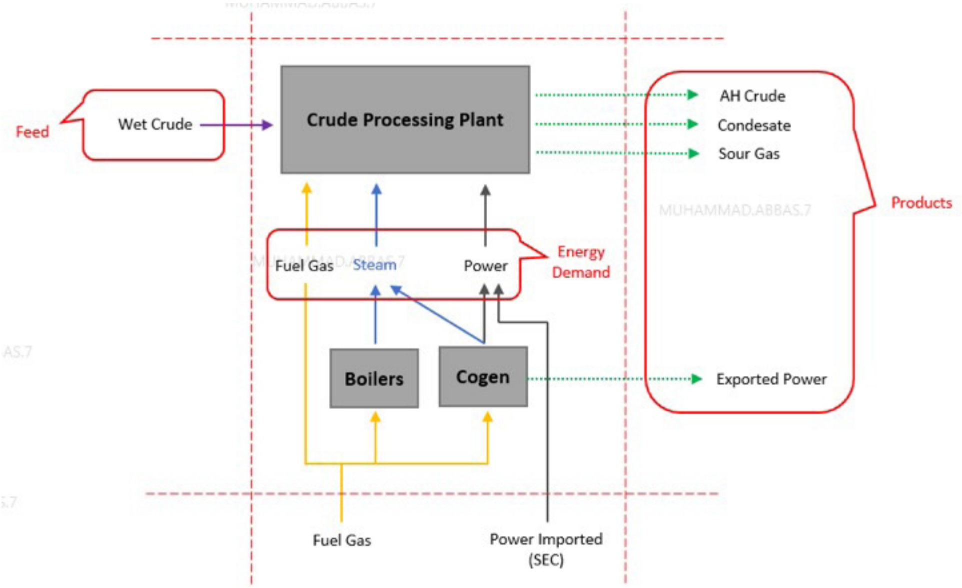

Figure 2. Crude Processing Facility Streams Summary

Data Cleaning and Filtration

Raw data were filtered and cleaned before developing regression equations for any dependent stream. The data cleaning comprised removal of missing data fields, erroneous values, duplicate instances, and outliers [5].

Demand Side Energy Equations

The demand-side energy is the direct energy that is used to process the facility's feed. It has a direct impact on the process streams. Following were the energy demand streams involved in this case study.

Power Consumption Demand (MW)

Power demand comes from the gas oil separation plants, gas compression and treatment facilities, water treatment system, plant utility water system, cooling water system, instrument air and utility air, nitrogen facilities, water injection system, water oil separators, crude shipping pumps and crude booster pumps.

Power demand (MW), a dependent variable, was estimated from the linear regression shown in Equation 1.

$$\begin{aligned}\text{Power Demand}&\\ \text{(MW) Fit} &= [(\text{Dry Crude}) * (\text{Coefficient 1})]\\ &+ [(\text{Sour Gas}) * (\text{Coefficient 2})]\\ &+ [(\text{Water Injection}) * (\text{Coefficient 3})]\\ &+ [(\text{Ambient Temperature}) * (\text{Coefficient 4})]\\ &+ \text{Constant} \qquad \text{(Eq 1)}\end{aligned}$$

Last 2 years' power consumption hourly data were used after filtering out any abnormal entries including shutdowns, faulty meter readings, etc. The coefficients and constant in Equation 1 were obtained using the Microsoft Excel Solver. Power demand fit obtained from the developed regression equation and actual last 2 years' power demand are plotted in Figure 3. The iterations were repeated until the error was less than 5%. Actual average power consumption (demand) for crude processing facility is 79.7 MW. Average power consumption achieved through regression equation was 81.7 MW.

Process Steam Demand (lb/h)

Medium pressure (MP) steam is used for crude stabilization as well as for deaerators. This MP steam is mainly extracted from the HRSGs, and the remaining steam demand is fulfilled through the boilers. The cogeneration facilities include two trains of combustion gas turbines generators and one

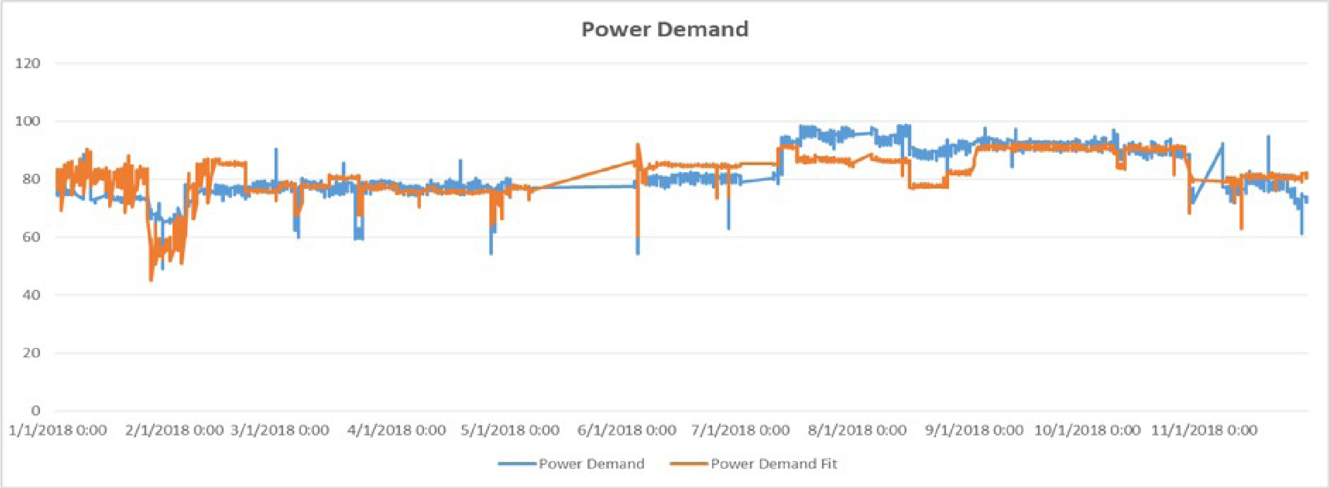

Figure 3. Power Demand Fit

steam turbine generator train (STG). Facility's steam system also carries excess steam for contingency purposes. Last 2 years' hourly data is trended in Figure 4 against the steam consumption fit obtained through the linear regression shown in Equation 2.

$$\begin{aligned}&\text{Process Steam}\\ &\quad\text{(lb/h) Fit} = [(\text{Dry Crude}) * (\text{coefficient 1})] + \text{Constant} \qquad \text{(Eq 2)}\end{aligned}$$

Supply Side Energy Equations

After establishing the demand side parameters, sources for the energy demand are identified. This is called the supply side energy. The following are the major sources of supply side energy for the facility under study:

Cogeneration Power and Steam

Power and steam are generated by the two trains of combustion gas turbines (CGTs) generators and two steam turbine generators (STG). Power generation from the cogeneration units is associated with the cogeneration loading as well as the site ambient temperature. Linear Equation 3 was used to find the power generation fit. Last 2 years' actual power generation from cogeneration units was trended and compared against the power generation fit obtained through the regression Equation 3.

$$\begin{aligned}&\text{Cogeneration Power Generation}\\ &\quad\text{Fit (MW)} &&= \{[\text{Actual load (\%)}] * (\text{Coefficient 1})\}\\ & &&+ [(\text{Ambient Temperature}) * (\text{Coefficient 2})]\\ & &&+ \text{Constant} \qquad \text{(Eq 3)}\end{aligned}$$

Steam generation from the cogeneration units is associated with generated power, and is directly proportional to it. Actual steam generated in the last 2 years was plotted against the steam generation fit through the regression Equation 4. Figure 5 reflects a plot for predicted cogeneration steam vs. actual cogeneration steam.

$$\begin{aligned}&\text{Cogeneration Steam}\\ &\quad\text{Generation Fit} &&= [(\text{Cogeneration Power}) * (\text{Coefficient 1})]\\ & &&+ \{[\text{HRSG Diverter Pos. (\%)}] * (\text{Coefficient 2})\}\\ & &&+ \text{Constant} \qquad \text{(Eq 4)}\end{aligned}$$

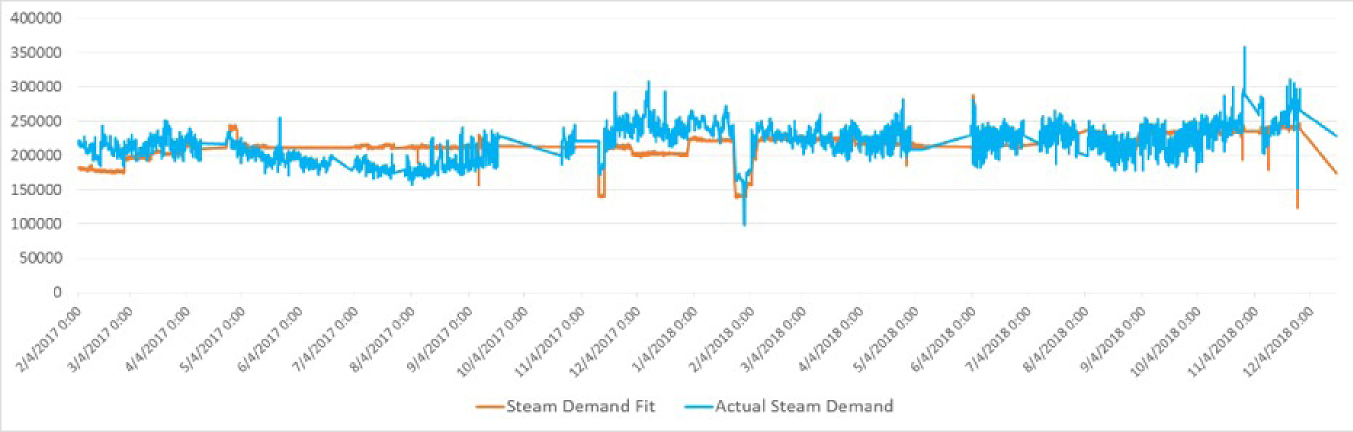

Figure 4. Steam Demand Fit

STGs Power Generation

Steam from HP header passes through two STGs to generate power, which was determined from Equation 5. Figure 6 reflects a plot for predicted STG power versus actual STG power.

STG Power Generation Fit
(MW) = [(Cogeneration HP Steam Generation
− HP to MP Letdown Flow) * (Coefficient 1)]
+ [(Extraction Steam) * (Coefficient 2)]
+ Constant (Eq 5)

Cogeneration Fuel Gas Consumption

Cogeneration fuel gas consumption is mainly associated with the power generation. There is a separate flow meter to measure the fuel gas being consumed by the CGTs. CGT fuel gas was obtained by Equation 6. Figure 7 represents actual fuel gas versus fuel gas fit using regression Equation 6.

Cogeneration Fuel Gas Fit
(MMSFD) = [(Cogeneration Power Generation) * (Coefficient 1)]
+ [(Intake Air Temperature) * (Coefficient 2)]
+ Constant (Eq 6)

Boiler Steam Generation and Fuel Gas Consumption

Boiler steam generation is mainly acting as balance steam between the steam generated by other sources such as heat recovery steam generation (HRSG) and the steam demand (identified in the demand side). One boiler normally operates at minimum load and the second boiler is turned off at current operating conditions.

Energy Intensity Calculation

Based on the predicted data for demand side and supply side energy, the net required energy consumption was calculated to produce the desired quantities of products. Forecast energy intensity (EI) was then calculated, for each quarter of 2018, using Equation 7.

