OPTIMAL STRATEGY FOR DEMAND CHARGE REDUCTION IN AN OFFICE BUILDING UNDER DIFFERENT RATE STRUCTURE

Yuna Zhang, Ph.D.
Baumann Consulting Inc., Washington, DC

Godfried Augenbroe
Georgia Institute of Technology, Atlanta, GA

ABSTRACT

This paper targets the optimal combination of design and operational measures in a new design or retrofit project with the aim to reduce demand charges. To achieve this goal, this paper introduces an approach based on the analysis of all feasible energy consumption and peak reduction measures in an office building under different utility rate structure. The analysis includes all measures that are commonly adopted to decrease energy consumption and demand charges, specifically energy efficient measure and energy flexibility measures. The outcomes suggest the optimal combination that minimizes demand charges in commercial buildings.

INTRODUCTION

Up to 70% of a commercial building's monthly utility bill is caused by demand charges (Dieziger 2000). Demand charges represent the penalty levied by the utility provider for an electricity user, particularly for large electricity consumers in the power grid. Demand charges are typically a direct result of the shape of the electric load duration curve of the building, in particular, the hours that a certain power level is exceeded during a given billing period. According to the recently published data from the survey of EIA in 2016 (EIA 2016), the growth of floor space inside commercial buildings has been twice as fast as the growth of commercial buildings since 2003, which implies a trend of increased occupancy, number of equipment, and area of conditioned space inside average commercial buildings. As a direct result, the electricity usage of new commercial buildings may keep increasing as a result of size, despite the improved energy efficiency of new buildings. With increased peak power, a growing number of commercial building owners may face the problem of paying far more than what they actually consume due to their increased share in the cost of the grid infrastructure. This share is billed in the form of demand charges. Therefore, it becomes significant for commercial building owners and operators to realize the role of these demand charges in their monthly bills and to take effective measures to reduce them.

Demand is defined as "the rate at which electric energy is used at any instant or averaged over any designated period of time and is measured in kilowatt (kW)," in EIA's glossary of energy terms (EIA 2017). In reality, the demand kW is measured by the electric meter as the highest average demand in any 15-minute period during the month. This is counted as the amount of electric load required by the customer's electric equipment operating at any given time. Transmission and distribution utilities must have sufficient electric capacities such as properly sized transformers, service wires and conductors to meet customers' kW demand. The demand in kW is recorded for billing the demand charge each month and then reset on the bill cycle date.

Assuming two companies pay the same price for both electricity consumption ($0.437 per kWh) and demand charges ($2.79 per kW). Building A runs a 500 kW load continuously for 100 hours, building B runs a 50 kW load for 1,000 hours, their total cost of electricity is calculated as shown in Table 1. For the same amount of total kWh energy used, i.e. at the same consumption level, albeit with different intensities, the building having a flatter usage profile pays less. (This example does not reflect actual building energy usage and the price does not reflect actual prices.)

Table 1 Calculation of electricity costs

	Building A	Building B
Energy Charges ($)	21,850	21,850
Demand Charges ($)	1,395	139.5
Total ($)	23,245	21,989.5

Under current utility rate structures, demand charges can easily make up 70% of the monthly utility bill of a commercial building. According to the statistical data for the year 2016, PSE&G's Demand Peak Load

Contribution charge is $64.65/kW/yr. JCPL's Demand Peak Load Contribution charge is $43.33/kW/yr (Adjangba 2015). These numbers show the significance of what costs can be mitigated if building owners and their energy advisors are able to understand the core causes of demand charges and take action.

LITERATURE REVIEW

There are four technical interventions or measures used in the demand profile modification in the literature. The first one is energy efficiency, which refers to the techniques that help reduce the net demand during both on-peak and off-peak periods (Sadineni et al. 2012). The second technique is called peak shaving, which indicates reducing the on-peak demand when the demand in the power grid is high (Yao et al. 2012). The third method is load shifting, which means altering the demand profile to meet certain performance criteria (Klein et al. 2017). The fourth method is distributed renewable energy, which utilizes distributed energy resources (DERs) to coincidently reduce on-peak demand (Somma et al. 2017 & Somma et al. 2018). Figure 1 shows the difference between the four techniques that can help customers reduce demand charges. The existing method that falls within these four categories mentioned above can help reduce demand charges.

