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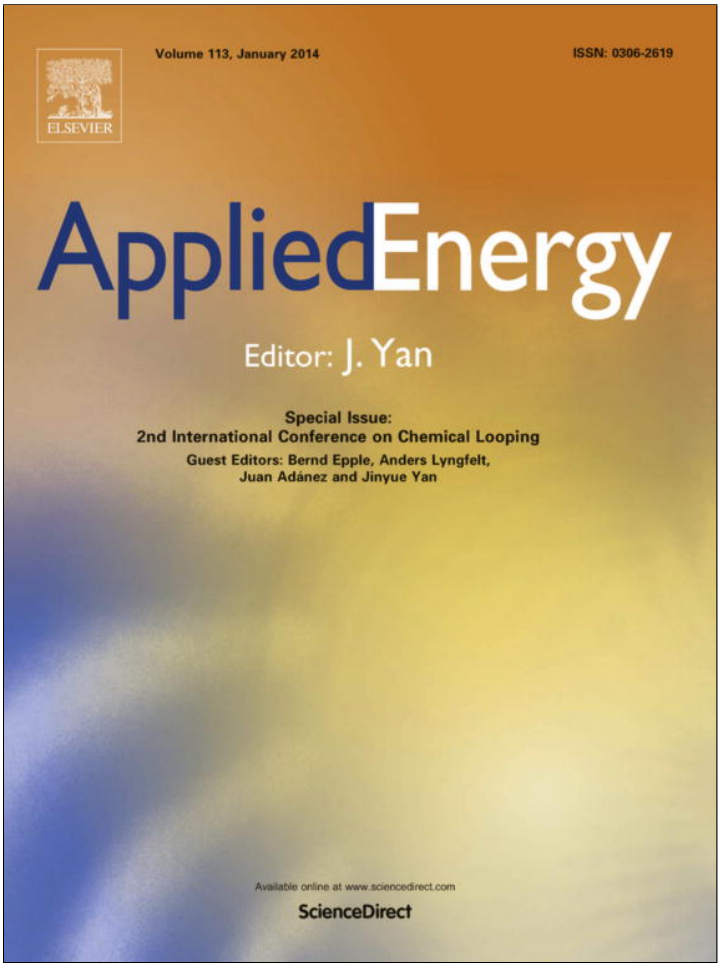

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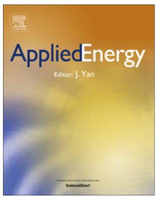

The impact of scheduling appliances and rate structure on bill savings for net-zero energy communities: Application to West Village

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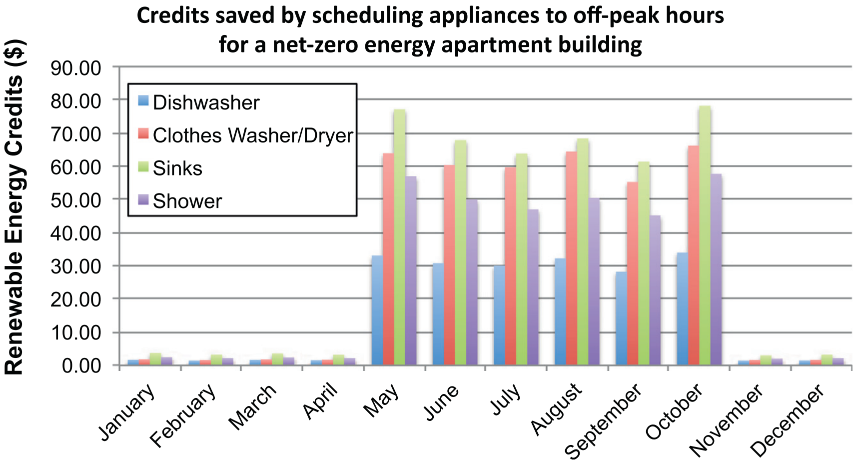
HIGHLIGHTS

- Appliance time-of-use in a net-zero energy apartment was shifted to off-peak hours.
- Net-metered residents were not charged for consuming more than they produced.
- Residents accrued twice as many credits by shifting heavy-duty appliances.
- For some rate structures it is only beneficial to schedule between May and October.
- Electrically heated homes accrued more credits than those using a heat pump.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper investigates the financial incentives of load shifting under a time-of-use rate and Net Energy Metering pertaining to the solar net-zero energy apartment community, West Village in Davis, California. By "smart-scheduling" the electricity and domestic hot water demand of the dishwasher, clothes washer, dryer, sinks and showers solely to off-peak periods, the peak demand is reduced by 18%, the part-peak demand by 32% and the off-peak demand increased by 12%. With this shifted schedule customers accrue twice as many credits as they would receive under a non-shifted schedule with the same time-of-use rate, totaling to $2975 of "free" electricity per year for one 12 unit building. But, under current rates smart-scheduling is found to be worthwhile only during the months from May through October, when 96% of the credits are accumulated. If the rate schedule is altered to include peak-periods during the winter months, the credit savings will double again in value. These comparisons are prepared using two photovoltaic simulation programs (PolySun by Vela Solaris and System Advisory Model by the National Renewable Energy Laboratory) and for apartments using an electric heater and a heat pump for domestic hot water. By quantifying these savings, PV generating customers are informed that a time-of-use rate can benefit them significantly, especially if the surplus generation is maximized and sold to the grid during peak day time hours. With this information, housing developers can create effective incentives for residents, and utility companies, policy makers and designers of smart-scheduling household appliances can encourage a more reliable, clean and economical national grid.

1. Introduction

Residential Time-of-Use (TOU) electricity pricing has recently received renewed attention as a way of incentivizing customers

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Nomenclature

AB	assembly bill
COP	coefficient of performance
CPUC	California Public Utilities Commission
DEG	Davis Energy Group
DHW	domestic hot water
MEL	miscellaneous electric load
NEM	Net Energy Metering
NEMV	Virtual Net Energy Metering
NREL	National Renewable Energy Laboratory
NZE	net zero energy
PG&E	Pacific Gas & Electric Company
PV	photovoltaic
REC	Renewable Energy Credits
SAM	System Advisory Model
SB	senate bill
TOU	time-of-use

to shift electricity loads to periods of the day that are more coincident with the utility's production. By reducing peak period electricity demand, TOU rates could potentially save residents $1.2 billion per year in California alone and benefit utility companies by reducing the need for expensive peaking generators, thereby cutting annual utility operation costs by $15 billion in the United States [1,2]. Overall, load shifting makes the overall grid more reliable and it facilitates the reduction of greenhouse gas emissions and the compatibility of renewable sources with the grid, thereby creating a more diversified, clean and secure energy portfolio [3–6].