Energy Intensity
(MBtu/BOE) = [Net Energy Consumption (MBtu)]
/ [Production (BOE)] (Eq 7)

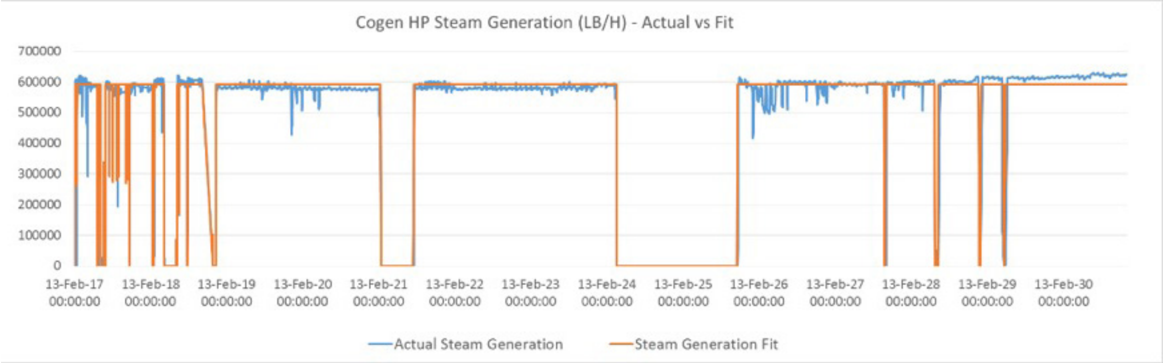

Figure 5. Cogeneration Steam Generation Fit

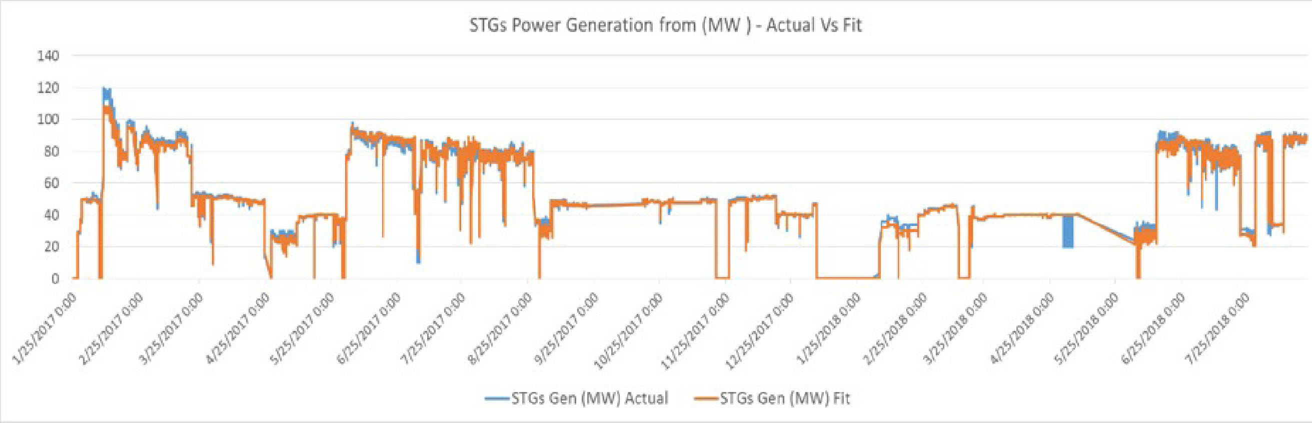

Figure 6. STG Power Generation

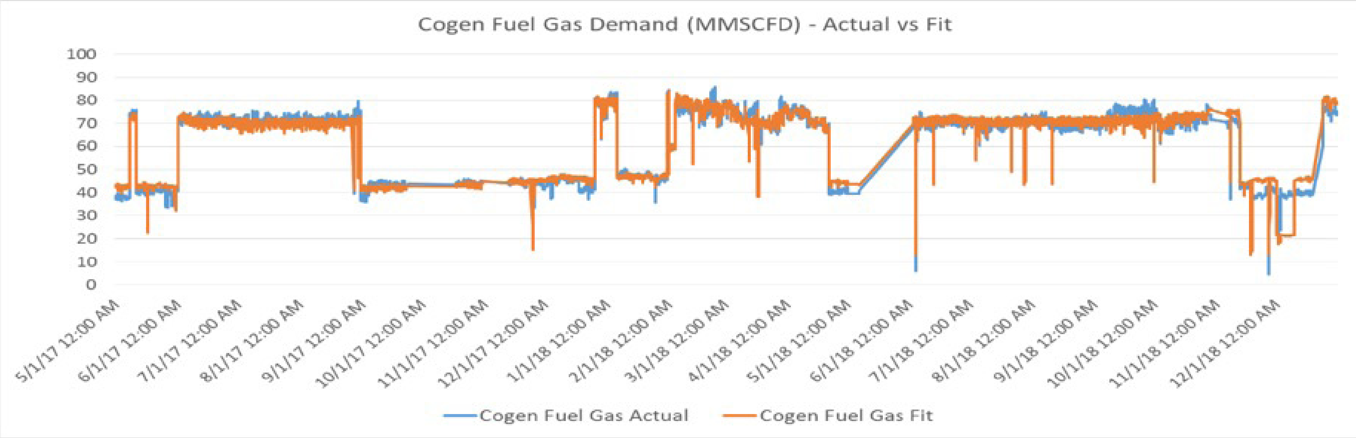

Figure 7. Cogeneration Fuel Gas Consumption

where BOE = barrels of oil equivalent of production i.e., all production quantities are converted to a common unit using the benchmark heating value of reference crude (5,800 MBtu/h).

The predicted value of EI was compared against the actual reported EI for each quarter to validate the accuracy of estimated quantity, which was calculated using the developed regression equations. Production (denominator) in Equation 7 was kept constant for both predicted and actual EI calculations. The final results for the EI comparison are provided in Table 1.

Table 1. Forecasted versus Actual Energy Intensity

Quarter		Energy Consumption [10^6 Btu/h]	Energy Intensity [1000 Btu/BOE]
Quarter 1	Forecast	889.75	32.99
	Actual	849.15	31.49
	Variance	4.78%	4.78%
Quarter 2	Forecast	801.5	29.13
	Actual	770.71	28.01
	Variance	4.00%	4.00%
Quarter 3	Forecast	835.98	29.24
	Actual	858.98	30.05
	Variance	-2.68%	-2.68%
Quarter 4	Forecast	785.45	27.65
	Actual	760.37	26.76
	Variance	3.3%	3.3%

CONCLUSIONS

A linear regression model is an effective and simplistic approach to predict energy demand against pre-set production targets. The development of regression equations is primarily dependent upon the availability of at least 12 to 24 months of old historical data, of dependent and independent variables. The biggest challenge during the case study was to filter and clean the data. Because of the process variability and upsets, the data was skewed for certain periods not representing the normal operation. Furthermore, ambient temperature plays a significant role in both energy consumption and generation, and hence should be considered as one of the independent variables. Facility operators' discretionary operating modes are also reflected in the data as varying pattern from the normal operation, and data sectors relevant to such period were removed during data cleaning. The validation of the final regression equations was performed by comparing the demand and supply side energy variables such as power and steam generation, and fuel gas consumption against the actual reported data for last 2 years. A variance of less than 5% was obtained for all the above mentioned dependent and independent variables individually as well as for overall facility's energy intensity.

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Evolving Utility Rate Design*

Edward J. Regan, P.E.

ABSTRACT

Customer choices are changing electric and gas utility load shapes and revenues. The drivers for change include the increased market penetrations of new or improved demand side management (DSM) technologies; distributed energy resources (DER) such as renewable energy and combined heat and power (CHP); and energy storage (ES). In response, utilities are beginning to reformulate their basic tariffs and are developing new regulatory constructs, which are beginning to show up in ratemaking dockets across the country. Rate designs are evolving based on advanced metering infrastructure (AMI) and bi-directional communications for electric, water, and natural gas delivery. These technologies enable new designs for hourly and seasonal production cost sensitive tariffs, such as time-of-use (TOU), critical peak period pricing (CPP), standby, and demand response (DR) tariffs. Regulatory proceedings in the news include the discussions and controversies that have surrounded solar photovoltaic (PV) net metering, standby rates for CHP, and Federal Energy Regulatory Commission (FERC) Order 841 that requires that the "value of energy storage" in wholesale markets be fairly compensated. Energy managers need to be forewarned about the potential sea changes in tariffs being considered by utilities, even if only to help them be prepared to seek win-win solutions and regulatory relief. This article will describe the consequences of new levels of DSM and DER on utility operations and revenues, and review how retail tariffs and ISO/RTO (independent system operators/regional transmission organizations) structures may evolve to accommodate the changing energy landscape.

INTRODUCTION

Utility ratemaking is a balance between revenue requirements and expected customer behavior. Rate designs are further tempered by regulators' policies related to reasonable profits, equitability among ratepayers, and efficient re-

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source use. Utilities have accepted limitations on earnings, commercial practices, and accepted an obligation to serve in exchange for obtaining the status of a natural monopoly. As natural monopolies, in the past, utilities have an obligation to serve but enjoy a regulatory contract with guaranteed rates of return and exclusive service territories. Monopoly rate designs have evolved since the late 1800s based on available metering technology, and what was then the nearly inescapable economy-of-scale advantage of centralized utilities. Since the late 1970s, the advantages of being a natural monopoly have been eroded by new requirements for competition and energy conservation. These challenges included open access to natural gas pipelines and electric transmission lines, requirements to allow independent power producers (IPPs) and cogeneration, and requirements to promote energy efficiency [9]. The imprecision of economic signals inherent in rate designs and the available metering technology of that time led to regulatory requirements for utilities to incentivize customers to adopt technologies beneficial to all ratepayers, promote energy conservation, and institute a number of relatively crude rate designs, such as increasing block rates [1, 2, 5, 13]. Competition, energy efficiency, and distributed energy resources have fundamentally changed the business model for utilities.

Energy policies have progressed to allow competition at a retail level, transparent energy markets, independent system operators/regional transmission organizations (ISO/RTOs), and technological advancement that allows customers to provide their own electric production and capture waste heat. Some of these technological advancements include advances in small turbines and reciprocating engines, combined heat and power systems (CHP), renewable energy, especially solar photovoltaic (PV), advanced metering technology, power electronics and smart inverters, appliance efficiency and control improvements, and the ability to arbitrage variable utility production costs with energy storage.

RATE DESIGN BACKGROUND

The changing patterns of energy consumption are indisputably problematic for utilities, and new rate designs will be required going forward. Underlying the analytic basis for new rate formulations are four fundamental ingredients:

- Cost allocation;
- Metering and control technology;
- Revenue risk management; and
- Customer and regulatory acceptance.

Cost Allocation

The heart of all electric rate design is the allocation of various categories of power supply costs to customer classes and to various categories of resource use. The three main categories of resource use for electric rate design are:

- Fixed costs for customer service, administration, and billing;
- Fixed costs for transmission and distribution (T&D) and generation capacity;
- Variable costs for power production and operations (fuels, chemicals, operations staff etc.).

It is worth noting that a significant proportion of electric power supply costs are the direct result of facilities needed to reliably meet peak demands and are largely fixed costs. Rate designs for natural gas utilities also have three major categories of cost allocation, with transmission and distribution pipelines instead of wires and gas, and commodity costs instead of power production. Because of the compressibility of natural gas, up until very recently retail gas metering has not typically measured peak flow rates, and retail rates do not address hourly peaks.

A considerable amount of judgment goes into cost allocations, which then forms the basis of the prices set for each element of an applicable rate. Some of the judgment calls include assumptions concerning economies of scale (especially for allocating shared T&D costs among customer categories), the contribution of a customer class to diurnal and seasonal production cost variations, how to consider long-run marginal costs as well as current embedded costs; and the effects of weather and fuel costs. The earliest forms of metering and load research technology required sweeping assumptions and broad categorization of cost allocations, resulting in relatively simple rate structures. Furthermore, customer load factors within a class tended to be more uniform than today, because there were fewer alternatives to centralized power. It was also easier for customers to understand bills that recovered both fixed and variable costs from a single kilowatt-hour (kWh) charge, than to understand bills based on two measures for what to them seems to be the same service! The fact that 1 hour a month was totally affecting their cost per unit energy does not lead to customer satisfaction, which has important political and regulatory implications

New metering technologies, coupled with policy emphasis on the design of price signals to promote resource use efficiency, have resulted in utilities' increased exposure to revenue risk inherent in certain rate designs. On top of that, increased levels of competition, customer self-generation, and improved appliance efficiency have slowed the growth rate of sales for electric utilities. Sales growth can compensate for pricing errors and stranded costs, but with less growth, these risks are greater.

Meter Technology and Cost-Causation

Edison's 1882 Pearl Street Station in Manhattan was the first commercial retail electric service in the USA, and costs were allocated to customers on the basis of light bulb counts [7]. Edison recognized that some customers left lights on longer than others, raising the cost for everyone, which led him to patent a relatively crude electro-chemical device to meter sales by the weight of chemical change. Electro-mechanical induction meters capable of measuring energy use and demand were invented by 1899, but first standards for meter accuracy were not adopted in the USA until 1931. Because of the expense of demand meters, flat rates per kWh were applied to most accounts, with monthly demand charges applied only to the largest accounts. This introduced the recovery of fixed charges as a function of energy usage, a practice that persists and is problematic today.

In the 1970s, electronic metering was introduced and by the mid 1980s it was economically feasible to implement time-differentiated rates using meters that had separate registers for energy and demand in various blocks of time (also called time bin metering), or even as continuous interval metering. As a result, it has become possible to much more completely characterize an individual customer's load profile and more nearly match revenue to cost causation.

Revenue Risk and Elements of Rate Design

Along with costs, rate designs employ assumptions about market and customer behavior and thereby inadvertently assign revenue risk to either customers or to the utility. Perhaps the most significant cost risk for a customer is how well the customer's load profile matches the load profile that forms the basis for the applicable rate design. Load profiles can be parameterized in a number of different ways, such as with load duration curves or with a ratio called a load factor. The load factor for any customer, or even an entire service area, is calculated by dividing average demand by peak demand for a specific time interval. The average demand is cumulative kWh divided by hours in the same period. The higher the load factor, the more nearly flat the load profile is. If a customer's load factor is higher than the rate class's average profile, then that customer is subsidizing other customers in that rate class, and vice versa. The broader the range of load factors included in a customer class, the more likely it is that individual customers are exposed to up and downside risk, while the utility has its costs covered.

One source of revenue risk is the consequence of variation in the number of days in a billing cycle. Without AMI to allow system wide remote metering reading over precise intervals, manual meter reading is required. This is currently the case for roughly half the revenue meters in the U.S. today, and there can be an appreciable variability in manual meter reading intervals. Under decreasing block rate structures, long billing cycles disadvantage the utility, whereas short billing cycles disadvantage the customer.

Price elasticity is another source of revenue risk, especially when introducing increasing prices for various rate elements. A measure of consumer choice, price elasticity is the percentage of changed consumption per percent change in price. Although electric and natural gas consumption is generally to be considered relatively inelastic (i.e., not very price responsive) consumers do respond to retail price. Electricity is generally reported in the literature to be roughly -0.20, and natural gas a little higher at about -0.30. This factor is not set in stone across income levels or uniform through time, and adds to error in forecasting revenues.