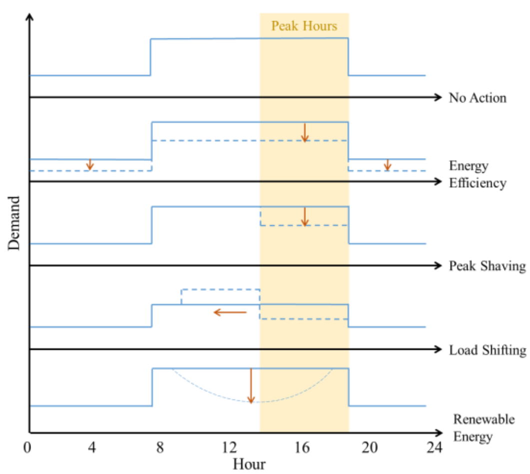

Figure 1 Technics to help modify the demand profile

There are various measures and technologies can help reduce demand charges as introduced in the literature. Multiple energy model parameters are associated with the realization of these proposed measures and technologies at different achievement levels. The parameter set contains both physical parameters that characterize a technology and its achievement, as well as parameters that characterize an operational measure. This presents a complex optimization problem given the fact that so many factors are correlated with each other. In the multi-parameter optimization space, it is difficult to reach the optimum point without a solid exploration method through the space. Although this approach has been applied in other building optimization settings (Weber et al. 2011, Ma et al. 2012, Sun et al. 2012, Simmons et al. 2015,), there is not a confirmed model that can generate the optimal solution to reduce demand charges for a given building and its baseline. This paper proposes a generic method to find the dependency between optimization parameters that define the discrete technologies and operational schemes and their significance in terms of increasing energy flexibility and demand charge reduction.

METHODOLOGY

A deterministic analysis of optimal investment strategies is conducted to reduce demand charges in an office building under five different utility rate structures. In order to find the optimal investment strategy, this paper proposes a framework that is translated into an optimal investment analysis instrument in the form of a spreadsheet-based analysis tool. Figure 2 illustrates the structure of the optimization platform.

The optimization analysis is conducted with a reduced-order building energy simulation model created in the Energy Performance Calculator (EPC) which originated from De Normalización (2008) and was later adapted for specific research use (Lee et al. 2013). The optimal investment strategy is tested with different rate structures. The ultimate optimization goal is to maximize the net present value (NPV) of the investment in energy efficiency measure (EEM) and energy flexible measure (EFM) over an investment time horizon of 20 years.

The starting point of this development is the EPC calculator and its add-on for optimization studies (EPC-Tech OPT). The inputs of EPC contain nine sections: building information, heat capacity, building system, building integrated energy generation system, energy source, zones, schedules, envelope, and material. Tech OPT is an extension of the calculator that finds the best mix of a user-provided set of candidate technologies based on a user-defined target. Moreover, every technology has a predefined discrete set of achievement levels. Each achievement level is associated with an actual product in the market, with a specified cost of that product. Tech-Opt is an added feature to the EPC calculator that performs the optimization by finding the optimum technology mix (requiring the solution of a mixed integer continuous parameter optimization problem) given a certain criterion, such as minimum total cost within a time horizon. The optimization scheme uses the 'solver' add-in provided in Excel®, and the input data provided in the EPC spreadsheet. There is no need for external software or computational code.

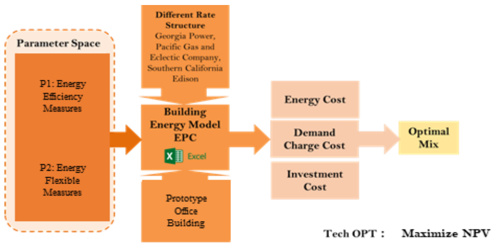

Figure 2 Optimization platform

The parameter space of the optimization study comprises two categories of parameters: EEM and EFM. The parameterized realization is detailed in Table 2. In energy efficiency interventions, five parameters are considered as input for the optimization analysis. Infiltration refers to the unintentional introduction of outside air into a building. Insulating the exterior envelope of the building reduces transmission losses and gains. This is a typical EEM in a retrofit project. The emissivity of the roof refers to the ability of the surface material on the roof to re-radiate the absorbed solar radiation back to the sky, which relates to the amount of total heat that is emitted by the roof material after the heat is absorbed. The solar reduction factor of the window represents the permanent installation of external shading devices or internal window treatment, which reduces the global transmission of solar radiation. (ISO 13790 Annex G.5.2). The Solar Heat Gain Coefficient (SHGC) is defined as the fraction of incident solar radiation that enters into the interior space through the window in the form of direct radiation and heat from absorbed solar radiation in the window and internal shades (an indirect result of radiation). The procedure for testing window products and assigning SHGC ratings is performed by the National Fenestration Rating Council (NFRC) first started in 1993. Solar heat gain through windows is a significant factor that will impact the cooling load in commercial buildings.