The introduction of Net Energy Metering (NEM) by 46 states[1] enables customers to receive cash compensation or Renewable Energy Credits (RECs) for excess electricity generated by on-site renewable sources [7]. As a result, NEM has invigorated a new growth of Net-Zero Energy (NZE) buildings, the number of which has doubled since 2008 [8,9]. In September of 2010 the California Public Utilities Commission (CPUC) progressively called for all new residential construction to be NZE by 2020 [10]. These NZE buildings have a unique capacity to leverage the advantages of both NEM and TOU rates in order to increase the value of REC savings through load shifting, or "smart scheduling". The incentive of TOU rates to net-zero households, and one that has not yet been quantified in literature to the authors' knowledge, is that by properly scheduling appliances during the off-peak hours consumers are able to use more electricity than they generate without paying for the extra consumption (see Section 3.2). Nevertheless, as of 2011 only 1% of utility consumers utilize some form of a TOU rate, in part due to the lack of smart meters, but also due to the uncertainty of whether or not TOU rates offer a great enough incentive for customers to opt-in [11,12].

Therefore, this paper quantifies the bill savings of residents who shift heavy duty electric and domestic hot water (DHW) loads from their typical time-of-use to the off-peak periods in a solar-powered NZE apartment building, in order to shed light on the advantages of rate structures, energy policies and new smart-scheduling household appliances, while also highlighting their shortcomings. The building under consideration is a new NZE housing complex called the West Village Ramble Apartments at the University of California Davis campus. At build out, the UC Davis West Village will contain 662 apartment units and 343 single-family homes [13]. It will be an all-electric campus, powered by a solar photovoltaic (PV) array and possibly a digester supplying a generator for additional electricity, and will use a heat pump with a backup electric heater for the DHW supply. In its current phase the PV array is 4 MW and each apartment unit operates under a NEM agreement with the local utility Pacific Gas & Electric Company (PG&E). The shifting of electricity and DHW consumption of five appliances – the dishwasher, clothes washer, dryer, sinks and showers – in the apartment's 4-bedroom units are considered.

The specific objectives of this study are as follows: (1) To quantify the REC savings of a NZE apartment complex by load shifting heavy-duty household appliances and applying various rate structures and cash reimbursement options, (2) To compare the REC savings of a heat pump vs. an electric heater system, (3) To understand which appliances affect load shifting the most and by how much, and (4) To compare two PV simulation programs, PolySun from Vela Solaris and System Advisory Model (SAM) by the National Renewable Energy Laboratory (NREL) in term of their predicted electrical output. We point out that TOU rates in most of California are fixed (by PG&E) and do not vary with time.

2. Literature review

2.1. Previous work

TOU rates and NEM have been studied extensively before; however few studies combine time-of-use shifting and NEM, especially for net-zero communities. Kwan and Kwan [14] considered a net-zero college campus in which they calculated the net present value of the PV system compared to the cost of electricity from fossil fuels. The analysis was based on the available state and federal rebates and NEM, but did not consider various rate structures or load shifting. Darghouth et al. [15] studied the value of net metering under various rate schedules, including TOU and market price referents throughout California, but did not consider TOU load shifting or net surplus Compensation (NSC) through California's Assembly Bill (AB) 920. A 2008 study [16] on 20 different electricity rates in California estimated that PV producing customers could save 5–20% by switching to a TOU rate as opposed to a set flat rate. The study also showed that the end-user load shape can make a modest difference in *demand* (kW) charge savings, but does not go into detail about the *energy* (kW h) charge savings, hourly load profiles, or shifting of specific appliances. Therefore, this paper focuses on the accrual of RECs and cash compensation through AB 920 by load shifting specific appliances within a TOU rate and flat rate.

It has been shown in several publications that TOU does alter end user load patterns, resulting in reduced peak loads (e.g. see [17]). Faruqui and George [18] calculated peak load reductions in response to TOU rates as much 10–15% and a 4% increased load during for the off-peak period, which means that TOU shifting could result in an overall energy decrease. An EPRI report confirms this, reporting a 20% reduction of peak-demand and 4.5% total consumption reduction due to TOU rates [2].

In other studies, all-electric homes have been found to have a greater demand response to TOU tariffs than homes with electricity and natural gas [17]. Fortuitously, the Ramble Apartments are all-electric and will be evaluated with an electric resistance heater as well as an electric air-to-water heat pump. Furthermore, new

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[1] As of October 2011, 43 states plus Washington DC mandate that utilities offer a TOU rate, while 3 states provide voluntary net metering.

home appliances such as timer-equipped dishwashers, timed thermostats, programmable timers, and all-in-one washer dryer units with delayed timing all make scheduling easier for the consumer [4]. The development of latent heat thermal energy storage that incorporates phase change materials into hot water tanks, such as those demonstrated by Sharma et al. [19], will further enable DHW to be heated during off-peak periods, stored, and used later for sinks and showers [20]. These advancements in energy efficient technologies make the study more relevant and validate the assumption that all electricity and DHW for the dishwasher, clothes washer, sinks and showers can be rescheduled to off-peak hours.

The optimization of TOU tariffs has been the subject of many studies in which algorithms are employed to maximize the consumer's bill savings while guaranteeing a fixed profit to the utility company [3,5]. In the case of Datchanamoorthy [3], a shifted load profile saved a household $0.68 per day, or $248.71 per year when using an optimized yet fictitious utility rate that does not vary by day of the week or season like the PG&E TOU rate does. The inclusion of a PV array with NEM, which this study explores, changes the bill savings by placing a customer in a lower tier.