Time and seasonal differentiated rates can exacerbate the revenue risk associated with weather, because of the allocation of substantial costs to the peak period price. Moderate weather during peak periods saves customers money but results in less than expected revenues for the utility. Severe weather, leading to additional heating or cooling, can result in excess fixed cost recovery for the utility.

Then there is the revenue risk resulting from changes in load factor. A good example is net metering. Net metering was first introduced in the early 1980s to encourage customer adoption of solar PV, to a large extent in response to consumer advocacy. In its simplest form, electro-mechanical meters ran backwards when excess solar energy was exported to the grid, thus earning full retail rates designed to recover both fixed and variable costs embedded in kWh usage charges. The low market penetrations in the early days did not engender large concerns by utilities. As PV costs decreased through time and market penetrations of solar PV began to accelerate, solar PV net metering became a threat to utility revenue sufficiency and cost allocation, especially under flat rate residential and small commercial energy charges. A unique aspect of the load solar PV production places on a utility capacity is that outage or reduced production is not very diversified unless the service area is large. The call on backup power from numerous solar PV systems coincides over relatively large geographic areas, because of exposure to similar weather (e.g., cloud cover). It quickly became apparent that the incumbent utility was obligated to back up the solar PV capacity, but without the fixed cost recovery from forgone kWh sales to pay for back up facilities.

KEY DRIVERS IN TODAY'S UTILITY MARKETS

The key drivers of the need for electric utilities to change their rate structures discussed here include:

- The plateau in retail sales of electricity;
- Sales and load factor effects from the substitution of utility electrical production with customer-owned electric and thermal energy production;
- Volatility in hourly electrical wholesale costs; and the
- Growing prevalence of natural gas to produce electricity.

The key driver for natural gas utilities to change their rate structures is increased demand on existing pipeline infrastructure peak capacity. These factors have resulted in an increased interest in rate design to appropriately assign risk to customers and to recover revenues lost to DER, within the constraints of equitability and cost-causation imposed by the regulators.

Plateau in Retail Electric Sales

As shown in Figure 1, retail sales of electricity in the U.S. plateaued in 2007 [12]. Because Figure 1 includes the total U.S. economy, obviously some utilities are experiencing a decline, not just a plateau in retail sales.

Figure 2 illustrates one of the contributing causes for decreased sales, the expansion of competing electric generation capacity, in this case from renewables [11]. Additional causes for the plateau include demand destruction from the 2008 economic recession, gains in energy efficiency, and continued growth in CHP. All of these factors are exacerbating the need for rate reform to compensate for the worsening load factors associated with backing up intermittent renewable energy as well as CHP.

To the extent rate designs recover fixed costs through kWh usage charges, customer-owned DER reduces fixed cost revenues while still requiring the utility to meet customer demand when the DER resource is out of service. This puts pressure on utilities to reform net metering, dual metering, and standby rates, while encouraging transitioning toward straight fixed-variable rates, which recover costs for peak demands and energy separately. Although electric vehicles (EV) and battery energy storage systems (BESS) have the long-term potential

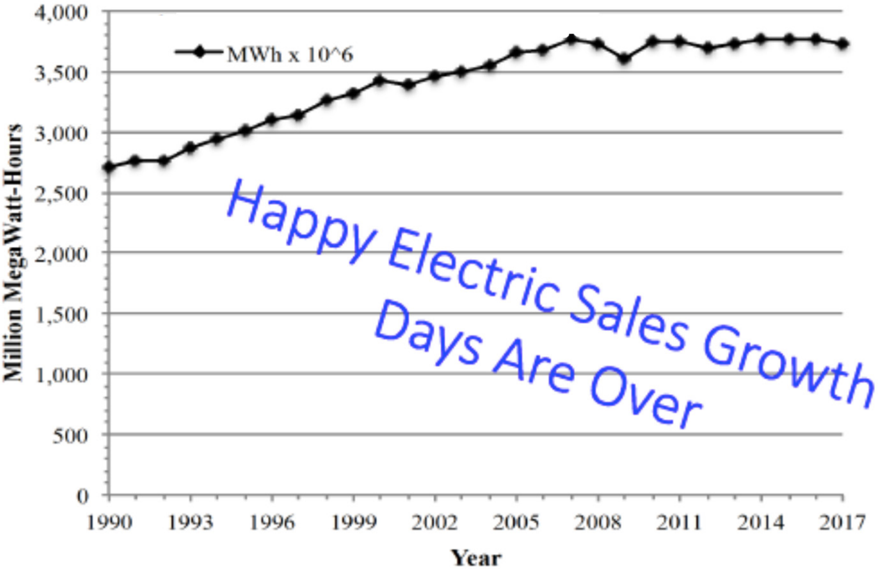

Figure 1. U.S. Annual Retail Electricity Sales Plateau

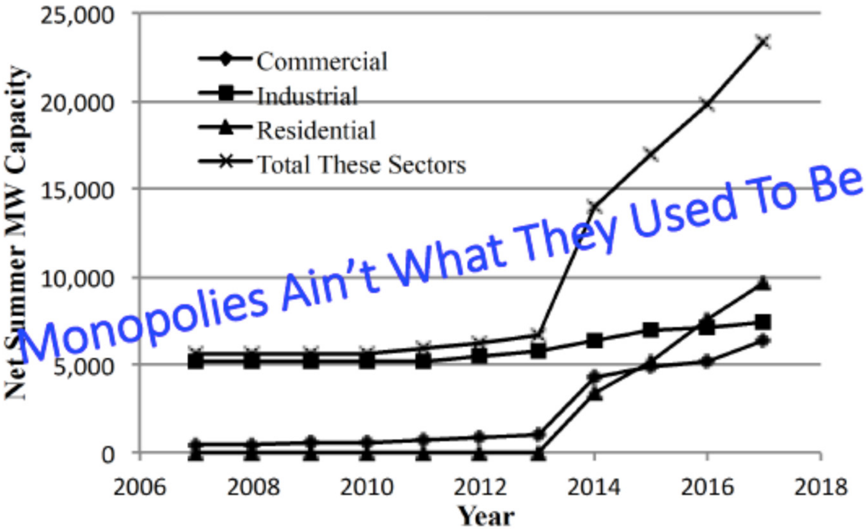

Figure 2. Growth in Private Sector Renewable Energy Generation Capacity

to be managed to improve load factors, more near term strategies are needed better manage their current revenue recovery risks.

Hourly Production Cost Volatility

Variation in electrical production costs adds another source of uncertainty to time-differentiated rate designs. Electrical production costs vary widely during the day as a result of loads changing and the types of units dispatched to meet those loads. They also vary day-to-day, season-to-season, and year-to-year, as shown in Figure 3 [6].

In wholesale RTO/ISO markets with market clearing prices set at the production cost of the last unit to clear the market, and with locational marginal pricing (LMP) to clear congestion, diurnal volatility appears to have become even more pronounced under periods of relative capacity shortage. In the past, applying load factors for various customer classes that were defined by amount of consumption was acceptable for rate development given the available metering technology, and is still a common practice today. This ignores the significant variability of load profiles within each class of customer, effectively shifting revenue risk from poor load factor customers to other customers in the rate class. Modern metering technology now allows an individual's load profile to be measured directly. Assigning costs to the various "time bins" developed for a specific TOU rate in turn transfers risk back to the utility.

Accelerated Natural Gas Consumption

The radical drop in prices for natural gas in 2008 attributed to fracking, combined with ever more efficient combined cycle generation technology as well as the numerous environmental benefits of using natural gas, have resulted in the accelerated use of natural gas throughout the U.S. economy. This acceleration is shown graphically in Figure 4 [10]. As a result, many pipelines are nearing capacity, especially during winter months. The use of rate structures to improve pipeline throughput by managing storage capacity (in line-pack as well as in-ground storage) is gaining increased attention.

RATE DESIGN AND IMPLEMENTATION TRENDS

Utility rate design proposals in the recent literature encompass three basic strategies. The first is to increase revenue stability with fixed monthly charges, minimum monthly charges, or even the introduction of subscription rates. The second is to decouple fixed cost recovery from usage volumes, through movement toward straight-fixed variable (SFV) rates, standby rates, dual metering

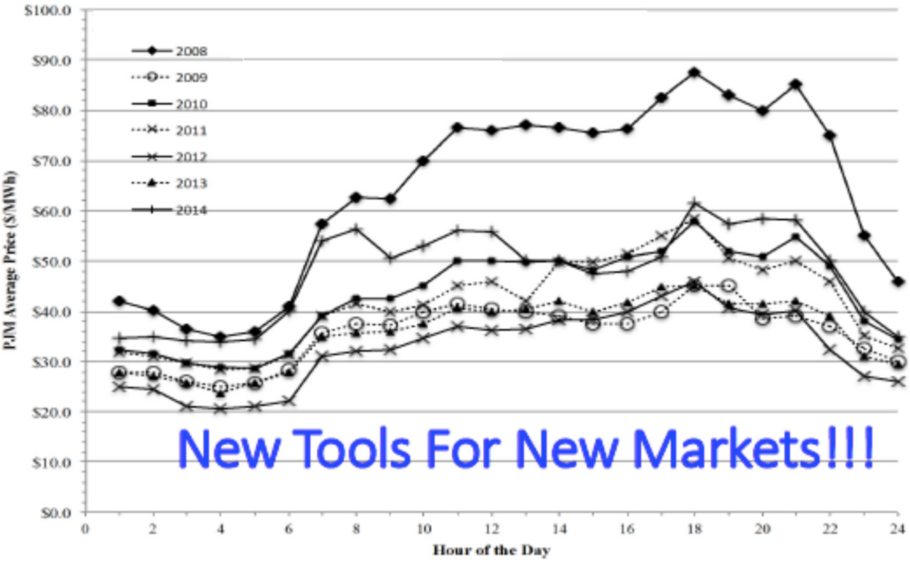

Figure 3. Hourly Average Electricity Production Cost Volatility Year-to-Year in PJM's RTO/ISO Market

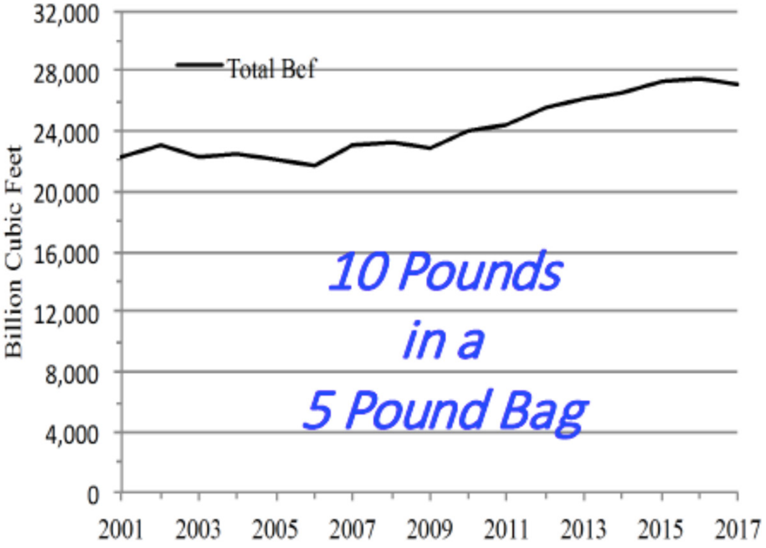

Figure 4. U.S. Annual Retail Natural Gas

of renewable energy, and out-and-out decoupling of revenues from usage. The third strategy is to bring base production cost risk directly to the customer and leave the choice to them [2, 4, 8].

Increased Customer Charges and Minimum Bills

Until recently, monthly customer service charges have largely been designed to just cover costs for metering, billing and administration. Monthly service charges are inherently non-volatile and present low risk. A quick fix for revenue volatility is to increase fixed monthly charges, for example, to include the fixed costs of distribution capacity serving a particular customer. A variant is to charge for a minimum level of consumption, regardless of the actual consumption. Because minimum bills not only stabilize utility revenue, it also creates up-side risk for the utility (downside for the customer). Resistance to increasing fixed monthly charges has stemmed from the effects on low-income customers and its disincentive for energy conservation as a result of reducing the cost per discretionary unit energy consumed [8].

Subscription Rates

A novel extension of the concept that has been proposed in the literature is called a "subscription service," modeled after Internet and video service concepts, such as Xfinity, Netflix or Amazon Prime [3]. A subscription rate has certain attractions for customers, as demonstrated in telecommunication industries, especially the notion of a known monthly charge. An interesting aspect of this proposal is that it creates bilateral risk, for both the
customer and the utility. Heavy use has an upside for the customer (lower average cost per kWh) and is a downside for the utility (lower revenue per kWh), and vice versa for light use

Straight Fixed Variable Rates (SFV)

SFV rates take the notion of cost allocations to the extreme, with as close as complete assignment of fixed costs (including transmission and distribution) to demand charges and variable costs to energy charges. The customer's monthly demand and energy is metered and billed accordingly. This overcomes some of the objections to merely increasing monthly fixed charges because customers have control of their appliances. A variant of SFV commonly used by joint action power supply agencies is to use the coincident monthly peak demand for setting demand charges, thereby improving price equity and avoiding cumulative demand charges in excess of actual peaks. Basing charges on coincident peak demand does require continuous interval AMI metering.

