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Electricity costs for a Level 3 electric vehicle fueling station integrated with a building

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HIGHLIGHTS

- Electricity cost for Level 3 electric vehicle refueling at a building is determined.
- Sharing of demand charges between drivers and a building provides largest savings.
- Savings are eliminated when maximum building and vehicle refueling demand coincide.
- Savings potential is primarily created for electric vehicles, not the building.
- Refueling operation can result in a utility rate switch that increases building costs.

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ABSTRACT

Despite the potential environmental benefits, plugin electric vehicles (PEVs) face challenges associated with driving range and long refueling times. Level 3 electric vehicle service equipment (EVSE) is capable of refueling PEVs quickly, but may face economic challenges, such as high utility demand charges. The current study extends prior work to determine if lower utility costs can be achieved by integrating Level 3 EVSE with a commercial or industrial building. Models are developed to simulate travel patterns using real travel data, building demand based upon real building data, and subsequent refueling of Level 3 compatible PEVs to evaluate cost implications of integrating public fast charging into real buildings operating under current electric utility rate structures. Two types of Level 3 refueling station operations are considered (conventional and valet parking). By integrating EVSE with a building, savings can be produced if lower cost energy is accessed, and by the sharing of demand charges between the PEV drivers and the building. These savings were determined to be much more significant to the refueled PEVs than any examined building. The dynamics of building electricity consumption have a large effect on overall demand charge cost reductions, with high load factor buildings providing the smallest savings. Lower load factor buildings may experience a larger benefit, but only if the maximum building demand does not coincide with the refueling of PEVs. In general, savings tend to disappear or turn into losses when valet parking is active and PEV traffic is moderate to high. Increasing building size reduces the risk of peak building and PEV refueling demand coinciding, maintaining savings for PEVs. However, the relative value of the savings due to integration disappears for larger buildings. Installing multiple EVSE can provide a cost benefit under conventional parking, but nearly always increases costs under valet parking. Increasing EVSE power always reduces savings, or increases losses. Finally, if multiple utility rates exist, EVSE integration can result in a rate switch for small buildings, significantly increasing utility costs for the building.

1. Introduction

Plugin electric vehicles (PEV) fueled by low carbon or renewable electricity sources reduce both greenhouse gas and pollutant emissions [1]. Barriers to widespread adoption include range, refueling time, and availability of electric vehicle supply equipment (EVSE) [2–4]. Research focused on Level 1 EVSE (3.3 kW output) and Level 2 EVSE (up to 14.4 kW output but typically 6.6 kW) [5] has shown that the viability [6] and environmental benefit [7] of PEVs can be increased through the use of public EVSE. In addition, Level 3 (or DC fast charging: up to 240 kW but typically 44–120 kW [5]) can

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Nomenclature

Abbreviations

DC	direct current
EVSE	electric vehicle supply equipment
NHTS	United States National Household Travel Survey
PEV	plugin electric vehicle
SCE	Southern California Edison
TOU	time of use

Equation variables

φ_i	Shapley value for member i
N	coalition of n participants
S	any coalition of participants that form a subset of N
$\nu(S)$	cost incurred by coalition S

refuel a depleted PEV up to 80% state of charge in a fraction of the time required by Level 1 or 2, potentially reducing concerns regarding range, refueling time, and EVSE availability. Also, other work has shown that only a fraction of total installed EVSE needs to be public [6]. Much research has been performed to determine the best location, operation, and impact of EVSE.

Optimal EVSE siting models have been developed. Specifically for Level 3 EVSE, work that determines optimal placement along travel routes where lower power EVSE are not viable [8] were studied in [9]. [10] explored the optimal mix of public Level 2 and 3 EVSE located along a travel route. Other work concerned with the optimal placement of EVSE within cities have been developed in [11–21].