2.2. Limitations of the current work

More appliances could have been considered in the analysis, like heating, air conditioning and refrigeration. It has been shown that homes with air conditioning have twice as great of a peak load reduction in response to TOU rates than those homes without air conditioning [18], but since the Ramble Apartments have high efficiency air conditioning this was not included. The study did not factor into account that TOU rates could result in an overall decrease in consumption [2,18], which would result in more savings, or that the PV system would be better faced southwest to capture the peak rates during the afternoon and early evening [21,22]. Wiser's study revealed that higher-usage customers in highly priced tiers save more money per installed kW of PV [15]. Therefore, it is reasonable to assume that higher-usage customers would save more money by load shifting because there is more electricity to shift. Furthermore, Mills et al. [16] shows that different TOU rates have different sensitivities to various load profile shapes. So, other non-PG&E rates, such as Southern California Edison, will likely have different responses to load shifting; In particular, the TOU rates with a larger spread between peak and off-peak rates will generate more benefit to the customer [16]. The present study uses tariffs currently applicable to the West Village, which are fixed by time of day, day of the week, and season. The effect of real-time market pricing and several algorithms and methodologies for an automated energy management system for distributed generation, have been described in recent literature and could be extended to include the present study in the future [23–26]. Nonetheless, the existing rate structures employed in this paper are representative of current tariff structures and demonstrate the importance of smart-scheduling for NEM homes or apartments anywhere.

3. California legislation and utility rate descriptions

3.1. California legislation

The California NEM program was established in 1995 through legislation SB 656 [27]; however, it was not until 2009 that AB 920 required utilities to reimburse customers for surplus electricity generated by on-site renewables [28]. Compensation is provided by an annual cash reimbursement at a rate set by PG&E in agreement with the CPUC's standards and public proceedings [29]. As of October 2012, it is at $0.03145/kW h and has declined by 22% since its start in January 2011, as shown in Fig. 1. Alternatively, compensation can be given in the form of RECs, which are calculated at the same rate as the time the excess electricity was produced and can be rolled over month to month indefinitely and used at any time.

SB 32 [30] limits NEM to installations of 3 MW or smaller, per metered household, and requires that customers cannot oversize the PV system to be greater than their expected annual load. Through AB 510 [31] the NEM program is capped so that the maximum net-metered capacity that a utility company can accept is 5% of its customers' aggregate peak demand. In July 2011, the CPUC voted in favor of expanding Virtual Net Metering (NEMV) to all multi-tenant housing with on-site generation. Under NEMV, RECs generated on-site are to be shared with tenants who do not have a net surplus generation in order to reduce their electricity bill [29]. Alternatively, the extra credits could be used to charge electric vehicles at no extra cost.

3.2. Time-of-use rate and REC accrual phenomenon

The value of a PV customer's bill savings and hence RECs, depends heavily upon the rate structure, as Darghouth et al., points out [15]. But smart-scheduling within a rate structure can also have a significant impact on the RECs for a net-zero home. For example, with a TOU rate structure the price of electricity may be three times larger during the daytime peak hours than it is at night. By shifting heavy-duty appliances from day to night, the cost of consumed electricity is reduced and the credit reimbursement for PV electricity generated during peak hours increases at the retail rate during which it was generated. With correct scheduling, it is possible for consumers to use more electricity than their PV array produces without paying for the extra consumption.

Table 1 shows an oversimplified example of this TOU phenomenon to demonstrate the point. Both the non-shifted and shifted schedules use 10 kW h and generate 10 kW h, but the shifted schedule transfers 5 kW h of consumption from the day to the night. The customer with the shifted schedule is credited one extra dollar, which can be used for an extra 3.3 kW h of electricity during the day or an extra 10 kW h of electricity at night. While actual rates are more complicated, the same concept holds true.

In the case of PV equipped net-zero apartments, the customer, who is often the housing developer as is the case for the UC Davis West Village, will have a much larger incentive to shift residents'

Table 1
Example calculation of time of use renewable energy credit phenomenon.

TOU Schedule	(Consumption − production) × rate = electricity bill				
Non-shifted					
Day	(10 kW h + −10 kW h) × 0.30 $/kW h = $0				
Total consumption	10 kW h	Total production:	−10 kW h	Total bill:	$0
Shifted					
Day	(5 kW h + −10 kW h) × 0.30 $/kW h = −$1.50				
Night	(5 kW h + 0 kW h) × 0.10 $/kW h = $0.50				
Total consumption	10 kW h	Total production:	−10 kW h	Total bill:	−$1.00

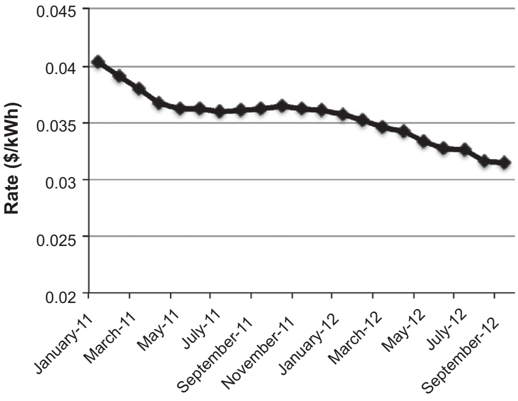

Fig. 1. Historic PG&E cash compensation rates.

usage because the REC savings will be magnified over a large number of units. Note that the standard compensation rate for receiving cash back (see Fig. 1) is completely independent of the time that energy was consumed or produced. The calculation is simply the annual net surplus energy at the end of the billing year multiplied by the compensation rate, in which this example contributes $0 to cash back.

Some studies have explored the scenario of shifting demand to the night and utilizing the solar generated electricity during the day for appliances or charging lead-acid batteries. A UK study found that storing or using surplus electricity is not a beneficial practice, even if the batteries were considered idealized and lossless [32].

4. Methodology

4.1. Consumption profiles

The total estimated annual DHW and electricity consumption data for the UC Davis West Village Ramble Apartments were originally produced by the Davis Energy Group (DEG). The NREL Building America report and eQuest, a building energy simulation tool that incorporates building type and weather location, were used to simulate the DHW and electrical consumption of each individual apartment unit [33]. This consumption profile provides a realistic hourly baseline load shape that distributes the consumption of appliances throughout the day based upon statistical data [15]. As an example, Fig. 2 shows the clothes washer load profile shape.

To see the effect of time-of-use, it is necessary to find the contribution of each controllable appliance to the hot water and electrical demand so that this contribution can be subtracted out from the total demand and shifted to a different time of day. The controllable appliances in this study are the clothes washer, dishwasher, shower and sinks. The maximum controllable load is 4477 kW h/year for an electrically heated unit and 2528 kW h/year for a heat pump unit. Fig. 3 shows the annual break down of each controllable appliance and how it compares to the total consumption.