Standby Rates

The obligation under the 1978 Public Utility Regulatory Reform Act (PURPA) to allow cogeneration led to the development of standby rates for those times when the cogenerator was out of service. Although most stand-by rates do not go to this extreme, a stand-by tariff designed to recover all the fixed costs for capacity at a particular customer's premise would result in the customer paying for capacity twice (utility and the cogeneration capacity) with only the value of any fuel and heat rate differences and the value of the ability to use waste heat. The use of CHP would be best enabled when standby rates are set upon coincident outage probabilities instead of norm demand load profiles.

Dual Metering

As history proved, solar net metering was a successful policy for promoting the use of solar energy. It is inescapable that any solar PV energy used behind the meter provides cost savings to the owner at the retail rate applicable to the customer at the time of consumption, whereas the price paid for excess energy sold to the grid is subject to other considerations. Not only are fixed costs for the capacity required to backup the solar system not recovered by forgone revenues from forgone kWh sales, but purchase of PV output further reduces revenue sufficiency from customers with solar capacity. In addition, State and local governments lose tax and surcharge revenues levied against billed charges. An alternative strategy for managing solar PV is dual metering. Under this decoupling strategy, the customer sells all of the solar PV production directly to the utility at an established price. All the customer's consumption is purchased from the utility and subject to retail tariffs, local taxes, and surcharges, thus protecting State and local revenues. The price paid for the solar PV energy could range from: a high value typical of feed-in-tariffs set to match the cost of solar PV production; to tariffs set to recover the value of solar capacity (VOS); or to a low rate based on the avoided variable cost [e.g., fuels and generation operations and maintenance (O&M)]. The outcome of VOS studies often depends on how the value of externalities is treated, which is by no means standardized across the U.S. However, setting the price paid for solar energy at less than retail incentivizes creative ways to use the solar PV energy behind the meter, for example using microgrids and battery systems.

Rate Decoupling

Decoupling insulates overall utility revenues from sales volume, by allowing automatic rate changes in proportion to sales to ensure revenue requirements are met. This reduces utility risk by assuring that revenue requirements are met regardless of weather, competition, alternative energy sources or market conditions. In some cases, automatic fuel adjustment charges are a limited form of decoupling. This is not a symmetric assignment of risk between the utility and its retail customers.

Load Management, Critical Peak Pricing (CPP) and Demand Response (DR)

One way to manage revenue risk and system reliability is to directly control the amount of load at any particular point in time. Of course, rotating blackouts could achieve this objective, but this is a very disruptive measure to take. One alternative is to offer a discount if the customer allows the utility to control certain target loads, such as hot water heaters or air conditioners, either for economic (CPP periods) or reliability reasons. The thermal aspects of target loads in theory makes short term "off cycles" transparent to the customer. In practice however, managing these appliances for a prolonged period has proven to lead to customer dissatisfaction and eventual departure from the program. Offering customers the ability to "opt out" during critical peak pricing periods is a variant of load control that is much more acceptable. DR is almost the inverse of load management, in that it allows customers to effectively "sell" load reductions or fuel use switching depending if the CPP offered is sufficient incentive. ISO/RTO capacity markets allow DR to be bid into capacity and energy markets.

Curtailable and Interruptible Rates

Curtailable and interruptible rates have been around for along time, but are likely to become more frequently exercised in the future, especially for natural gas. Often these rates include an economic "ride through" option, which is the price the customer is willing to pay to avoid curtailment or interruption.

BATTERY ENERGY STORAGE SYSTEMS (BESS)

Electric utilities have used the potential energy of elevated water to store energy for electricity production for years, using dams and pumped storage reservoirs. Natural gas utilities have used line pack (pressurization of gas pipelines) and underground storage (in geological formations such as salt domes) for years as well. More recently, the chemical storage of electric energy in battery systems has dropped in price to the point that deployment for utility applications, ranging from kilowatt-hours to megawatt-hours, has become economic for certain applications.

Combined with the appropriate inversion and control equipment, BESS has value to utilities and independent power producers (IPPs) in terms of energy arbitrage, firming up intermittent sources of renewable energy, and ancillary services such as voltage, power factor, and frequency support. Accordingly, IPPs and marketers are interested in bringing BESS into RTO/ISO markets for sale to utilities. The value of BESS for energy arbitrage can change widely for season-to-season and year-to-year. As shown in Figure 3, storing a MWh from the lowest annual average hour to selling it at the highest annual price hour varied from a 121% increase in price in 2008 to a 47% increase in price in 2011. Given this variability in the value of energy arbitrage, additional revenue potential from the recognition and use of EES for ancillary services as well as energy arbitrage is quite important to allow ESS investments to be cost-effective.

In response to IPP and marketer concerns, in 2018 FERC issued Order 841 to remove barriers for ESS to participate in wholesale capacity, energy, and ancillary services markets. More specifically the FERC requires ISO/RTOs to allow ESS to be dispatched, to buy/sell at the wholesale market LMP (locational marginal pricing) clearing price, allow bidding to account for ESS's operation characteristic, and to set the minimum size requirement at 100 kW.

On the other hand, customer applications of ESS behind the meter can also threaten utility revenues. For example, unless retail or better payments for solar PV energy are available, ESS systems help to maximize the value of solar production by smoothing short-term fluctuations and storing output to use at night. More sophisticated systems go a step further, and optimize the economic value of the PV output by timing usage and resale to the grid based on load profiles, TOU rates and CPP.

CONCLUSIONS

Electric utilities have historically allocated both fixed and variable revenue requirements into the prices for various elements of rate designs. For decades these designs have been successful in achieving revenue recovery and customer acceptance for the utility while employing available and cost-effective metering technology.

Recent acceleration in the deployment of customer-owned DER facilities, and improved DSM and appliance technologies, has led to worsening load factors and diminished sales expectations, which has caused electric utilities to be concerned about recovering fixed costs embedded in usage rates. A significant factor causing concern is the inadvertent back up for DER provided by the incumbent electric utility.

The increased use of natural gas for electric production, both by utilities and for customer-owned DER, and the resulting need to better manage existing pipeline capacity is likely to result in growing installation of demand meters and demand tariff designs, with new emphasis on curtailable or interruptible rate designs and incentives to better schedule line pack and other forms of natural gas storage.

Although there are at least two electric end use appliances that might work to improve load factors (electric vehicles and energy storage), utilities have begun to develop and employ strategies to better manage their revenue recovery risks. AMI, two-way communications, and new cost allocation methods are being applied to develop DR, and DER sensitive rate designs. New strategies being considered, or even deployed, include increased monthly fixed cost recovery, movement toward SFV rate designs, coincident versus peak demand rate structures, and time differentiated rates. In particular, how diversity of DER outages and production cost volatility are used in rate designs can have significant affect on the pricing of standby, CPP, and DR rates.

New tariffs and rate designs will present both problems and opportunities for energy managers. The first step of an energy manager toward protecting the interests of the facility is to be aware of, intervene, and potentially take advantage of rate restructuring initiatives by utilities. Energy managers should never forget that customer perspectives are important to regulators.

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Roles of Combined Heat and Power In a Commercial Near-Zero Net Energy Demonstration*

Joe Y.S. Shiau, PE, CEM and Jason H. Wang, PE

ABSTRACT

Southern California Gas Company (SoCalGas), Brookfield Residential Properties, and the Los Angeles Department of Water and Power (LADWP) partnered to demonstrate a commercial near-zero net energy (near-ZNE) project (the resort) in Playa Vista, California, USA. This case study presents the 3-year test results following up previous publications (Shiau and Wang 2018, 2017, respectively). The results indicate that the energy efficiency and environmental benefits of a high performance and LEED (Leadership in Energy and Environmental Design) Platinum® building can be further enhanced by incorporating a variety of energy efficiency measures and self-generation, including combined heat and power (CHP) and photovoltaics (PV).

The resort is a 25,000 square-foot resident club with fitness rooms and ancillary outdoor swimming pools. It is LEED certified 2009 Platinum® for New Construction and features passive ventilation, green roofs, variable refrigerant heat pumps, natural-gas-fired water heaters, space heaters and pool heaters. The facility has onsite generation including a 62.5-kW PV system for assigned loads. A 75-kW CHP system serves the remaining loads, which are separately metered. The CHP generation output to the grid is limited by the assigned electric load.

The main building energy use was modeled for 2010 California code compliance. The facility's calculated operating time dependent valuation (TDV) of all actual loads exceeded the modeled compliance TDV, suggesting that current ZNE initiatives should consider campus-based solutions for buildings with significant operating process loads to include onsite generation credits from both CHP and PV.

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*Updated from a paper previously published in the 2018 West Coast Energy Management Congress proceedings.

BACKGROUND

California is a national leader in energy efficiency resulting from state policy, regulations, and utility energy efficiency programs funded by public benefits surcharges in utility rates. California's Building Energy Efficiency Standards (Title 24) and Appliance Efficiency Regulations (Title 20) are revised every few years. In 2008, the California Public Utilities Commission (CPUC) adopted the California Long-term Energy Efficiency Strategic Plan with the aspirational goals that all new residential construction in California be ZNE by 2020 and that all new commercial construction in California be ZNE by 2030 (CPUC 2008). In June 2011, CPU published an action plan update (CPUC 2011) for the ZNE commercial building to include stakeholder input.

In December 2017, the CPUC issued the draft commercial ZNE Action Plan (CPUC 2017) for review and comment. This draft action plan is voluntary, but sets a goal that "Beginning in 2030, all new commercial buildings and major renovations of the existing buildings achieve zero net energy performance (onsite or offsite renewables) and support grid optimization." as well as the targeted outcome: "ZNE buildings and districts are integrated as key distributed energy resources that substantially reduce carbon emissions, better meet customer needs, and create more resilient communities."

On the CPUC's website, under the subtitle "District ZNE/Grid Connected Microgrid (Onsite)," the recommended tools for commercial ZNE include "multi-faceted distributed energy system onsite, connected to the grid normally, but a level of self-reliance during events. May include CHP/district system."

Over the years, utilities and builders have been urged to lead voluntary efforts to transform the market by demonstrating pilot projects and publishing case studies. This project at The Resort answered this call to action, and after more than 3 years of continuous operation, the results are very positive and consistent with the spirit and aspirations of the Action Plan and supportive of California's goals.

Recent California ZNE Initiatives

In a May 9, 2018 news release, the California Energy Commission (CEC) announced it would adopt building standards (CEC 2018) that require solar PV systems, to reduce new home energy use by more than 50% starting January 2020. This requirement is a first in the nation. To support this change, CEC staff indicated that the compliance calculation software models are being revised and expected to affect the future architectural design and compliance options significantly. Residential ZNE and commercial ZNE share similar, although not identical, technological solutions and obstacles in compliance. The progress in residential ZNE initiatives is expected to be seen in commercial areas in similar steps or in variations later.

TDV is the common compliance measure for both residential and commercial buildings. Code compliance traditionally counts the energy budget and credit for each building separately, because TDV among multiple buildings in the same project or campus sharing a district energy plant may be difficult to separate and enforce. TDV credit from onsite generation or waste heat recovery, and negative TDV from process loads have not been part of the compliance before.

Challenges and Discussion

A few common challenges for both commercial and residential ZNE building designs and assessment of operating costs and project-economics include: (1) insufficient roof space for solar PV with capacity to support not only the baseline building permit compliance, but also the operating and added plug loads when occupied; (2) heavy process loads in exterior and ancillary systems, such as swimming pool heating and water pumping, that need robust and resilient energy sources; and (3) the potential uncertainty regarding future electric rates, such as the potential introduction of residential and commercial time-of-use (TOU) rates.

The roof space dedicated for PV at The Resort is only sufficient to support approximately 50% of the campus' peak load. The project considered other renewable energy sources, such as wind turbines, but those sources were determined to be less viable at the time, so they were not included. Thus, the design team's focus is to demonstrate the use of existing and mature technologies to show what can be achieved in energy efficiency, economics, and emissions.

District energy plants or a community or campus-based solution offer large scale of economy and optimization for both commercial and residential projects located nearby. National level researchers have renewed interest and advocated for using source-energy definition instead of site-energy definition and to include all end uses in the community (Zaleski, et al. 2018). In the owners' and tenants' perspective, merely a LEED plaque on the wall, or the initial compliance permit for the shell buildings are not enough. A zero-energy project without taking care of the associated and significant process loads would not be as meaningful as a holistic solution.

The California-specific compliance codes are geared for the initial building permits. The next revision of the codes is expected to include the credit of solar PV, but not yet the waste heat recovery or the community-based solutions, according to CEC staff. Therefore, this project explored a few avenues, and offers clues on how important the process loads are and how CHP generation can contribute as a potential next step towards ZNE.

In California, the shift of electric grid peak demand toward the afternoon and evening (i.e., the Duck Curve) is well recognized. Potential strategies are being developed to address this issue and currently include, among others, the introduction of residential TOU rates and the installation of battery storage to balance PV generation with demand. Such strategies add complexity to evaluation of system operation, operating costs and life cycle costs, and should be considered in future demonstrations and assessments.

In Reaching ZNE – Other Concerns

In California, Title 24 compliance is met if the building's modeled proposed design TDV is less than the standard design TDV. Current code, however, does not consider the contribution of renewable onsite generation or allow trading TDV credits among buildings within the same project or permit entitlement.