Table 2 List of parameters and costs

	Building Parameters	Value		Cost
		Min	Max	
Energy Efficiency Measure	Infiltration Rate ($m^3/h/m^2$)	0.2	0.8	\$4-\$10/m
	Wall Insulation Thickness (mm)	0	100	\$10-\$17/m^2
	Emissivity of Roof	0.4	0.9	\$10-\$22/m^2
	Solar Reduction Factor	0.8	1	\$45-\$65/each window
	Window SHGC	0.25	0.8	\$450-\$650/each window
Energy Flexible Measure	Temperature Control (℃)	0	2.5	Productivity lost
	Lighting Dimmer	0	30	\$300/each dimmer
	Voltage Throttling	0	1	Productivity lost
	Area of the PV System (m^2)	0	200	\$520 per m^2

In the EFMs, four parameters are considered are considered as input for the optimization analysis. Temperature control of the building refers to thermostats that can be set toward the bottom of the comfort zone instead of the top (at 25℃ instead of 22℃, for example) from 12 p.m. to 4 p.m. in summer months to reduce peak demand. The lower temperature allows the air–conditioning compressor to be turned off or its output to be reduced for short periods without raising the temperature enough to bother occupants. Lighting dimmers installed in the lighting system can be used to control the lights in certain areas of the building from 12 p.m. to 4 p.m. in summer months to reduce the coincident peak. Voltage throttling with voltage-reduction controllers could effectively lower the coincident peak demand and energy over time by regulating the voltage output of high power-consuming equipment, i.e. chillers. The PV arrays installed on the roof can generate electricity during a clear day with sufficient solar radiation. The area of the PV system is considered as variables for the optimization analysis.

Among the two categories of optimization parameters, the EEMs impact the “steady” building load in terms of permanently changing the physical property of the building to improve its thermal performance. Implementing EFMs increases the energy flexiblity of a building. The load/energy flexibility of a building refers to the ability to control its power demand and generation to adapt to the local climate conditions, user needs and grid requirements (Huber et al.2014, Blarke 2012). The impact of both static interventions and dynamic interventions on the reduction of peak demand will be analyzed in the case studies. The correlation between optimization factors will also be discussed in the case studies. It should be noted that thermal and electric (battery) storage are potentially useful additional EFMs. Thermal storage in the building could be utilized in the form of pre-cooling dring nighht or early morning. Battery storage could be used to shift charge during non peak hours and discharge during peak hours. It will add a set of operational parameters and installed battery pack to the set of EFM parameters, increasing the complexity of the optimization.

CASE STUDY

This paper carries out the optimization analysis of the optimal investment strategy for an office building. The baseline model is taken from the U.S. Department of Energy (DOE) prototype commercial building models (DOE 2017). The reference office building shown in Figure 3 is located in Atlanta, GA. The building has six stories. The setpoint temperature of the building is 21℃ for heating and 24℃ for cooling. The primary energy source for heating and domestic hot water is natural gas, and the primary energy source for cooling is electricity. Table 3 lists the simulated monthly peak demand and consumption. The summer peak load is 257.87 kW occurring in August. Each case considers five different combinations of EEMs and EFMs. Combination 1 represents the baseline building with no EEMs. In each of the following combinations (2 to 5), there is a \$50,000 increment in the budget for the EEMs compared to the previous one, which representing the incremental of energy efficiency features in the building. In all the five combinations, there is no restriction on the budget of the EFMs. The intention of designing these five combinations with different budget for EEMs is to explore the interaction between EEMs and EFMs. In general, a building with more EEMs would have a relatively low space for improvement in energy savings. The role of EFM diminishes as more is invested already in EEM. In the optimization study, the relative economic significance of EEMs and EFMs will be analyzed. One objective of the analysis is to reveal the mechanism of how specific demand charge rates lead to different investment choices. The other objective is to show whether after implementing EEM with increasing available budgets, the role of EFM will diminish.

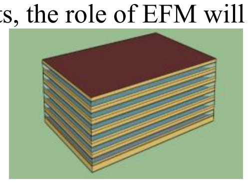

Figure 3 Prototype office building model

Table 3 Monthly peak demand and energy Consumption

	Peak Demand (kW)	Monthly Total Power (kWh)
Jan	175.67	32,305.48
Feb	217.50	34,612.50
Mar	231.59	51,876.44
Apr	238.28	54,453.42
May	256.66	67,682.24
Jun	248.74	69,184.85
Jul	257.84	71,616.00
Aug	257.87	77,519.15
Sep	256.98	62,185.22
Oct	247.15	50,971.54
Nov	197.30	40,945.80
Dec	181.93	33,230.08

Case 1-Georgia Power (GP) PLM-11

Case 1 adopts the rate structure of GP's schedule PLM-11 in the electricity bill calculation. Schedule PLM-11 (PLM-11 2017) is designed for any customer with a demand higher than 30 kW but less than 500 kW. GP charges its customers $8.24 per kW of billing demand. The energy rate is based on hours use of demand (HUD), which is based on the customer's total energy consumption as well as the usage frequency.