To create the shifted schedule, the hourly load profile of each appliance is first calculated by multiplying the hourly-normalized load profile (like the one shown in Fig. 2) by the appliance's total daily consumption. An appliance's total daily consumption is calculated from formulas also provided in Building America and is

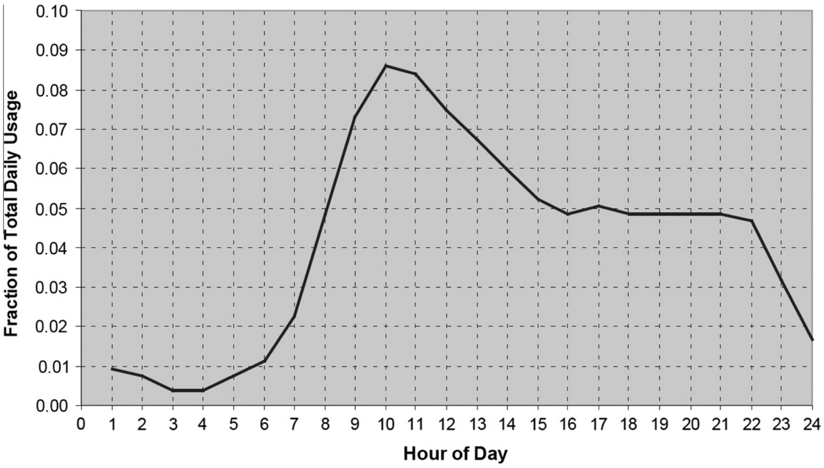

Fig. 2. The normalized load shape profile for a dishwasher's electricity and DHW [28].

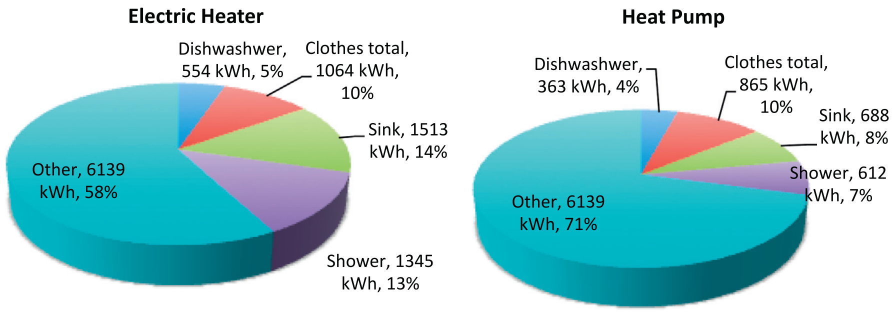

Fig. 3. Breakdown of annual consumption for controllable appliances for an electrically heated apartment (left) and heat pump apartment (right).

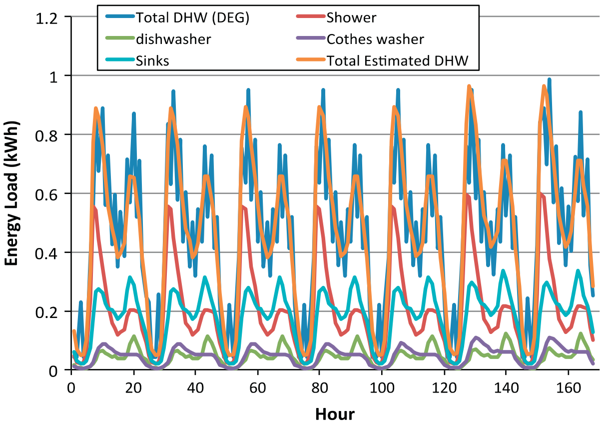

Fig. 4. First week's DHW load profile by appliance for an electric heating system.

based on the number of rooms, the day of the week, and the average daily mains temperature as shown by the following formulas.

DHW consumption (gal/day):

$$\text{Clothes Washer} = 2.35 + 0.78N_{br}$$

$$\text{Dishwasher} = 2.26 + 0.75N_{br}$$

$$\text{Shower} = 14 + 4.67N_{br}$$

$$\text{Sinks} = 12.5 + 4.16N_{br}$$

where N_{br} is the number of bedrooms. The daily thermal energy is then calculated using[2]:

$$Q = mc_p(T_{setpoint} - T_{mains})$$

The mains temperature is calculated from [34]:

$$T_{mains} = (T_{amb,avg} + \text{offset}) + \text{ratio}\left(\frac{T_{amb,max}}{2}\right)\sin[0.986 \times (\text{day}\# - 15 - lag) - 90]$$

where T_{mains} is the mains supply temperature (°F), $T_{amb,avg}$ is annual average ambient air temperature (°F), $T_{amb,max}$ is maximum difference among monthly average ambient temperatures (°F), 0.986 is degrees/day (360/365), day# is day of the year (1–365, 1 January = 1), offset is 6 °F, and lag is 35–1.0($T_{amb,avg} - 44$).

Upon multiplying by the hourly-normalized load profile, the hourly contribution of each controllable appliance is found, as shown in Fig. 4.

To find the electrical contribution of each controllable appliance, the annual electrical consumption (kW h/yr) is calculated using the following equations from Building America:

$$\text{Clothes Washer} = 38.8 + 12.9N_{br}$$

$$\text{Clothes dryer} = 538.2 + 179.4N_{br}$$

$$\text{Dish Washer} = 87.6 + 29.2N_{br}$$

This annual consumption is divided by 365 days and multiplied by a day-of-the-week multiplier and finally the normalized hourly load shape (like Fig. 2) to yield its hourly consumption. Since the West Village Ramble Apartments are powered completely by PV, even the DHW becomes an electrical load, either through an electric resistance heater or a heat pump. For the units utilizing a heat pump, the consumption for DHW appliances was divided by a yearly average COP of 2.2, which was obtained from actual data collected at the Ramble Apartments.

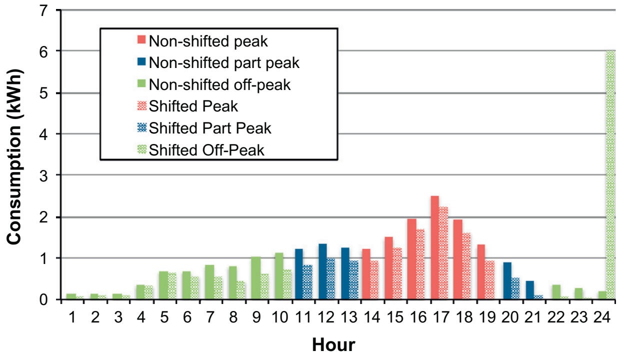

Fig. 5. The total shifted and non-shifted consumption for a 4-bedroom, heat pump operated unit, on a typical summer weekday.