TDV varies with time-of-use and climate zones and represents the regional and marginal value of source energy in the selected year. Because the regional and marginal economic condition may change with time, this evolving standard may have complex implications for the building industry, which produces buildings expected to last 40 years or longer. Therefore, it is reasonable to consider the societal effects, affordability, energy diversity, and resilience of the sources. The base year TDV values for the project site location are shown in Appendix A.

The 2019 building codes (CEC 2018) will be considering the credit of onsite renewable generation as well as heat recovery in reducing the compliance TDV in the residential buildings. Whichever is implemented in 2020 may trigger a change in the design and construction trends. Codification for sharing the TDV budget and credits among multiple commercial buildings in the same campus may be beneficial.

California has an electric resource loading order (CEC 2005) to set priority in using various electric resource technologies. Among these, PV and CHP are not new, but their integration to achieve the ZNE goals is new and innovative. It should be noted that micro-CHP* integrated with solar is, so far, rare in California.

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*Micro-CHP is loosely defined by trade people as CHP with very small output capacity, such as from 1 to 30-kW, in contrast to commercial or utility size that can range in hundreds or higher kW.

THE ORIGINAL PERMIT COMPLIANCE

The compliance certificate is shown in Figure 1 to illustrate the relative energy density of various energy systems inside the building, not including the ancillary pool equipment outside.

Site Plan, Energy Flow, and Pictures at the Resort

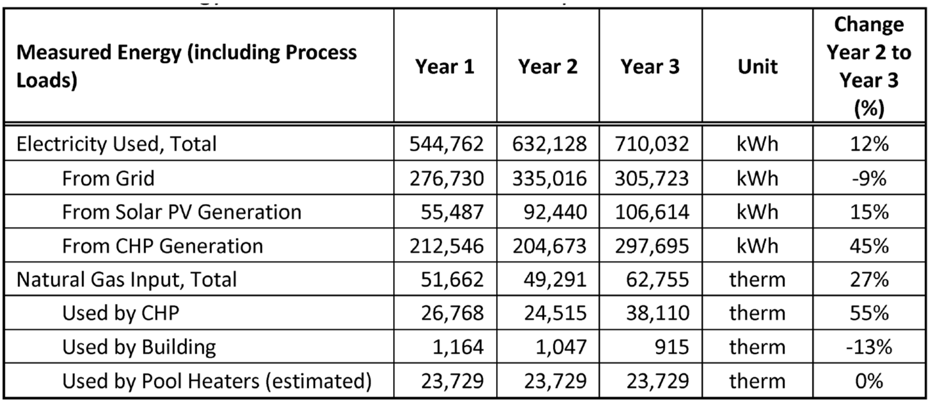
Figure 2 shows three energy sources, two electric load groups, two generation and heat outputs and flow paths using different colors. The east pools consist of a Junior Olympic size main pool, a kid pool, and a family spa, which are heated by CHP and supplemented by regular pool heaters. The west pools consist of an adult pool and spa, do not get supplemental heat from CHP.

Figure 3 shows photos of the resort. It is a recreational facility designed to serve residents of more than 2,800 homes.

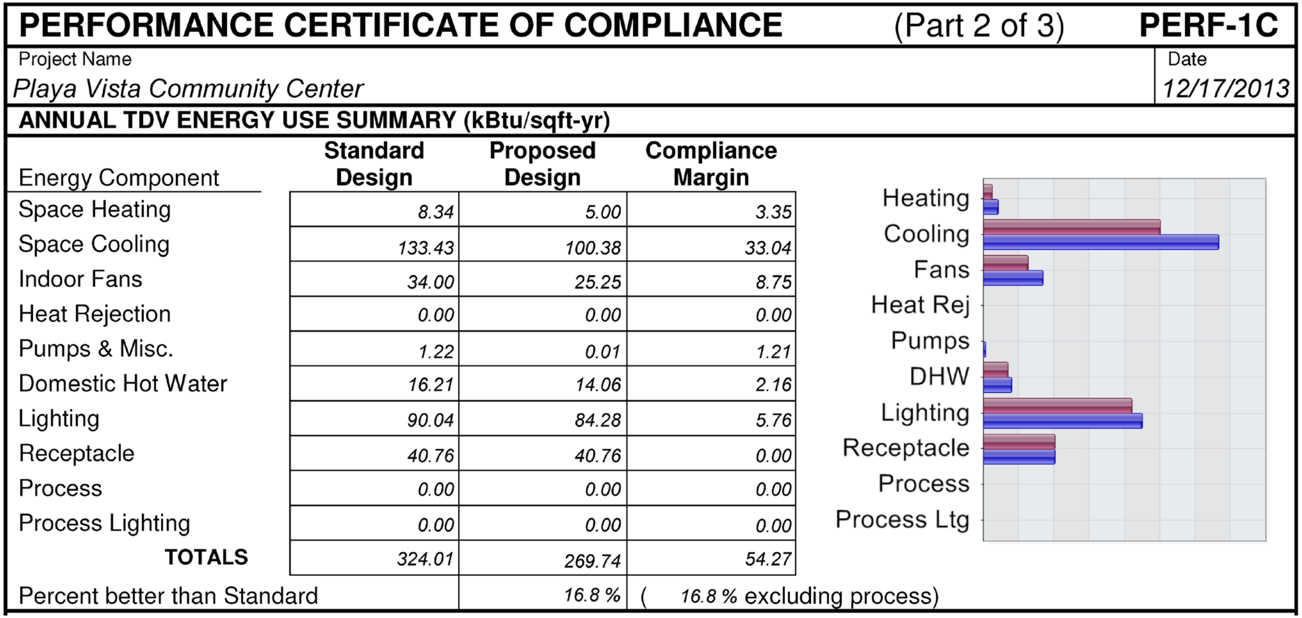
3-YEAR TEST RESULTS SUMMARY

The total energy usage as measured for the period September 2015 through August 2018 is summarized in Table 1. Year 1 is from September 2015 through August 2016; Year 2 is from September 2016 through August 2017; and Year 3 is from September 2017 through August 2018. The occupancy and total electricity usage grew every year, while the PV output increased after a blown fuse was repaired in early 2017.

Table 1. Total Energy Use and Onsite Generation 3-year Results



Measured Energy (including Process Loads)	Year 1	Year 2	Year 3	Unit	Change Year 2 to Year 3 (%)
Electricity Used, Total	544,762	632,128	710,032	kWh	12%
From Grid	276,730	335,016	305,723	kWh	-9%
From Solar PV Generation	55,487	92,440	106,614	kWh	15%
From CHP Generation	212,546	204,673	297,695	kWh	45%
Natural Gas Input, Total	51,662	49,291	62,755	therm	27%
Used by CHP	26,768	24,515	38,110	therm	55%
Used by Building	1,164	1,047	915	therm	-13%
Used by Pool Heaters (estimated)	23,729	23,729	23,729	therm	0%



PERFORMANCE CERTIFICATE OF COMPLIANCE (Part 2 of 3) **PERF-1C**

Project Name: *Playa Vista Community Center*

Date: *12/17/2013*

ANNUAL TDV ENERGY USE SUMMARY (kBtu/sqft-yr)

Energy Component	**Standard Design**	**Proposed Design**	**Compliance Margin**
Space Heating	8.34	5.00	3.35
Space Cooling	133.43	100.38	33.04
Indoor Fans	34.00	25.25	8.75
Heat Rejection	0.00	0.00	0.00
Pumps & Misc.	1.22	0.01	1.21
Domestic Hot Water	16.21	14.06	2.16
Lighting	90.04	84.28	5.76
Receptacle	40.76	40.76	0.00
Process	0.00	0.00	0.00
Process Lighting	0.00	0.00	0.00
TOTALS	324.01	269.74	54.27
Percent better than Standard		16.8 %	(16.8 % excluding process)

Figure 1. Project Compliance Baseline

Source: The Brookfield design team Rios Clementi Hale Studios and Innovative Engineering Group (Reprinted with permission of SoCalGas)

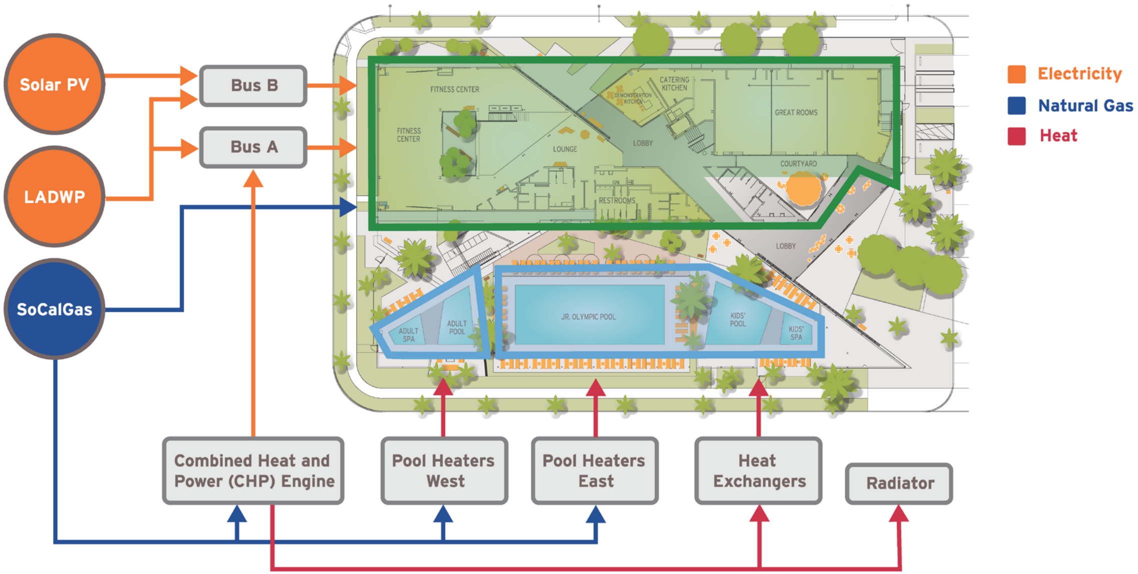


Figure 2. Site Plan: 3 East (right side) Pools/Spa are Connected to the CHP System Source: http://blog.playavista.com/wp-content/uploads/2014/08/Playa-Vista-The-Resort-Floorplan.pdf

Figure 3. The Resort with Green Roofs and PV, Interior and Outdoor Pools, and Spas. (*Continued*)

CHP Observations

The CHP run is automated with adaptive control algorithms, following electric rate schedule priority as possible, especially at high-peak and expensive periods, and preferably above 50% if possible. However, it is also limited to the assigned electric loads such that not to export. At late night as the facility is closing for the day, the CHP will stop typically. However, if there is an electric load increase above a preset threshold, the CHP will run to support this irregular

Figure 3 (*Concluded*)**. The Resort with Green Roofs and PV, Interior and Outdoor Pools, and Spas.**

load. Waste heat is a secondary byproduct and is used as available with priority set before the regular pool heaters interlocked.

Shown in Table 2, the CHP overall load factor was similar for the first 2 years and increased significantly in Year 3, which was as a result of meeting the increased electric load assigned to its dedicated electric meter.

CHP's byproduct heat is used for pool and spa heating and any excess is dumped to the atmosphere. The regular pool heaters are turned on automati-

Table 2. Onsite CHP Generation Utilization

Year	Average Output (kW)	Rated Output (kW)	Load Factor
Year 1	24	75	32%
Year 2	23	75	31%
Year 3	34	75	45%

Load Factor = (Average Output) / (Rated Output)

cally on an hourly basis if called to supplement the heat. Table 3 indicates that more than 64% of CHP heat was used in each, Year 1 and 2, but only 41% in Year 3. It should be noted that the facility has additional thermal loads that are not, but could be, served by the remaining CHP heat. Figure 4 shows the monthly heat use trends, illustrating a seasonal pattern of high usage in the winter and low in the summer. The unusual out of season peaks, are thought to be associated with operator isolating the wading pool from the CHP hot water loop, and possibly pool draining and reheating to accommodate sanitary regulations.

The pool water circulated through the heat exchangers on the CHP cooling water system is driven by the corresponding pool-filter pump. Therefore, water balancing may affect the share of the heat going to the three pools. It can be controlled and proportioned via manual valve opening positions. There were times the east kids wading pool was getting too much heat. Operators adjusted and later isolated it out. That contributed to the Year 3 heat utilization decrease from 67% to 41% shown in Table 3.

Table 3. CHP Heat Utilization

Year	Useful Heat (therm)	Waste Heat (therm)	Percentage Used
Year 1	9,581	5,346	64%
Year 2	9,328	4,569	67%
Year 3	8,401	12,094	41%

Solar PV Observations

Table 4 shows the PV output for the full year (8,760 h/yr). Because the sun is available only during the daytime without fog or clouds, the load factors are relatively lower than the CHP. Load factors in Year 2 and 3 are higher after an independent auditor discovered and repaired a blown fuse in the PV system.