Table 4 Electricity rate of GP PLM-11

HUD		Energy Rate($/kWh)
HUD < 200	First 3,000 kWh	0.112561
	Next 7,000 kWh	0.103091
	Next 190,000 kWh	0.088885
	Over 200,000 kWh	0.068955
200 < HUD < 400		0.011437
400 < HUD < 600		0.008606
HUD > 600		0.007486

HUD indicates how consistently a customer is using electricity during the billing month. The higher the HUD, the more hours the customer is operating and usually the lower their unit (kWh) cost. HUD equals to monthly total energy consumption divided by the billing demand. The HUD of the case building in August is $77{,}519(\text{kWh})/258\ (\text{kW}) = 300$. According to Table 4, the electricity price for the case building is $0.011437 per kWh. Table 5 illustrates the steps to calculate the monthly electricity bill in August. The total amount to be paid by the building is $6,704.76. The result reveals that demand charge is almost 30% of the total bill.

Table 5 Calculation of the monthly electricity bill

Customer Charges	1 month @ $19.00	$19.00
Demand Charges	257.87 kW @ $8.24	$2,124.85
Energy Charges	77,519.15 kWh @ $0.01143	$886.04
Subtotal		$3,029.89
ECCR Charges	$3,029.89 @ 0.100131	$303.39
NCCR Charges	$3,029.89 @ 0.075821	$229.73
FCR Charges	77,519.15 kWh @ $0.03258	$2,525.88
Subtotal		$6,088.89
MFF Charges	$6,088.89 @ 0.029109	$177.24
Subtotal		$6,266.13
Sales Tax	$6,266.13 @ 7%	$438.63
Total Electric Charges		**$6,704.76**

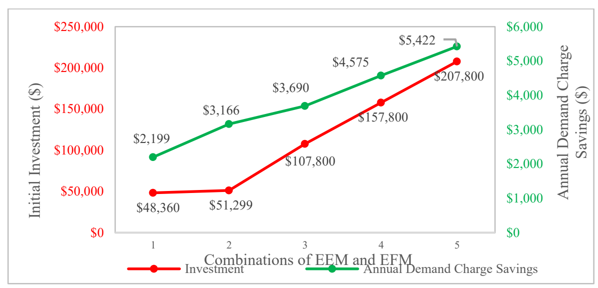

Figure 4 Investment and demand charge savings of combined EEM+EFM

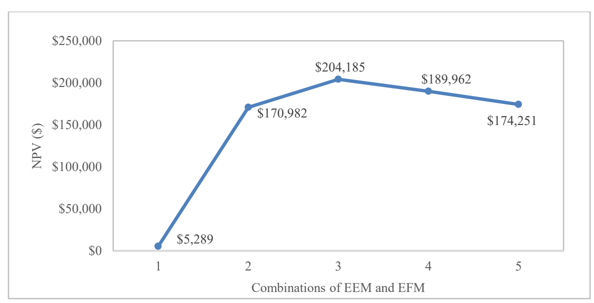

Figure 5 NPV results of combined EEM and EFM

The optimal combination is determined by maximizing the NPV over a 20-year period. Figure 4 illustrates the total investment and demand charge savings. The NPV results displayed in Figure 5 imply that the optimal investment strategy in combination 3 has the maximum investment payback over twenty years. If the case building user wants to achieve maximum investment gains in a twenty-year period, they should choose the optimal investment strategy suggested in combination 3.

Case 2- PG&E's Schedule A-10 Non-TOU

Case 2 adopts PG&E's schedule A-10 non-TOU (Time-of-use) rates to calculate the cost of electricity. If the end user successfully attempts to reduce the peak demand below 200 kW, they could switch to schedule A-1 for small general service, which has the same energy rate as A-10, but no demand charge. Therefore, if the results show that demand charges contribute a lot to the electricity bill, the end user should make a serious effort to bring the peak demand below 200 kW. Table 6 illustrates the calculated the monthly electricity bill in August. The total amount to be paid by the building is $18,462. Demand charge is 20% of the total bill.