An appliance's hourly load profile is then subtracted from the total non-shifted profile and its sum is added to the midnight hour, an arbitrarily chosen off-peak hour such that the shifted and non-shifted profiles integrate to the same total demand. Fig. 5 gives an example of this, although each day's load profile is unique. In practice, the shifted energy can be scheduled any time between 10 pm and 10am so as to avoid exceeding peak power of the residence. The remaining non-shifted consumption is due to the non-controllable building loads derived from the DEG predictions for the Ramble Apartment.

Over the course of the year Table 2 shows that the peak period reduces by 18% between the shifted and non-shifted consumptions, which is in line with other load shifting predictions [2,18]. The part peak reduces by 32%, and the off-peak period increases by 12%. This results in more than tripling the annual surplus generation during peak hours and more than quadrupling the part and off-peak net surplus generation. Table 2 also shows that the peak period consumption is relatively small because it is only enforced six months a year, and the off-peak consumption is large because it is enforced year-round and during the winter months it accounts for most of the hours.

Other survey and simulated data exists for apartment building energy use profiles [35]. The methodology presented here was chosen because it is tailored to the specific location in Davis, CA.

4.2. Solar production simulation

The software packages PolySun and SAM were used to predict the hourly production of the solar PV system, which makes the apartment building net-zero in energy over the course of a year. Both programs account for solar variability through statistical weather forecasting. A comparison of these two programs, their usability and performance, is provided in the Section 5.

The simulation settings for PolySun and SAM are shown in Table 3. The wind fraction refers to the percentage of wind that effectively falls on the solar panels; it is a user defined variable in PolySun but not in SAM. The soiling factor, cable factor, mismatch factor, and name plate factor all represent losses in the system, and the combination of these factors is the total de-rate factor. The degradation of the panel efficiency is 0.5% per year. The soiling factor was set to 98%, but all other values were left at their default.

The PV system was modeled as closely as possible to the actual Ramble Apartment system, using the same panels, inverters and site-specific weather conditions. The only exception to this rule

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[2] The dishwasher and clothes washer set point temperature is 54 °C and showers and sinks are set to 43.3 °C. The volumetric hot water consumption was 275 l/day for the 4-bedroom apartment unit. The simulation ran without any absences. The Ramble Apartment units also use EnergyStar dishwashers and clothes washers.

Table 2
Annual shifted and non-shifted energy consumption values for a heat pump unit (Unit 204 SAM).

	Peak (kW h)	Part-peak (kW h)	Off-peak (kW h)	Total (kW h)
Non-shifted consumption	1322	1394	5952	8667
Shifted consumption	1090	941	6636	8667
Net non-shifted consumption[a]	−96	−136	222	−11
Net shifted consumption[a]	−328	−589	906	−11

[a] “Net consumption” refers to consumption minus production. A negative value

Table 3
Simulation parameters for PolySun and SAM.

	PolySun	SAM
Orientation	South	South
Tilt	31°	31°
Wind fraction	50%	–
Soiling factor	98%	98%
Cable factor	96%	96.5%
Mismatch factor	96%	98%
Name plate factor	–	95%
Total de-rate factor*	90.3%	88.1%
Degradation per year	0.5%	0.5%

* The inverter is modeled explicitly; its losses are not included here.

Table 5
PG&E residential rates and time periods as of July 1, 2012 [36].

Rate	Time	Tier 1 rate[a]	Day of week
E1 Flat	All year	\$0.12845	Everyday
E6 TOU			
Summer			
Peak	1–7 pm	\$0.27883	Monday–Friday
Part-peak	10–1 pm	\$0.17017	Monday–Friday
	7–9 pm	\$0.17017	Monday–Friday
	5–8 pm	\$0.17017	Saturday and Sunday
Off-peak	9–10 am	\$0.09781	Monday–Friday
	All other	\$0.09781	Saturday and Sunday
	All day	\$0.09781	Holidays
Winter			
Peak	None	–	
Part-peak	5–8 pm	\$0.11776	Monday–Friday
Off-peak	All other	\$0.10189	Monday–Friday
	All day	\$0.10189	Saturday, Sunday and Holidays

[a] Units of \$/kW h.

is the tilt of the PV panels, which is simulated at an optimal angle of 31° instead of the Ramble's rooftop pitch of 18°. All the panels have a fixed angle and face due south. Two different 4-bedroom units, Unit 204 and Unit 104, were evaluated. Table 4 shows the array design and the simulation results, which will be elaborated upon in Section 5.4. For now, it is confirmed that the PV arrays provide sufficient electricity for the units to be net-zero, plus a small buffer of extra electricity that is typical of engineering designs.

4.3. Utility rate descriptions

The cost analysis is based upon California's PG&E rates and rules, as of July 1, 2012. The electricity rates available to residential customers with NEM are the standard flat rate (E1), which is independent of time or day, and the TOU rate (E6), which is categorized by season, type of day (weekday, weekend or holiday) and time of day: peak, part-peak, and off-peak. Table 5 shows the time and cost breakdown of each rate. It is important to note that the Peak period is only in effect during the summer months. The E1 flat rate is the default tariff for all PG&E customers and customers must call PG&E to switch to the E6 TOU tariff.

Both E1 and E6 are divided into four tiers and the cost of electricity increases with each tier as a resident's consumption surpasses prescribed percentages of a baseline quantity. The baseline quantity is a set kW h value that depends on the territory, days in the month and whether or not the household is all-electric. Only tier 1 is shown in Table 5 for conciseness, and it turns out that in most cases, tier 1 is the only tier used for NZE buildings because the monthly net consumption is rarely large enough to exceed the baseline quantity. For this reason, the savings due to load shifting will be fundamentally different for NZE buildings.

Bills are calculated by summing the month's net hourly consumption within each TOU period, dividing by the total use, and then multiplying by the baseline quantity and the period-specific rate. See Table 6 for a breakdown of the formulas. If the production is greater than the consumption, the customer is issued RECs or cash reimbursement at the end of the year. If the net consumption is exactly zero, the bill is evaluated in tier 1.

5. Results

5.1. Effect of rate structure and smart-scheduling on electricity bill

Fig. 6 plots the production, consumption and net consumption for each TOU period in the non-shifted scenario. Note that the production curve only captures about half of the peak period during this typical summer day.

The value of shifting the consumption to off-peak periods, like that shown in Fig. 5, is compared to the non-shifted schedule using the E6 TOU rate. These monthly bills for the heat pump and electric heating systems are plotted in Fig. 7 along with the E1 flat rate.