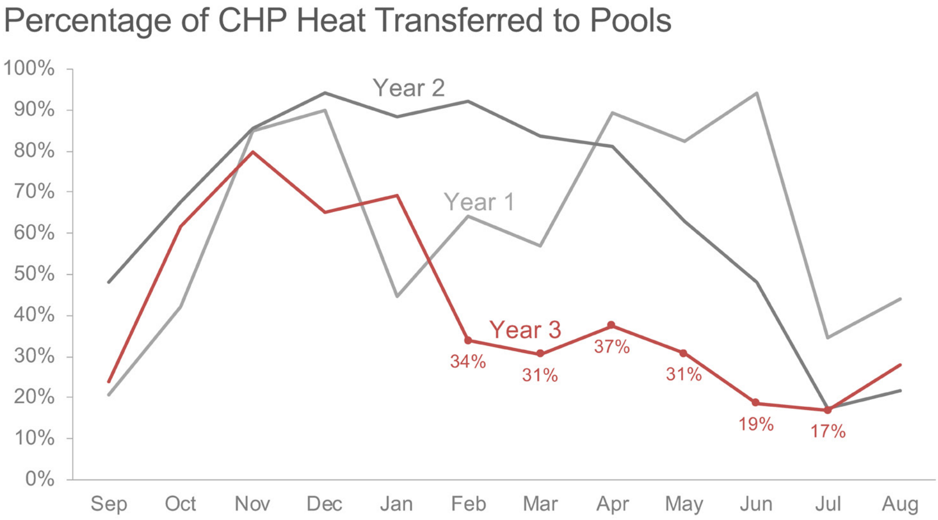


Figure 4. CHP Available Heat and Monthly Utilization

Table 4. Solar PV Utilization

Year	Average Output (kW)	Rated Output (kW)	Load Factor
Year 1	6.32	62.5	10%
Year 2	10.54	62.5	17%
Year 3	12.10	62.5	19%

TDV Analysis

The compliance baseline TDV for the main building without ancillary processes is 11,858,162 kBtu/yr as taken from the permit certificate. The incremental onsite generation resulted in the adjusted baseline, the “campus operational TDV,” including ancillary pool equipment, almost doubled that to a total of 21,822,091 kBtu/yr. The current code recognizes the building and omits the process loads, so only 54% “operational TDV” is accounted for, although the actual improvement in TDV for the campus is significantly more. See illustration in Table 5 for contributors and their relative weights.

Table 5. The 3-year TDV Summary Report

	Scenario	kBtu/yr	Difference from Baseline	Remarks
Year 1	Code Standard (2010)	21,822,091	Baseline	Main building as simulated* + Actual Year 1 process loads
	Proposed Design, 12 months	20,388,276	-6.60%	
	Total Onsite Generation	3,180,737	-14.60%	Sep. 2015-Aug.2016
	CHP	1,845,387	-8.50%	3/5 of total
	Solar PV	1,335,350	-6.10%	2/5 of total
Year 2	Scenario	kBtu/yr	Difference from Baseline	Remarks
	Code Standard (2010)	22,284,785	Baseline	Main building as simulated* + Actual Year 2 process loads
	Proposed Design, 12 months	20,832,711	-6.50%	
	Total Onsite Generation	4,064,020	-18.20%	Sep. 2016-Aug.2017
	CHP	1,809,542	-8.10%	2/5 of total
	Solar PV	2,254,478	-10.10%	3/5 of total
Year 3	Scenario	kBtu/yr	Difference from Baseline	Remarks
	Code Standard (2010)	21,964,013	Baseline	Main building as simulated* + Actual Year 3 process loads
	Proposed Design, 12 months	20,512,004	-6.60%	
	Total Onsite Generation	3,633,065	-16.50%	Sep. 2017-Aug.2018
	CHP	1,060,804	-4.80%	1/3 of total
	Solar PV	2,572,261	-11.70%	2/3 of total

Note:
* 11,858,162 was the proposed compliance TDV, without process loads (pool and gym equipment, etc.)

The Weather Dependency

Solar PV is a passive system, dependent on the available daylight, while CHP is independent and can be ramped up or down in a short time or adapted to load growth and time-of-use pattern changes over the years.

Using the weather data from Santa Monica airport, we can sort by various cloudiness and air temperature conditions. Interesting correlation results are illustrated in Figure 5.

1. As weather becomes colder, cloudy and rainy, both solar PV and CHP generation declined. CHP declined because its electric output is restricted to not to export to the grid on its dedicated meter on an hourly basis (see

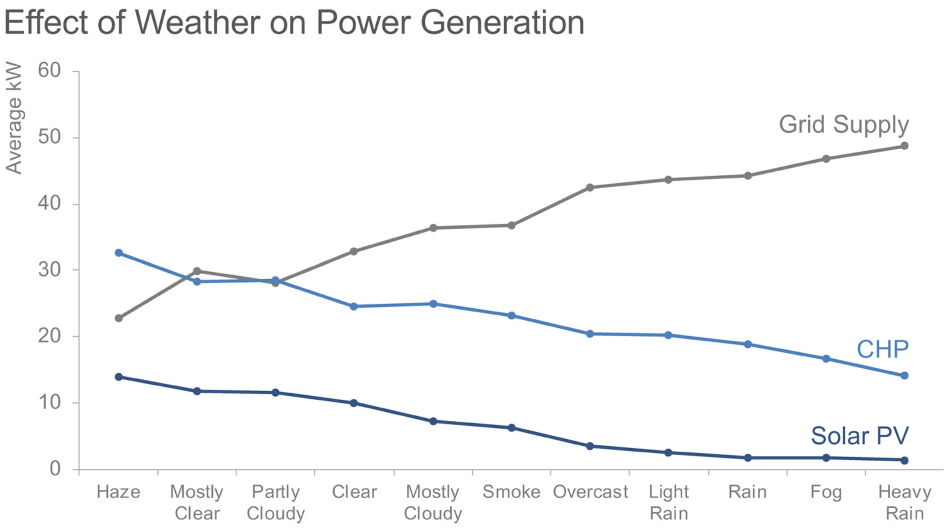


Figure 5. Campus Electric Power Mix versus the Weather and Seasons

Appendix D for more details), although the building overall electricity use increased from previous years. The PV is on a separate meter and the CHP cannot support the PV-served loads directly even when PV has low or no generation. Had the CHP been able to operate more, it could have met more of the unfilled thermal need of the pool, which instead was met by additional operation of the backup pool heaters, which aren't as efficient in comparison.

2. Simple trends and monotonous correlations between weather/seasons and the onsite generation or grid import are observed. Outdoor temperature was high during hazy atmospheric conditions, on the left side of Figure 5, which typically are associated with Santa Ana winds*, or brush fires nearby, in the late summer and fall seasons. Conversely, on the right side of Figure 5, lower temperatures and rain are typical winter weather.

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*According to Wikipedia (https://en.wikipedia.org/wiki/Santa_Ana_winds), the Santa Ana winds are strong, extremely dry downslope winds that originate inland and affect coastal Southern California and northern Baja California. They often bring the lowest relative humidity of the year from high elevation deserts to coastal Southern California. These low humidity, combined with the warm, compression-heated air mass at low elevation, plus high wind speeds, create critical wildfire weather conditions. The typical thermal inversion layers also tend to trap smog and smokes from the fires.

3. In Figure 6, a rare solar eclipse event on August 21, 2017 produced effects like those of morning coastal fog on the previous day, but, of course, in a more distinct and dramatic manner.

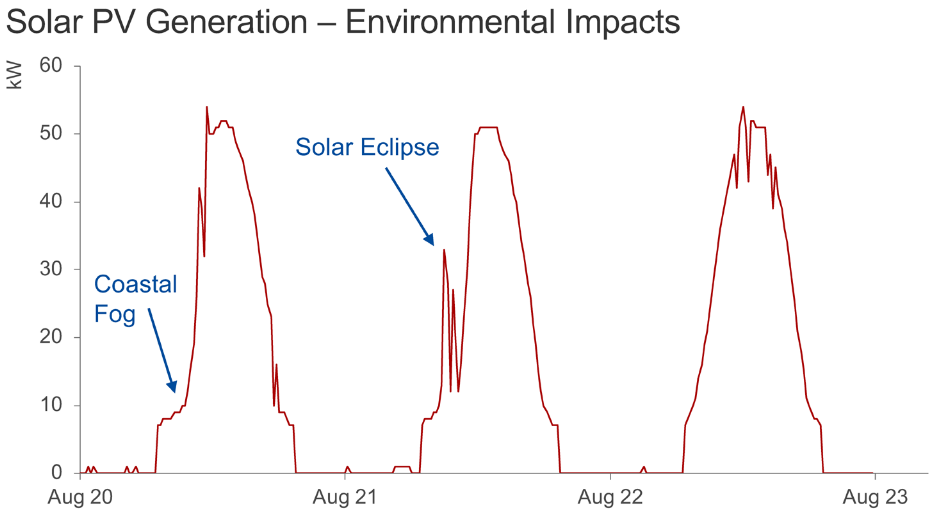


Figure 6. Solar Eclipse Effects and Coastal Fog Both Diminish PV Output

Criteria Emissions and Greenhouse Gas Reductions

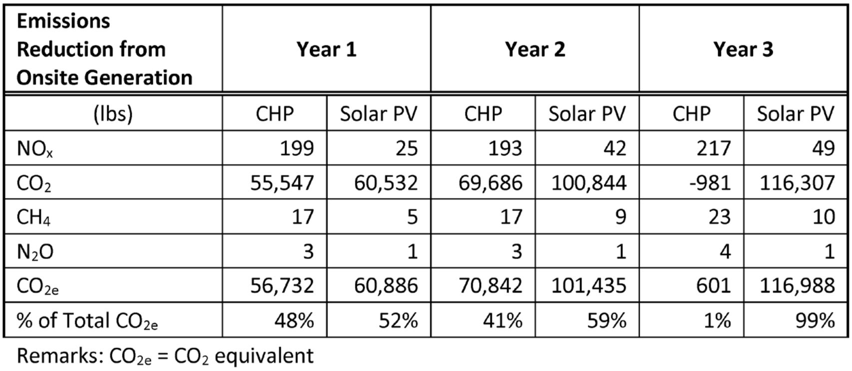
Both CHP and PV contributed significantly in both Year 1 and Year 2 for NO_x reduction. In Year 2, CHP operated more efficiently with less useful heat being wasted, and the solar PV output doubled after a blown fuse was discovered and fixed. The CO_2 -equivalent reductions are significant and higher in Year 2 for both CHP and solar PV, with PV much higher. Although CHP consumed natural gas, it still yielded a net credit due to displacing grid power and pool heater operation.

Table 6 shows a breakdown of the modelled emissions reductions for the project. Table 6 shows that in Year 3, CHP generation is approaching a breakeven point with respect to greenhouse gas (GHG) reduction benefits, as its share of contribution to $CO_{2\ e}$ reduction changes from 48% to 1% between Year 2 and Year 3. The authors believe that this is mostly caused by the current piping configuration not taking full advantage of the unit's waste heat. This could be significantly improved by adding the remaining unconnected pools/spas to the CHPs thermal service. CHP's contribution to CO_2 reduction is highly sensitive to waste heat utilization. A sensitivity analysis showed that only a 1% heat use increase would have reversed the negative 981

CO_2 reduction to positive.

The authors used EPA models for emission calculations. CHP source tests in this project show ultra-clean emissions below the EPA criteria pollutants standards. See Appendix B for the analysis algorithm.

Table 6. Air Emission Reductions



Emissions Reduction from Onsite Generation	Year 1		Year 2		Year 3	
(lbs)	CHP	Solar PV	CHP	Solar PV	CHP	Solar PV
NO_x	199	25	193	42	217	49
CO_2	55,547	60,532	69,686	100,844	-981	116,307
CH_4	17	5	17	9	23	10
N_2O	3	1	3	1	4	1
CO_{2e}	56,732	60,886	70,842	101,435	601	116,988
% of Total CO_{2e}	48%	52%	41%	59%	1%	99%

Remarks: CO_{2e} = CO_2 equivalent

Operating and Maintenance (O&M) Savings

Electricity savings normally consider peak demand and total usage savings. Table 7 includes the cost savings from usage only, even though the omitted electricity demand savings can be significant. This omission, however, allows the PV and CHP savings to be compared more directly, because demand savings can only be fully realized if onsite generation is consistent and continuous for consecutive days within the utility billing months. Weather conditions, time-of-use constraints, or maintenance outages may not allow for such consistency.

Not included are the costs for local air quality permit recertification (approximately \$3,000 to \$7,000), required at 8,760 hours of run-time, staff training, and the initial and onetime installation for both solar PV and CHP. The initial per kW installed cost for CHP was slightly less than that for PV. The reserve for CHP was included but not for PV because there is no available historical data. However, we heard from the LADWP project engineer in a recent and similar commercial PV demonstration at La Kretz Innovation Center in Los Angeles that solar PV maintenance cost is not zero, as contrary to the cost at The Resort as stated by the operator there. Thus, the comparison is relatively conservative for CHP in the authors' opinion.

Note that in Year 2, the CHP and PV savings are almost equally important with respect to cost savings in Year 2. The building occupancy and total electric

Table 7. O&M Savings Summary

CHP Savings Subtotal	**Year 1**	**Year 2**	**Year 3**
CHP fuel, commodity and transportation	($17,016)	($17,984)	($25,592)
O&M, as an insurance and evergreen reserve	($10,071)	($10,733)	($12,731)
Avoided pool heater fuel	$12,972	$11,564	$8,265
Avoided grid power, consumption component only	$22,724	$28,843	$38,410
Net Savings/Year	**$8,609**	**$11,690**	**$8,352**
Solar PV Savings Subtotal			
Avoided grid power	$5,981	$12,901	$15,240
O&M and evergreen insurance or overhauls	$? >0	$? >0	$? >0

load have steadily grown in Year 2 and Year 3. Also, the electricity time-of-use profile is probably a bit different year-to-year. In Year 2, a blown fuse was repaired for PV allowing its output to almost double; the LADWP electricity rates increased, so the value of the onsite generated electricity increased. Year 3 PV savings is higher, while CHP savings lower due to waste heat utilization lower because the operator disconnected the wading pool on the east and pool heater controls for other reasons. As a result, the combined savings in Year 3 is close to but slightly lower than that in Year 2.