Table 6 Calculation of the monthly electricity bill

Customer Charge	31 days	@	$4.60	$142.59
Demand Charges	257.87 kW	@	$16.78	$4,327.06
Energy Charges	77,519.15 kWh	@	$0.14	$10,518.57
Transmission Rate Adjustments	77,519.15 kWh	@	$0.00472	$365.89
Public Purpose Programs	77,519.15 kWh	@	$0.01416	$1,097.67
Nuclear Decommissioning	77,519.15 kWh	@	$0.00149	$115.50
Competition Transition Charges	77,519.15 kWh	@	$0.00100	$77.52
DWR Bond	77,519.15 kWh	@	$0.00549	$425.58
New System Generation Charge	77,519.15 kWh	@	$0.00238	$184.50
Subtotal				$17,254.88
Sales Tax	$17,254.88	@	7%	$1,207.84
Total Electric Charges				$18,462.72

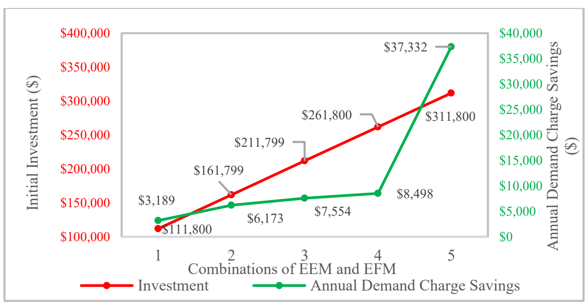

Figure 6 Investment and demand charge savings

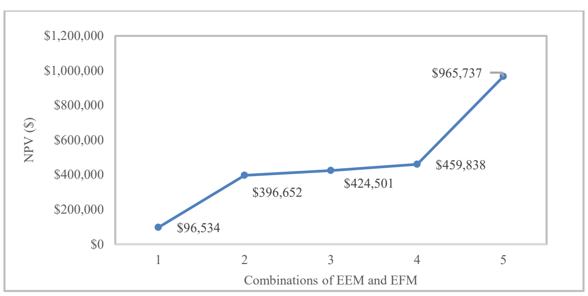

Figure 7 NPV results of combined EEM and EFM

Figure 6 depicts the change of total investment and demand charge savings. The sharp rise of demand charge savings at combination 5 is caused by the specific rate structure in PG&E. In PG&E, if the end user's peak demand is below 200 kW for three consecutive months, that customer will be transferred from the current schedule A-10 to schedule A-1, which has no demand charge. The user needs to trade off between the increment in energy cost and reduction in demand charges after implementing the optimal investment strategy. The NPV results displayed in Figure 7 imply that the optimal investment strategy is combination 5 which has the maximum investment payback over twenty years. The optimization result suggests that the financial benefit of reduced demand charges exceeds the rise in the energy price.

Case 3- PG&E's Schedule A-10 TOU

Case 3 applies the PG&E's schedule A-10 TOU rates to calculate the cost of electricity and to evaluate the best measure and investment strategies to reduce demand charges. Different from the flat daily rate structure in case 2, the schedule A-10 TOU adopts a TOU rate structure. Table 7 details how times of the day are defined and how much is the hourly rate during a day. This rate schedule also includes the peak day pricing (PDP) rate, which is a demand response (DR) pricing plan released to complement the TOU pricing. Table 8 shows the calculation of the monthly electricity bill in August. The total amount to be paid by the building in August is $18,462.72. The result reveals that the demand charge is 20% of the total bill.

Table 7 TOU rate of PG&E A-10 and PG&E A-1

		Energy Rate ($/kWh)	
		PG&E A-10	PG&E A-1
Summer	Peak	0.21972	0.25943
	Partial-Peak	0.16459	0.23578
	Off-Peak	0.13652	0.20842
Winter	Partial-Peak	0.13641	0.21692
	Off-Peak	0.11935	0.19601

Table 8 Calculation of the monthly electricity bill

Customer Charge		31 days	@	$4.60	$142.59
Demand Charges		257.87 kW	@	$16.78	$4,327.06
Subtotal					$4,469.65
	On-Peak	30,314.67 kWh	@	$0.22	$6,660.74
	Partial-Peak	26,814.37 kWh	@	$0.16	$4,413.38
	Off-Peak	17,390.51 kWh	@	$0.14	$2,374.15
	PDP Events	2,999.60 kWh	@	$0.90	$2,699.65
Total Energy Charges		77,519.15 kWh			$16,147.92
Transmission Rate Adjustments		77,519.15 kWh	@	$0.00472	$365.89
Public Purpose Programs		77,519.15 kWh	@	$0.01416	$1,097.67
Nuclear Decommissioning		77,519.15 kWh	@	$0.00149	$115.50
Competition Transition Charges		77,519.15 kWh	@	$0.00100	$77.52
DWR Bond		77,519.15 kWh	@	$0.00549	$425.58
New System Generation Charge		77,519.15 kWh	@	$0.00238	$184.50
Subtotal					$22,884.23
Sales Tax		$22,884.23	@	7%	$1,601.90
Total Electric Charges					$24,486.12

Figure 8 depicts the change of total investment and demand charge savings. Combination 5 gains the highest demand charge savings. The NPV results displayed in Figure 9 imply that combination 5 has the maximum investment payback over twenty years. Case 2 and 3 are different options of the same electricity rate structure that customers can choose from. In both cases, the optimization result suggests that the peak demand can reduce below 200 kW, which indicates that the financial benefit of reduced demand charges exceeds the rise in the energy price.