Table 4
PV array design and production for two 4-bedroom Ramble Apartment units.

	Unit 204 heat pump		Unit 204 electric heater		Unit 104 heat pump		Unit 104 electric heater	
	PolySun	SAM	PolySun	SAM	PolySun	SAM	PolySun	SAM
Solar module	SunPower 225E-BLK-D (225 W)				SunPower 425E-WHT-D (425 W)			
Number	24		30		12		15	
String × module	4 × 6		3 × 10		2 × 6		3 × 5	
Inverter	SPR 6000 m		SPR 7000 m		SPR 5000 m		SPR 6000 m	
Simulation result (AC kW h/yr)	8930	8678	11,140	10,705	8423	8043	10,519	10,129
Total demand (kW h/yr)	8667		10,615		7980		9928	
DHW demand (kW h/yr)	1624		3572		1624		3572	
Electric demand (kW h/yr)	7043		7043		6356		6356	

Table 6
Time-of-use formulas for calculating bills under PG&E [37].

Period	Formula
Peak	
Tier 1	[(Peak use)/total usage) × (baseline quantity)] × tier 1 peak rate
Tier 2	[(Peak use)/total usage) × (baseline quantity)] × 30% × tier 2 peak rate
Tier 3	[(Peak use)/total usage) × (baseline quantity)] × 200% × tier 3 peak rate
Tier 4	Remainder kW h of peak usage × tier 4 peak rate
Total peak charges/credit: sum of tiers 1–4	
Part-peak period	
Tier 1	[(Part-peak use)/total usage) × (baseline quantity)] × tier 1 part-peak rate
Tier 2	[(Part-peak use)/total usage) × (baseline quantity)] × 30% × tier 2 part-peak rate
Tier 3	[(Part-peak use)/total usage) × (baseline quantity)] × 200% × tier 3 part-peak rate
Tier 4	Remainder kW h of part-peak usage × tier 4 part-peak rate
Total part-peak charges/credit: sum of tiers 1–4	
Off-peak period	
Tier 1	[(Off-peak use)/total usage) × (baseline quantity)] × tier 1 off-peak rate
Tier 2	[(Off-peak use)/total usage) × (baseline quantity)] × 30% × tier 2 off-peak rate
Tier 3	[(Off-peak use)/total usage) × (baseline quantity)] × 200% × tier 3 off-peak rate
Tier 4	Remainder kW h of off-peak usage × tier 4 off-peak rate
Total off-peak charges/credit: sum of tiers 1–4	
Total monthly charge or credit: sum of peak, part-peak, and off-peak periods	

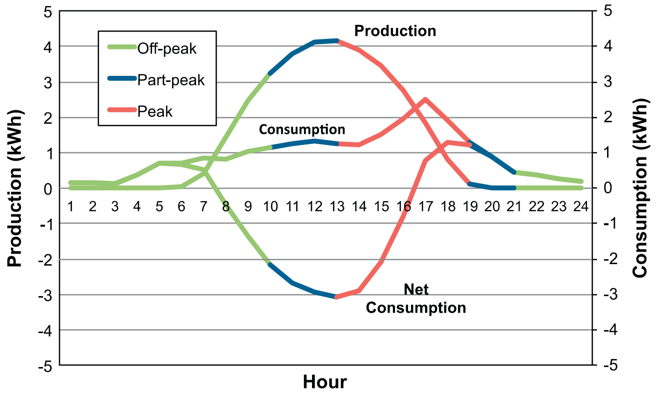

Fig. 6. Production, consumption and net consumption of a non-shifted apartment unit.

Although cash compensations are calculated annually the monthly equivalent is plotted as well for reference.

For both the electric heater and the heat pump, NZE consumers can expect to generate extra credits from March through October under any rate structure. The shifted E6 TOU rate results in the greatest savings for nine months of the year, followed by the non-shifted E6 TOU rate and most expensively, the default flat rate. During March and April the flat rate is slightly better because the solar production is large during these months but the summer TOU peak-period is not in effect until May, which puts the flat hourly rate slightly higher than the TOU rate.

Overall, the net annual bill is negative (compensation is due) for all three cases, which is expected for a NZE community with excess capacity. However, the annual reimbursement amount varies drastically depending upon which rate is chosen and whether or not the customer chooses credit or cash compensation. Fig. 8 shows the annual reimbursement for Ramble Apartment Unit 204. The cash compensation is almost negligible for both heating systems. With a heat pump system under the default flat rate the customer would receive $34 in credit at the end of the year, $83 under a non-shifted schedule E6 TOU rate, and $149 with smart-shifting. The electric heater shows the same trends, and the difference between the two heating systems is further discussed in Section 5.2.

In the case of the UC Davis West Village and future multi-tenant dwellings, the value of smart-shifting is magnified by the collective savings across the whole complex. The Ramble Apartments at Davis' West Village have twelve units per building and upon completion will have 1005 apartment units and single-family homes. Table 7 shows the difference between the annual RECs accrued for a shifted TOU schedule vs. several non-shifted schedules. While the Ramble Apartments utilize a heat pump, the results for a hypothetical electric heater are shown for comparison. All numbers are averaged over PolySun and SAM results and for units 104 and 204.

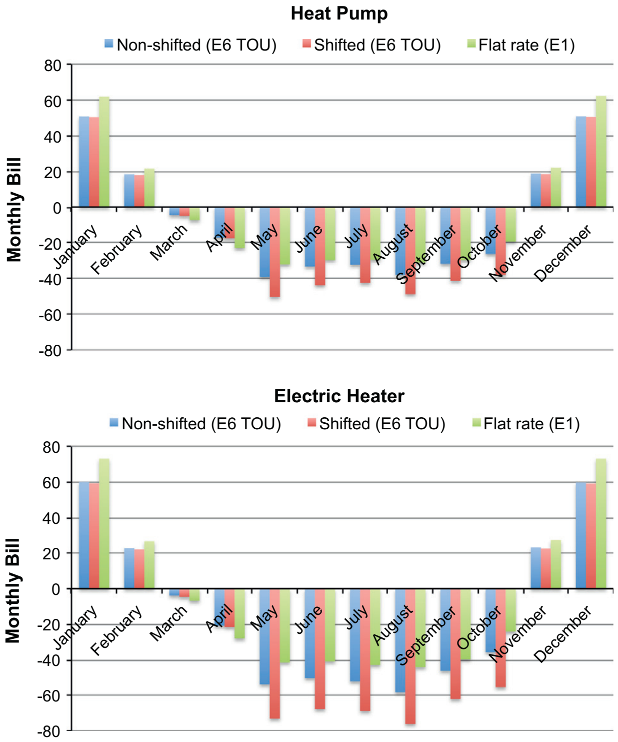

Fig. 7. Effect of rate structure and load shifting on monthly bill for a heat pump (above) and electric DHW heater (below) using PolySun software.