The CHP installed per-kW cost was slightly below that for the PV, according to a source from the original construction team. The life cycle costs of the CHP and PV systems are difficult to compare for this project. The CHP cost included an evergreen insurance payment, which will cover the overhaul and maintenance, and the system is always maintained and repaired to ensure continuous and sustainable operating. Thus, the owner will not have to finance a reserve. The solar PV installation does not have such coverage, so as its performance degrades over time, the PV system will eventually need an overhaul. At the time of this writing, the authors had not identified established field data for the cost of such an overhaul. It's expected that the owner may need to consider a reserve for funding such overhauls.

The utility rates used for the analysis are:

- LADWP TOU Rate A-2B
- SoCalGas GT-NC5 for CHP transportation
- SoCalGas GN-10 Core Commercial for non-CHP
- \$1.98/run-hour for CHP O&M evergreen contract in 2016.

LESSONS LEARNED AND CONCLUSIONS

The following are the primary lessons learned and conclusions from this project.

1. Process loads should be considered in all ZNE initiatives. Among the current state of art technologies, only CHP appeared to be cost-effective and robust enough to service process loads.

2. CHP, correctly designed and operated, can contribute significantly to reductions in TDV, emissions, and carbon, on a similar order or magnitude as PV, despite many tariff and metering constraints imposed on this project. Carbon benefits can be maximized by fully using the waste heat. Ultra-low

NO_x CHP can displace the emissions and carbon from alternative sources, especially as the grid power mix and the regular pool heaters are inferior.

3. The overall project environmental and economic benefits can vary, depending on uncontrollable weather conditions, controllable operating parameters, and utility tariffs. Balancing electric and thermal loads is the always the key to success.

4. Projects with limited roof area, large thermal loads, and/or total electric demand that does not peak in the early afternoon can benefit from CHP greatly. Examples likely include community centers, housing projects, senior-care centers, aquatic facilities, and large campuses.

5. The results suggest future roadmaps for community based zero net rulemaking should include and allow CHP to deliver its full potential by allowing added electric load beyond the current permits and electric tariff, to incorporate aggregated buildings and process loads. CHP should be allowed to supplement the PV for the loads assigned to that dedicated meter, while allowing CHP to run at full capacity and have more heat available when most needed, e.g. winter nights. Appendix D illustrates such scenario is very feasible daily on the low-peak hours.

6. Solar PV is passive. CHP is active and resilient, therefore very suitable for varying process loads and district applications. Working together, they can complement each other and achieve zero grid demand for selected hours, such as the special and random cases demonstrated in Appendix C.

7. Net metering is currently only available for renewable sources and fuel cells. Future public policy and rate design changes could consider adoption of clean gas technologies by offering aggregated billing.

8. For designs compliance using campus or community approach for ZNE, waste heat recovery and CHP should be considered.

9. The architectural and design-built trades for swimming pools integrated with CHP needs to be in the industrial grade to have control and water balancing priority set right, instead of using the residential grade which pieces modular filter-pumps together but neglected the CHP heat priority. Similarly, the electrical load assignment and pump selection should give CHP priority, to be truly integrated. Typical value-engineering process to cut cost, commissioning neglected items, and operator's modifications without

engineering of the energy aspects, can all reduce the project success level and cause unintended shortfalls in energy and environmental benefit.

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Appendix A—
The TDV for Zone 6

Figure A1 shows the hourly TDV values extracted from the EnergyPro model for the Resort for the California Climatic Zone 6 in the compliance year 2010. It shows the electric TDV hourly curve has a volatile pattern and very high momentary peaks in the summer. In contrast, gas TDV stays low and relatively flat in all hours. As a result, a gas appliance will "cost" less TDV than its electric competition and requires a smaller PV to compensate.

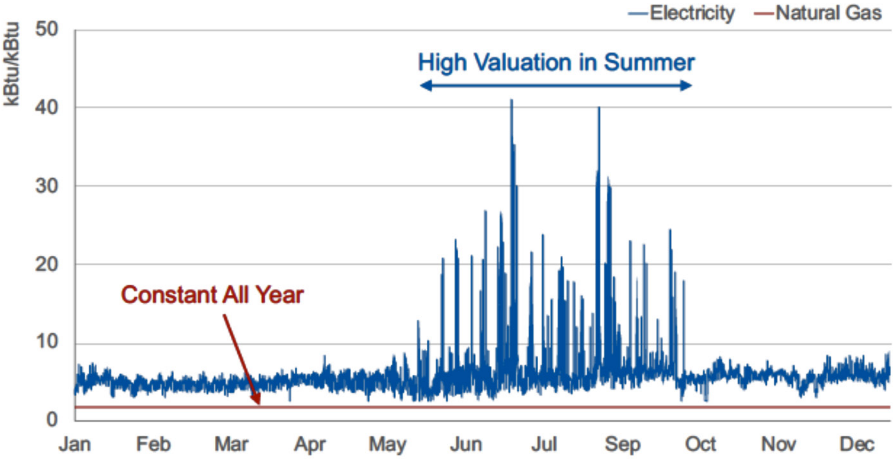

Figure A1. TDV 8760 Hours, Design Year 2010, Project Site (Climate Zone 6)

Appendix B—
Emission Reduction Calculation Details

Onsite power generated by CHP and solar PV displace supply from the LADWP grid. Useful heat output from the CHP system displaces the usage of pool heaters, which reduces emissions. The calculations are shown as follows:

- Total CHP Emissions Reduction (lb) = CHP Useful Heat Output (MMBtu)
  * Gas Boiler Emissions Factor (lb/MMBtu)
  + CHP Generation (MWh) * LADWP Emissions Factor (lb/MWh)
  – CHP Gas Use (MMBtu) * CHP System Emissions Factor (lb/MMBtu)
- Solar PV Emissions Reduction (lb) =
  Solar PV Generation (MWh) * LADWP Emissions Factor (lb/MWh)

Table B1. Emissions Factors Assumptions for Onsite Gas Equipment

Emissions Factor	CHP System	Gas Boiler (represents gas pool heaters)
NO_x (lb/MMBtu)	0.0055	0.1
CO_2 (lb/MMBtu)	116.9	116.9
CH_4 (lb/MMBtu)	0.0022	0.0022
N_2O (lb/MMBtu)	0.0002	0.0002

Table B2. Estimated Electricity Generation Resource Mix for LADWP (CEC 2014)

Resource	Power Content	Emissions Factor Used
Total Eligible Renewable (Biomass and Biowaste, Geothermal, Eligible Hydro, Solar, Wind)	20%	None
Coal	40%	Coal Boiler with Selective Catalytic Reduction
Large Hydro	2%	None
Natural Gas	22%	Gas Combined Cycle
Nuclear	9%	None
Other	0%	None
Unspecified Sources of Power	7%	Gas Turbine Peaker

Table B3. Emissions Factors Assumptions for Grid Electricity Generation

Emissions Factor	Gas Combined Cycle	Gas Turbine Peaker	Coal Boiler with Selective Catalytic Reduction	LADWP Weighted
NO_x (lb/MWh)	0.2647	1.1029	0.8	0.4554
CO_2 (lb/MWh)	935	1,403	1,967	1,091
CH_4 (lb/MWh)	0.0176	0.0264	0.2303	0.0979
N_2O (lb/MWh)	0.0018	0.0026	0.0335	0.0140

Appendix C—
Random Examples of Various Power Mix and Zero Peak on Grid

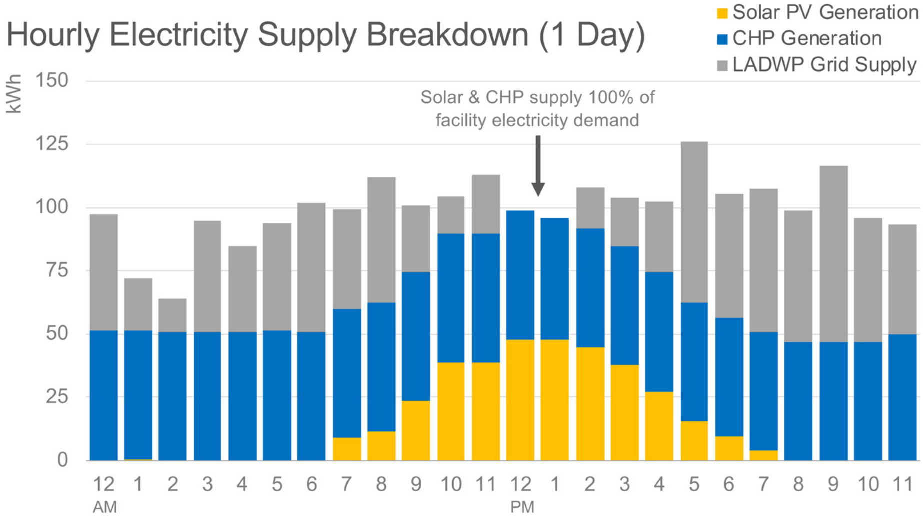

Figure C1. The project achieved zero grid power purchase near the noon-hours. It also demonstrates CHP complement PV in many ways.

Appendix D—
Average Hourly Electric Power Mix and Natural Gas Heat Mix at the Resort

Electricity Usage

Total electricity usage increases starting around 5 am, peaks in early evening around 6 pm, drops around 10 pm, and then declines through the night. This matches with The Resort's operating hours of 5 am to 10 pm. Electricity is sourced from the grid, CHP, or PV. When the CHP and PV are unable to provide enough power, the grid supplements.

Solar PV only generates when there is sun and daylight, while CHP is able to generate a consistent amount of electricity at any time.

Figure D1 was generated from data January 2017, after the PV fuse was fixed, through January 2018. It shows the evening peak dominates the hourly profile. It also illustrates that there are several hours in a day for CHP to be fully loaded to improve the project economics, if the separate metering and electric load separation for PV/CHP and tariff limitations were not in place.

Gas Consumption

There are three dedicated natural gas meters for the main building kitchen, locker room water heaters, and space heaters. CHP is the highest user of gas, followed by east pool heaters, west pool heaters, and finally the main building (kitchen, locker room, and space heaters). CHP use dominates during the day, as is restricted from exporting electricity, and to support the pool heating whenever and possible. The following trends are noticeable:

- West pool/spa: Since the west pool and the adult spa do not have CHP support, their load does not vary much throughout the day. There is a small dip in the middle of the day, as the ambient temperature warms up.

- East pools: The east pools include a Junior Olympic size main pool, a child wading pool, and a family spa. They are supported by CHP. The plot in Figure D2 shows that when the CHP starts up at about 5 a.m., the east pool

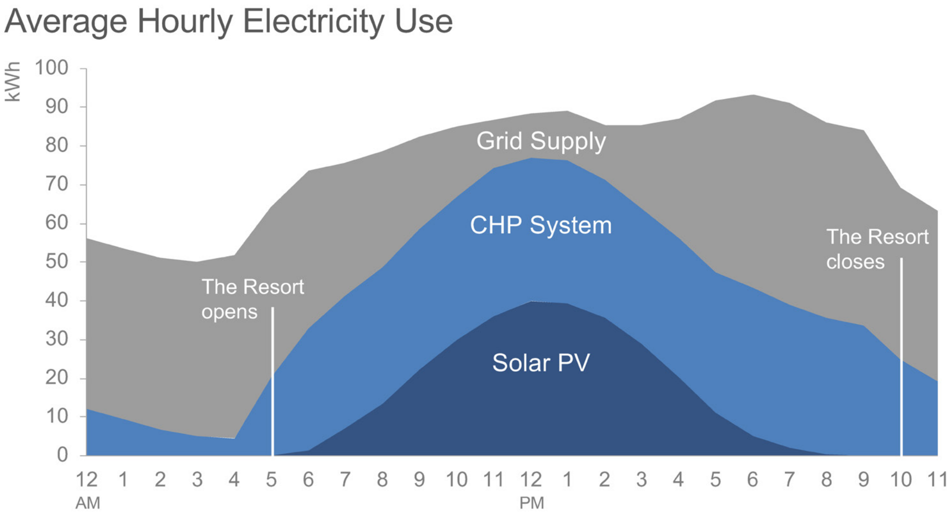

Figure D1. The Average Hourly Electric Power Mix in kW (January 2017 – January 2018)

heaters gas usage drops significantly. When the CHP tapers off around 10 p.m., the east pool heaters gas demand increases back to normal.

- Building: There is not much variability in gas usage by the building.

Figure D2 was generated from data read off the three natural gas meters in the period the pool heater on-off loggers were still working.