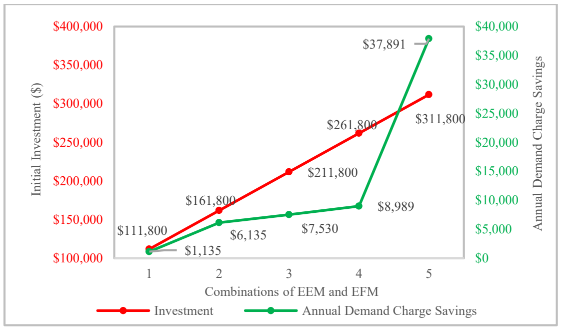

Figure 8 Investment and demand charge savings

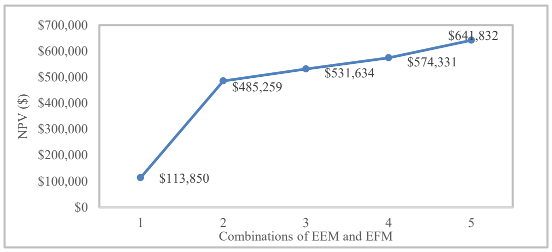

Figure 9 NPV results of combined EEM and EFM

Case 4- Southern California Edison TOU-GS-3 A

Case 4 adopts the rate structure of Southern California Edison's schedule TOU-GS-3 option A. It is designated for any customer with a demand higher than 200 kW but less than 500 kW. If the optimization result could bring the billing demand below 200 kW, the rate calculation method will switch to schedule TOU-GS-2 option A. Option A is a TOU rate structure with the energy cost varying by season and time of day. Table 9 lists the energy rate of TOU-GS-3 and TOU-GS-2. Customers will be charged $17.81 and $15.48 per kW of billing demand correspondingly (Schedule TOU-GS-3 2017).

Table 9 TOU rate of SCE GS-3 and GS-2

		Energy Rate ($/kWh)			
		SCE TOU-GS-3 Option A	SCE TOU-GS-3 Option B	SCE TOU-GS-2 Option A	SCE TOU-GS-2 Option B
Summer	Peak	0.31634	0.11537	0.34167	0.11665
	Partial-Peak	0.10999	0.07813	0.11601	0.07921
	Off-Peak	0.05944	0.05944	0.05918	0.05919
Winter	Partial-Peak	0.0738	0.0738	0.07589	0.0759
	Off-Peak	0.0643	0.0643	0.06573	0.06574

Table 10 details the steps to calculate the monthly electricity bill in August. The total amount to be paid by the building in August is $19,935.74. Figure 10 shows demand charge savings and investments of different combinations. The result from these analyses reveals that the combination 5 achieves the maximum NPV in twenty years. The NPV results displayed Figure 11 imply that the combination 5 has the maximum investment payback over twenty years. The optimal EEM and EFM package brings the peak demand down below 200 kW. Although TOU-GS-2 option A has a higher energy rate, the result of the optimization analysis suggests that the financial benefit of reduced demand charges exceeds the rise in the energy price.

Table 10 Calculation of the monthly electricity bill

Customer Charge	1 month	@	$466.13	$466.13
Demand Charges	257.87 kW	@	$17.81	$4,592.66
Subtotal				$5,058.79
On-Peak	30,314.67 kWh	@	$0.32	$9,589.74
Partial-Peak	26,814.37 kWh	@	$0.11	$2,949.31
Off-Peak	17,390.51 kWh	@	$0.06	$1,033.69
Total Energy Charges	77,519.15 kWh			$13,572.75
Subtotal				$18,631.54
Sales Tax	$18,631.54	@	7%	$1,304.21
Total Electric Charges				$19,935.74