By shifting heavy-duty appliances under a TOU rate, a customer's RECs will be 192% and 203% of the non-shifted RECs, for an electric heater and heat pump system, respectively. Assuming other units behave similarly, the entire West Village operating with a heat pump can accrue an *extra* $66,363 per year, or

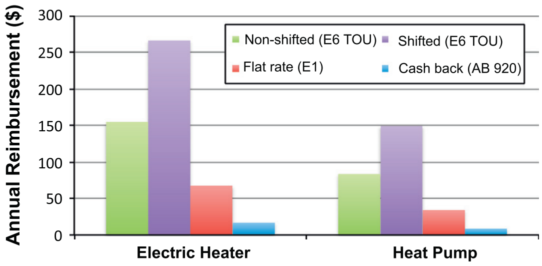

Fig. 8. Comparison of the annual electric bill between an electric heater and a heat pump for DHW (PolySun).

Table 7
Annual extra renewable energy credit saved by smart scheduling, averaged over PolySun and SAM, and units 104 and 204.

Schedule (*A* vs. *B*)	Ratio (*A*/*B*)	Savings per unit (*A* – *B*)	Savings per building (12 units)	Savings for West Village (1005 units)
Electric heater				
Total shifted credits[a]		$248	$2975	$249,154
Shifted vs. non-shifted	192%	$111	$1336	$111,848
Shifted vs. flat rate	874%	$203	$2434	$203,816
Shifted vs. cash	3569%	$237	$2842	$238,054
Heat pump				
Total shifted credits[a]		$146	$1747	$146,323
Shifted vs. non-shifted	203%	$66	$792	$66,363
Shifted vs. flat rate	2717%	$121	$1447	$121,176
Shifted vs. cash	11,095%	$139	$1674	$140,166

[a] Total annual RECs accrued under a shifted TOU schedule using the formulas in Table 6.

$111,848 with an electric heater by smart-scheduling. The incentive is even greater for those who are on the default flat rate, which is a vast majority of the U.S. population. Moreover, the cash compensation can be considered miniscule compared to RECs.

Fig. 9 takes the shifted vs. non-shifted data from Table 7 and plots the difference in credits by the month for an apartment-wide heat pump and electric DHW heating system. Strikingly, the only months when it is worthwhile to shift is between May and October, when PG&E's peak-period is in effect.

5.2. Comparison of the electric heating and heat pump systems

As Fig. 7 shows, a unit with an electric DHW heater consumes more electricity than the heat pump during the winter, but it produces more electricity during the summer because of its larger PV array. Under SB 32, an oversized PV array is prohibited for NEM customers, so the heat pump system cannot have an array equal to that of the electric heating system. Therefore, over the course of the year Fig. 8 shows that the electric DHW unit will have a larger return on RECs. From Table 7 the quantity of REC savings for one apartment building is $1336 minus $792, or $544 more per year. Over the 25-year PV lifespan, the electric DHW heater would accrue $13,600 more RECs than the heat pump. A back of the envelope calculation estimates that the additional cost of PV panels and an electric heater is about[3] $6375 more than the purchase of a heat pump, whose price was adapted from DEG [38]. Ironically, assuming an electric heating system costs $6375 more upfront but saves $13,600 in credits over its lifetime, the electric system would save a net $7225 compared to an energy efficient heat pump, in the case of one Ramble Apartment building. Even using a higher balance of system cost for PV, the heat pump does not break even over the course of 25 years.

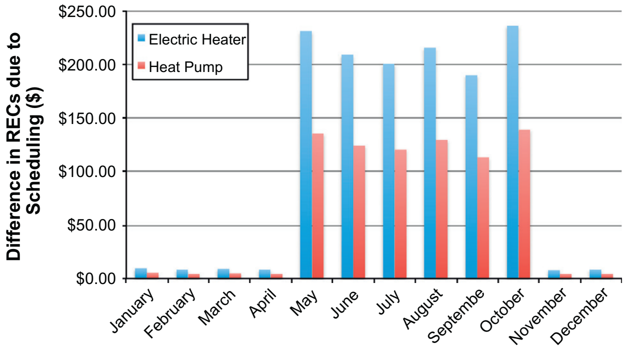

Fig. 9. Apartment building savings between shifted and non-shifted schedules on a TOU rate.

5.3. REC savings by appliance

The individual appliances are tested as well in order to understand the amount of credit each appliance saves by load shifting. Fig. 10 shows the monthly extra credits for an apartment building with an electric hot water heater, which switches from a non-shifted to a shifted TOU schedule. The sinks' hot water has the highest potential to generate extra credits, totaling to $451.53 per year, followed by the combined hot water and electricity of the clothes washers and dryers ($394.72 per year), the showers ($335.36 per year) and finally the dishwasher ($212.05 per year). Again, it is shown that because of PG&E's peak-periods being in effect during the summer only, there is virtually no incentive to shift appliances from November through April.

So then, what if PG&E changed its TOU rate to include peak periods during the winter as well? Below, Fig. 11 shows what happens to the savings due to scheduling when the summer rates and hours are used for the winter too. By shifting heavy-duty appliances in the winter months, the annual savings can increase by 202% and 205% for a heat pump and electric water heating system, respectively. Referring to Table 7, this means that for one apartment building, the shifted vs. non-shifted savings would increase from $1336 to $2742 for an electrically heated building.

For the West Village, the incentive to schedule appliances would grow to $133,966 of extra credits, giving a total of $231,634 RECs per year. Table 8 summarizes the average savings and total RECs for shifted apartments.

5.4. Comparison of PolySun and SAM Software

SAM consistently yields more conservative results with electricity production being slightly lower than that of PolySun and therefore resulting in smaller annual reimbursement estimates, as

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[3] From Table 4, an extra 23,376 kW h of electricity would be needed for an electric DHW heater, which is an extra $14,136 W. The cost of PV is estimated at $1.00/W, a second 120 gallon electric heater $2000 and the heat pump was $9763, from DEG. Installation costs excluded. Balance of System cost estimated at $1.34/W [39].