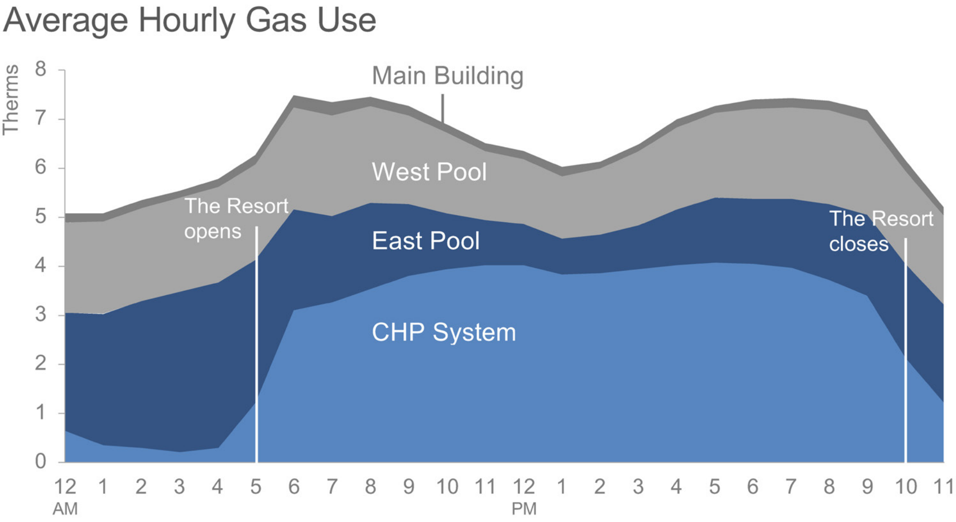

Figure D2. The Average Hourly Natural Gas Consumption Mix in Therms (January 2017-January 2018)

Integrating Solar Power with Thermal Storage at the Thomas E. Creek VA Medical Center*

Samuel E. Hagins, P.E., C.E.M.

ABSTRACT

The Thomas E. Creek Veterans Affairs (VA) Medical Center in Amarillo, TX constructed a renewable energy project for solar photovoltaic (PV) covered parking. This innovative PV system is significant because it was the first PV project in the VA specifically designed to be used in conjunction with an ice thermal storage system. Integrating PV renewable energy with thermal storage load shifting has made Thomas E. Creek the first VA Medical Center to export PV energy back to the local utility during peak solar generation. The PV system is rated at 2,289 kilowatts (kW) and is designed to generate 3,641,130 kilowatt-hours (kWh) of energy annually. It avoids 2,570 metric tons of greenhouse gas emissions per year and subsidizes the center's commercial power approximately 30 percent. It has clear quality-of-life features such as keeping vehicles cooler during summer and protecting them from rain, snow, and hail. The medical center negotiated renewable energy rebates with the local utility provider totaling $400,305. This synergy of solar PV and thermal storage helped set the standard for integrating different types of sustainable energy within the VA and led the way for similar integrated systems at other VA medical centers.

OVERVIEW

The Thomas E. Creek VA Medical Center constructed photovoltaic (PV) covered parking as part of a project to integrate PV renewable energy with thermal storage load shifting. Together these sustainable technologies reduce both kWh consumption and peak kW demand for the center. The

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* Updated from a paper previously published in the 2019 AEE East Proceedings.

idea of combining these technologies occurred after the construction of an ice thermal storage system, which consists of a 400-ton air-cooled chiller plus 18 CALMAC ice tanks at 1,775 gallons each, as shown in Figure 1. The system can produce a total of 32,000 gallons of ice slush and is designed to make ice at night, store it, and then "burn" ice during the day. A schematic of this operation is shown in Figure 2. The purpose is to shift the medical center's air conditioning load from daytime to nighttime. The shift is especially prevalent during the fall, winter and spring when 100 percent of air conditioning load can be transferred to nighttime using thermal storage. This being the case, a decision was made to also add a solar PV system to further reduce daytime energy with a goal of zero energy consumption during peak hours of sunlight. Obtaining periods of net zero energy means the interaction of PV renewable energy and thermal storage would produce an effect greater than the sum of their individual benefits. Solar PV was chosen as the renewable half of this combination because Amarillo is in the semi-arid region of the desert southwest and enjoys plentiful sunlight. Covered parking was chosen as the PV mounting structure because this configuration did not impede on any future expansion plans or cause any roof warranty issues. Three large parking lots surrounding the medical center were chosen for PV covered parking because they have excellent southern exposure with no obstructions from buildings or trees. Covering these three lots required a total of 27 carport canopies that could shade 721 parking spaces, as shown in Figure 3. They were sloped at a 10-degree tilt with a southern facing azimuth to maximize their sun exposure relative to the medical center's latitude. The canopies were topped with 9,269 Samsung PV modules rated at 247 Watts each. This gave a total system rating of 2,289 kW. The PV covered canopies were connected to three inverter power vaults that change PV power from direct current to alternating current. Then the vaults were connected to the medical center's power grid. So far, the PV system generates about one-third of the medical center's energy. In addition, the ice thermal storage system is programmed to run in tandem with the PV system to defer daytime air conditioning. Diminishing this large air conditioning load has allowed the medical center to export energy during peak PV generation. This teaming of PV and thermal storage has distinguished the Thomas E. Creek VA as the first medical center to export energy back onto the local utility's power lines. The center also applied for and received a renewable energy rebate from the local utility provider totaling $400,305.

Figure 1. Thermal Storage System at the Amarillo, VA

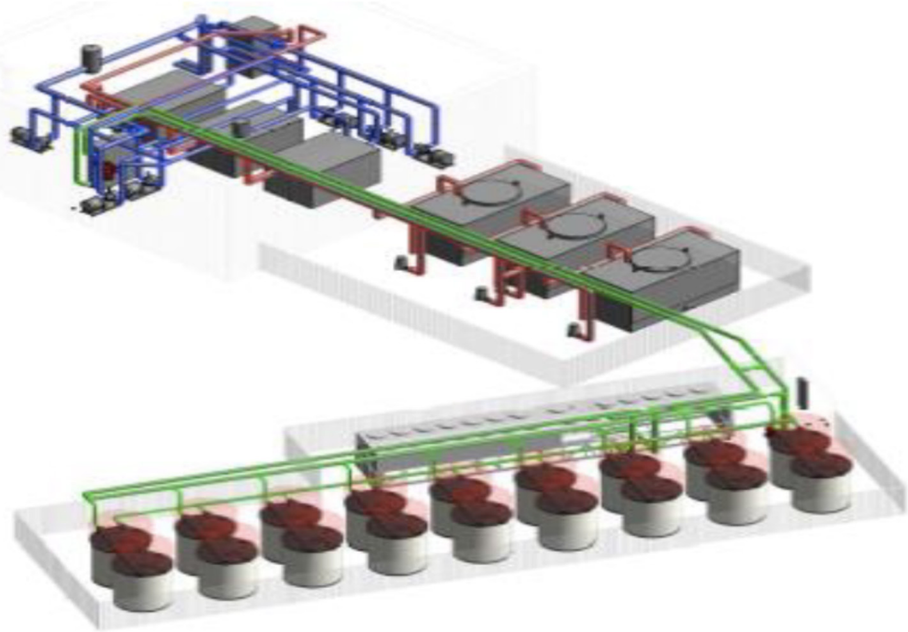

Figure 2. Thermal Storage Schematic at the Amarillo VA

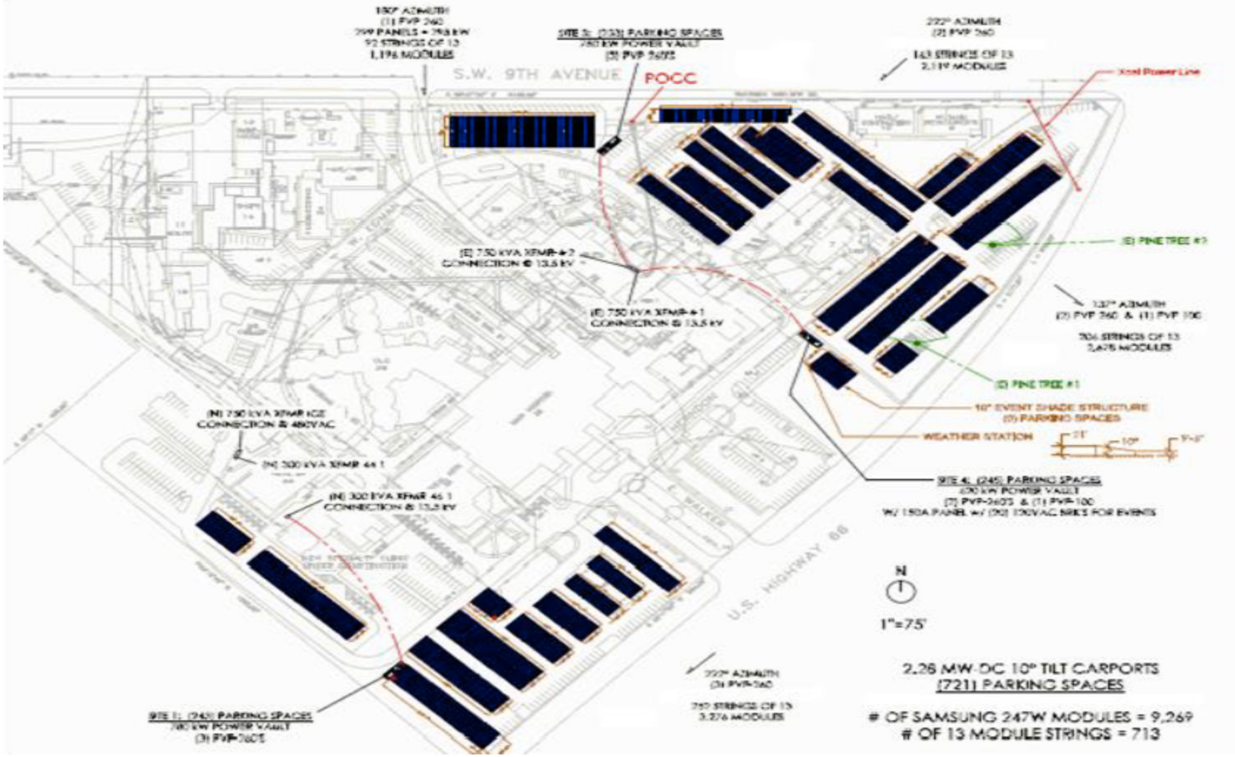

Figure 3. PV Parking Layout for the Amarillo VA

SAVINGS

The PV system is rated at 2,289 kW and has an estimated energy generation of 3,641,130 kWh per year. The life expectancy of the system is 30 years, which means the lifecycle energy generation is approximately 109,233,900 kWh over the lifetime of the system. This translates into a projected 373 billion Btus of renewable energy to the medical center. What's more, the operation of the PV covered parking in conjunction with the thermal storage system allows some energy to be exported back onto the local utility grid every billing cycle. Currently, the medical center is exporting upwards of 30,000 to 65,000 kWh per month back to our local utility provider, XCEL Energy. According to the US Department of Energy, the average electricity consumption for a U.S. residential home is about 1,000 kWh per month. So now the medical center is exporting enough energy to power over 30 American homes. A renewable energy rebate of $400,305 from XCEL Energy helped alleviate project cost. This rebate was part of XCEL's Standard Offer Program that provides monetary incentives to its customers for energy efficient and renewable infrastructure. XCEL was brought in as a consultant during the design phase of the PV system and has remained a partner with the medical center on this project ever since. The kWh energy generation from PV and kW demand reduction for thermal storage save the medical center about $245,000 annually on its electric utility bill at today's rates.

TRANSFERABILITY

PV covered parking is rapidly becoming the desired choice of solar power within the VA. The attraction of this type PV project is the ability to construct a renewable energy system without taking up limited acreage or distressing and cluttering hard to maintain roof areas. To date PV covered parking is being duplicated at more than 25 other VA medical centers around the nation. In addition, similar projects to integrate PV covered parking with thermal storage are currently being adopted by at least three additional VA medical centers. These more recent pairings of PV with thermal storage have been initiated as a direct result of the success of these technologies at the Thomas E. Creek VA Medical Center. Likewise, this project has also sparked interest outside of the VA. Facility engineers from Texas Tech University and two private hospitals in Amarillo have toured the medical center's PV and thermal storage systems and requested information about designing similar projects.

INNOVATIVE TECHNOLOGY

PV covered parking is an innovative design that is more functional and serviceable than roof mounted or ground mounted PV systems. For example, there are no concerns with roof penetrations, rack ballasting, footprint size, and grounds maintenance issues that accompany roof and ground mounted systems. There are no environmental or wildlife impacts because there is no disturbance of the surrounding ecosystem during construction. The PV system is nontracking, so it is virtually maintenance free. And the parking areas continue to be used as originally intended with the added bonus of being shaded from the hot desert sun, as shown in Figure 4. However, the uniqueness of this particular PV covered parking project was the decision to integrate it with thermal storage. The idea was a novel concept when first

Figure 4. Typical PV-covered Parking at the Amarillo VA

conceived, yet combining these two sustainable technologies has proven to be highly effective. As a result, the center is easily meeting its Federal goals for renewable energy as well as supporting the VA's mission priorities for increased safety and security for our veterans and employees. This total synergy of PV and thermal storage has also given the medical center the means to generate more energy than it uses during periods of peak solar energy production, and then export this excess energy back to the local utility. This capability to export PV energy is unique within the VA and the Thomas E. Creek VA is the first medical center to accomplish this.

CONCLUSION

The Thomas E. Creek VA Medical Center has an impressive history of energy and water conservation initiatives. So, it is no surprise that they sought out this groundbreaking project to combine renewable energy with thermal storage. But the ultimate confirmation of the success of this effort is that other VA Medical Centers are now integrating similar renewable energy and thermal storage projects at their facilities.

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