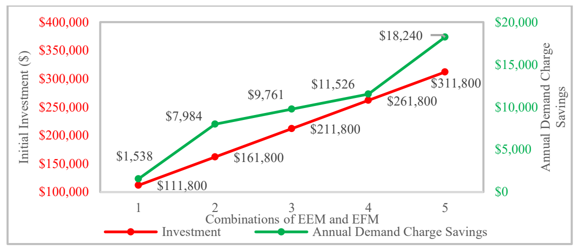

Figure 10 Investment and demand charge savings

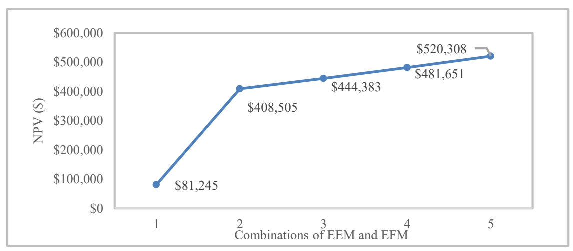

Figure 11 NPV results of combined EEM and EFM

Case 5- Southern California Edison TOU-GS-3 B

Case 5 employs the rate structure of SCE's schedule TOU-GS-3 option B. If the optimization result could bring the billing demand below 200 kW, the rate calculation method will switch to schedule TOU-GS-2 option B. Option B in schedule TOU-GS-3 and TOU-GS-2 is a TOU rate structure with the energy cost varying by season and time of day. Different from option A introduced in case 4, option B includes a continuously active facility-related demand charge and additional time-sensitive demand charges.

Figure 12 shows demand charge savings and investments of implementing the optimal combinations. The NPV results displayed in Figure 13 imply that the combination 5 has the maximum investment payback over twenty years. Case 4 and 5 both apply to SCE's customers with peak demand greater than 200 kW but less than 500 kW. The customer can choose which option they want to enroll in. SCE TOU-GS-3 option A has a higher energy rate, but a lower demand charge. Buildings with high energy consumption and a relatively low peak demand should choose option B to save on energy bills. By comparing the monthly electricity charge in case 4 and 5, we could draw the conclusion that for our reference office building, before applying any EFM or EEM, choosing the TOU-GS-3 option B with time-related demand and DR incentive has the lower electricity bill.

Table 11 Calculation of the monthly electricity bill

Customer Charge	1 month	@	$466.13	$466.13
Facility	257.87 kW	@	$17.81	$4,592.66
On-Peak	257.87 kW	@	$17.42	$4,592.66
Partial-Peak	239.09 kW	@	$3.43	$820.08
Total Demand Charges				$10,005.40
Subtotal				$10,471.53
On-Peak	30,314.67 kWh	@	$0.12	$3,497.40
Partial-Peak	26,814.37 kWh	@	$0.08	$2,095.01
Off-Peak	17,390.51 kWh	@	$0.06	$1,033.69
Total Energy Charges	77,519.15 kWh			$6,626.10
Subtotal				$17,097.63
Sales Tax	$17,097.63	@	7%	$1,196.83
Total Electric Charges				$18,294.47

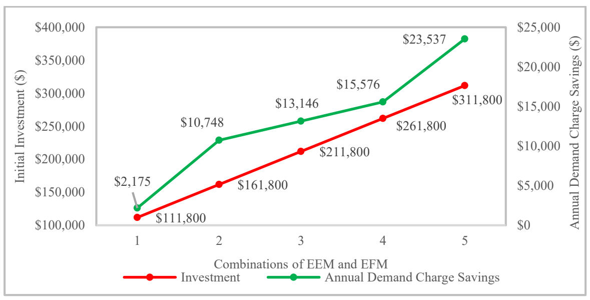

Figure 12 Investment and demand charge savings

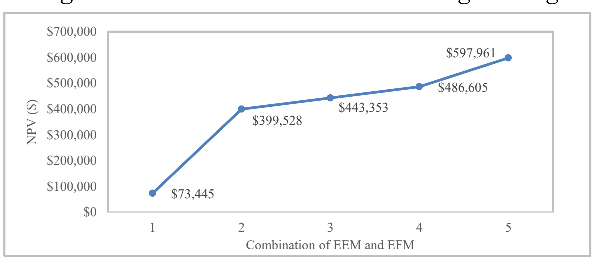

Figure 13 NPV results of combined EEM and EFM

RESULTS AND CONCLUSION

Table 12 details the investment of all combinations and in all rate structures. It shows for all budget levels and rate structures which EEM and EFM were chosen in the optimal package. For the EEMs, roof emissivity, solar reduction factor, and window SHGC are selected in all optimizations when there is enough budget.