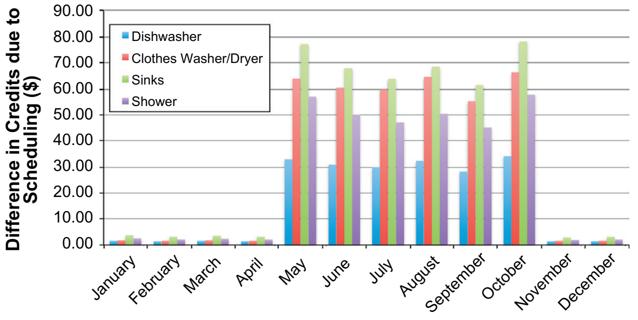

Fig. 10. Apartment building credits by individual appliance for electric DHW.

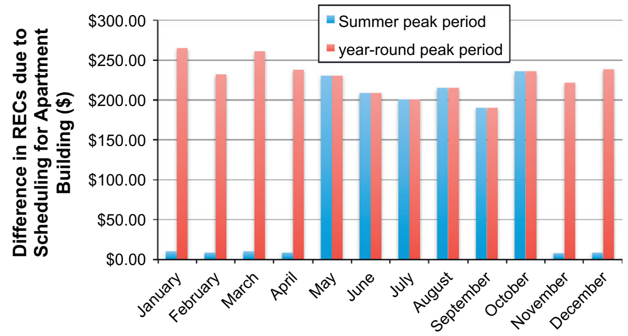

Fig. 11. The difference in savings between the existing E6 TOU rate and a hypothetical rate where the peak rate is applied year-round for an apartment building with an electric DHW heater.

Table 8
Summary of REC savings and total RECs if peak period TOU rate was enforced all year.

Schedule (*A* vs. *B*)	Savings per unit (*A* – *B*)	Savings per building (12 units)	Savings for West Village (1005 units)
Electric			
Shifted vs. non-shifted	$228	$2742	$229,603
Total shifted RECs	$390	$4680	$391,981
Heat pump			
Shifted vs. non-shifted	$133	$1600	$133,966
Total shifted RECs	$230	$2766	$231,634

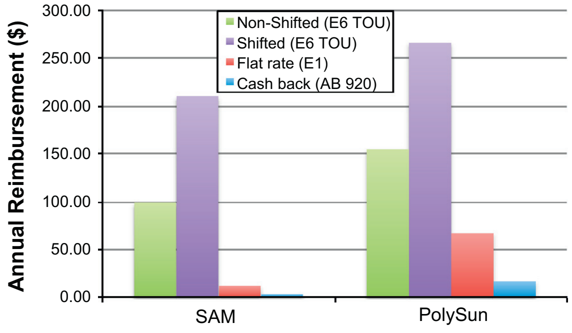

Fig. 12. Annual electric bill for Unit 204 comparing SAM and PolySun software.

Table 9
Comparison of REC savings between SAM and PolySun and units 204 and 104.

Schedule	Unit 204 electric heater		Unit 104 electric heater	
	SAM	PolySun	SAM	PolySun
Shifted vs. not-shifted	$111.29	$111.29	$111.29	$111.29
Shifted vs. flat rate	$198.57	$198.81	$206.36	$207.47
Shifted vs. cash back	$207.25	$249.61	$225.86	$264.74

shown in Fig. 12. From Table 4, PolySun is expected to give 2.5% greater output since the total de-rate factor of PolySun (90.3%) is greater than SAM's de-rate factor (88.1%). The actual outputs from Table 4 are on average 3.9% greater.

However, the savings between the shifted and non-shifted schedules are identical for PolySun and SAM, as shown in Table 9. Similarly, the savings are the same between Units 204 and 104. This is because the load profile is shifted exactly the same and the net consumption for each month is small enough so that the bill is always calculated in the same tier 1. For the flat rate and cash compensation options, PolySun predicts a larger production than SAM, which explains its larger savings. Likewise, the PV array for Unit 104 produces slightly more net surplus electricity than Unit 204, which results in Unit 104 having slightly larger savings. Overall, there is minimal variation of REC savings between different 4-bedroom units and simulation software. So long as the magnitude of the shifted load is the same for each time period, the savings are largely independent of the household's consumption because net-zero communities will likely fall into tier 1.

6. Discussion and conclusions

NZE buildings with similar consumption and production patterns as the West Village Apartments and Building America homes can expect to generate surplus electricity from March through October, resulting in a surplus of free electricity in the form of RECs. Smart-scheduling electricity consumption to off-peak periods is a strong incentive to consumers, nearly doubling the amount of RECs accrued, but only from May through October when 96% of the savings are accrued. For the West Village complex this corresponds to $66,363 more credits for a total of $146,323 RECs per year. The incentive is considerably greater (up to $391,981 RECs per year) if (1) the unit is electrically heated, (2) the peak period was enforced during the winter months, and (3) customers switch from the default flat rate, which is a vast majority of the U.S. population.

In terms of feedback effects to the system, the incentive to shift appliances does not diminish as more load shifting occurs. If a consumer doubles the amount of energy shifted that consumer will accrue twice as many credits. Furthermore, as the discussion in Section 5.4 illuminates, the savings due to shifting are independent of any variations in the total consumption (i.e. if air conditioning is used in one home and not another), so long as the magnitude of energy shifted is constant within each time period. Scheduling the sink hot water will make the most impact on REC savings, followed by the washer and dryer, the shower and then the dishwasher. Therefore, energy efficient hot water heaters that run only during the off-peak hours should be the highest priority. Cash compensation through AB 920 is negligible for NZE residents. Reconciling the difference between RECs and cash compensation is a topic that consumers, utilities and policy makers should address.

Interestingly, when load shifting is considered the extra RECs accrued with an electric DHW system suggests that there may not be a financial incentive to justify the heat pump system since it may not pay itself back over the lifetime of the PV array. Stronger economic incentives for energy efficient heating systems, like heat pumps, will accelerate their adoption.

The introduction of NEMV is attractive to developers of large apartment complexes. Under NEMV, the RECs can be used to offset a neighbor's consumption or other loads like plug-in hybrid vehicles. Another option is that building developers can reduce the size of the solar array to cover a majority of the energy needs but not all of it; this would lead to the concept of a net-zero financing rather than net-zero energy. Future research in the area of smart-scheduling could reveal greater REC savings than what is indicated here, especially if other appliances, PV orientations and TOU rates are considered, as mentioned in Section 2.2.

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