PV is typically considered to be a cost-effective investment based on energy savings alone (Cengiz 2015). This changes at high capacity installations when there is a substantial amount of excess generation (more generation than the concurrent demand of the building). In that case, the economic viability depends strongly on the local feed-in rate or the cost of local storage. In our case buildings, the PV areas are rather limited and excess generation is not a big issue or does not occur at all. This means that PV in rate structures with sufficiently high electricity price is an automatic choice, even without counting the benefits of demand charge reduction as result of PV installation. All the cases under GP PLM-11 schedule do not select PV or only install a small number of the PV system, while in other utility rates, the optimal result suggests maximizing the size of PV system to gain a high NPV. This is because GP PLM-11 uses HUD to categorize the peak load frequency of the building. HUD is calculated as the monthly total energy consumption divided by the peak demand. Buildings with low HUD have a higher occurrence frequency of the peak demand and will be charged for a higher energy and demand charge rate.

Table 12 Investment in the office building

Deterministic Analysis		EEMs					EFMs			
		Infiltration Rate	Insulation Thickness	Emissivity of Roof	Solar Reduction Factor	Window SHGC	Temperature Control	Lighting Dimmer	Voltage Throttling	PV System
Case 1	Combination 1	-	-	-	-	-	-	$7,800	Yes	$40,560
	Combination 2	-	$2,400	$7,500	$24,200	$15,900	-	$1,300	Yes	-
	Combination 3	-	$4,300	$7,500	$24,200	$64,000	-	$7,800	Yes	-
	Combination 4	-	$5,800	$7,500	$24,200	$112,500	-	$7,800	-	-
	Combination 5	$9,700	$12,800	$7,500	$24,200	$145,800	-	$7,800	-	-
Case 2	Combination 1	-	-	-	-	-	Yes	$7,800	Yes	$104,000
	Combination 2	-	-	$7,500	$24,200	$18,300	Yes	$7,800	Yes	$104,000
	Combination 3	-	-	$7,500	$24,200	$68,300	Yes	$7,800	-	$104,000
	Combination 4	-	-	$7,500	$24,200	$118,300	Yes	$7,800	-	$104,000
	Combination 5	-	$1,800	$7,500	$24,200	$166,500	Yes	$7,800	-	$104,000
Case 3	Combination 1	-	-	-	-	-	Yes	$7,800	-	$104,000
	Combination 2	-	-	$7,500	$24,200	$18,300	Yes	$7,800	-	$104,000
	Combination 3	-	-	$7,500	$24,200	$68,300	Yes	$7,800	-	$104,000
	Combination 4	-	$900	$7,500	$24,200	$117,400	Yes	$7,800	-	$104,000
	Combination 5	-	$2,500	$7,500	$24,200	$165,800	Yes	$7,800	-	$104,000
Case 4	Combination 1	-	-	-	-	-	Yes	$7,800	-	$104,000
	Combination 2	-	-	$7,500	$24,200	$18,300	Yes	$7,800	-	$104,000
	Combination 3	-	-	$7,500	$24,200	$68,300	Yes	$7,800	-	$104,000
	Combination 4	-	-	$7,500	$24,200	$118,300	Yes	$7,800	-	$104,000
	Combination 5	-	-	$7,500	$24,200	$168,300	Yes	$7,800	-	$104,000
Case 5	Combination 1	-	-	-	-	-	Yes	$7,800	Yes	$104,000
	Combination 2	-	$1,200	$7,500	$24,200	$17,100	Yes	$7,800	Yes	$104,000
	Combination 3	-	$2,700	$7,500	$24,200	$65,600	Yes	$7,800	-	$104,000
	Combination 4	-	$3,100	$7,500	$24,200	$115,200	Yes	$7,800	-	$104,000
	Combination 5	-	$3,500	$7,500	$24,200	$164,800	-	$7,800	-	$104,000

In our case buildings, installing a PV system reduces the monthly total energy consumption, therefore reducing the HUD. Install a large PV in the case building will reduce the HUD below 200, at which point the building will be charged a much higher energy rate. Therefore, most optimal investment packages in GP PLM-11 do not suggest installing a PV system. This is an important insight as it is counter-intuitive to what most building operators would expect from PV installations. It turns out that this particular rate structure can, in fact, be a disincentive for PV installation.Since utilities have been typically charging flat rates for electricity in the past, building owners only pay attention to EEMs that focused solely on reducing energy usage within a building while indifferent to the time in which energy usage was reduced. If the building transfer to a dynamic pricing rate, the monthly reduction through EEMs will get lower. Some utility companies provide TOU and non-TOU options for their clients. Building owners should evaluate the energy flexibility feature in their buildings and decide which option could bring them the maximum bill savings. The study presented in this paper has been extended to hospital and retail buildings in Zhang 2017 and stochastic optimization is carried out in Zhang et al.

2018. The latter also presents the validation of the reduced order tool against a higher fidelity model.

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