Once EVSE sites and layout have been determined, other research has examined how to control PEV refueling to improve grid performance [22,23], minimize electricity cost [24], or both [25,26]. If special EVSE with bi-directional capabilities are installed, a PEV battery can be discharged for the purposes of supplying electricity in support of improving the performance of a building [27–29], micro-grid [30–32], or macro grid [33] as well as reducing the need for electric energy storage in systems with high renewable penetrations [34]. Other work has focused on pricing methods for public EVSE to minimize cost of operation [35], improve customer access to EVSE [36], improve return on work place EVSE investment while remaining cost competitive with gasoline vehicles [37], improve overall grid operation [38], and developing refueling algorithms that reduce the impact of local distribution circuits [39].

The refueling of PEVs introduces new challenges to operating and maintaining the electric utility grid network [40]. Grid reliability [41,42] and voltage stability [43,44] may be reduced in regions with high PEV use. In addition, research on the impact of PEV refueling in residential areas has shown that grid equipment upgrades will be needed if Level 2 EVSE is used and refueling is uncontrolled [45,46]. On the other hand, unscheduled PEV refueling may only increase peak demand by 1% for some regions in the United States [47]. Also, PEV refueling loads have the potential to be aggregated and controlled during off-peak periods to improve grid performance [22,48,49] and reduce grid emission factors [50].

Currently, PEVs comprise a tiny fraction of all vehicles on the road today and Level 3 EVSE make up only 8.5% of all publicly available EVSE (70% is Level 2) [51]. Much of the current literature suggests that improving PEV refueling infrastructure will lead to increased PEV adoption. While PEV adoption is positively correlated with EVSE availability, improving refueling infrastructure does not guarantee an increased number of PEVs on the road [52]. In addition, at an early stage of PEV adoption, investment in Level 3 EVSE is not profitable [53]. The reasons for using Level 3 EVSE along travel corridors are clear (e.g., to enable longer and more convenient travel). However, the viability of using Level 3 EVSE to power our most frequent trips, such as shopping, going to a restaurant (a few commonly suggested locations for Level 3 EVSE [54]), or work travel, has not yet been fully determined. In addition to understanding optimal placement, control, and dispatch of public Level 3 EVSE, the economics of operation must also be evaluated when deciding whether or not to invest in this technology.

Prior work that examines a public Level 3 EVSE stations powered through a dedicated utility meter has shown that the cost to purchase electricity under real utility rates can be prohibitively expensive when demand charges are applicable and PEV traffic is low, or if no parking management occurs [55]. This work also showed that demand charges become relatively small when a large number of PEVs are refueled, i.e., when a demand charge is shared by many customers. While that work examined the utility cost associated with a public Level 3 EVSE station, the results suggest that integration of the EVSE with a building (or installing the Level 3 EVSE on the same utility meter as a building) will lower the cost to refuel PEVs due to the sharing of demand charges between the PEVs and building, even when PEV traffic is low.

This current work is an extension of the work presented in [55], and attempts to answer the question of whether integration of Level 3 EVSE with a building leads to lower PEV refueling costs? Fig. 1 shows a schematic of the scenario considered in the prior work [55], where the EVSE is powered through a dedicated utility meter, and in the current work, where the EVSE and a building share the utility meter. The models developed in [55] that describe PEV travel patterns based on the U.S. National Household Travel Survey (NHTS) [56] and possible EVSE operation scenarios that span most types of public EVSE operation are used to produce an electrical demand load profile for Level 3 EVSE. This load profile is then combined with a building energy model using real building data for summer and winter [57] to produce a combined building and EVSE load. The cost of supplying electricity to this combined load is then determined using utility rate models based on rates for Southern California Edison. The combined utility cost is then split between the EVSE and building through calculation of the Shapley value. Finally, the results with building integration are compared to the results without building integration as presented in [55]. The primary contribution of this work is to address the question of whether the cost to refuel PEVs can be reduced by integrating EVSE with a building, and how such integration affects building energy costs. This analysis assumes that any PEV that can be refueled using Level 3 EVSE is refueled if possible, providing the most supportive (optimistic) case for public Level 3 EVSE.

The paper is organized as follows: Section 2 describes the models and methods used in this work, including the PEV travel model, Level 3 station operation strategy, building energy model, electric utility rate structures, and cost allocation method. Section 3 reviews the cost of electricity for each studied building prior to EVSE integration. Section 4 presents the results from analyzing the integration of the various buildings with Level 3 EVSE operated

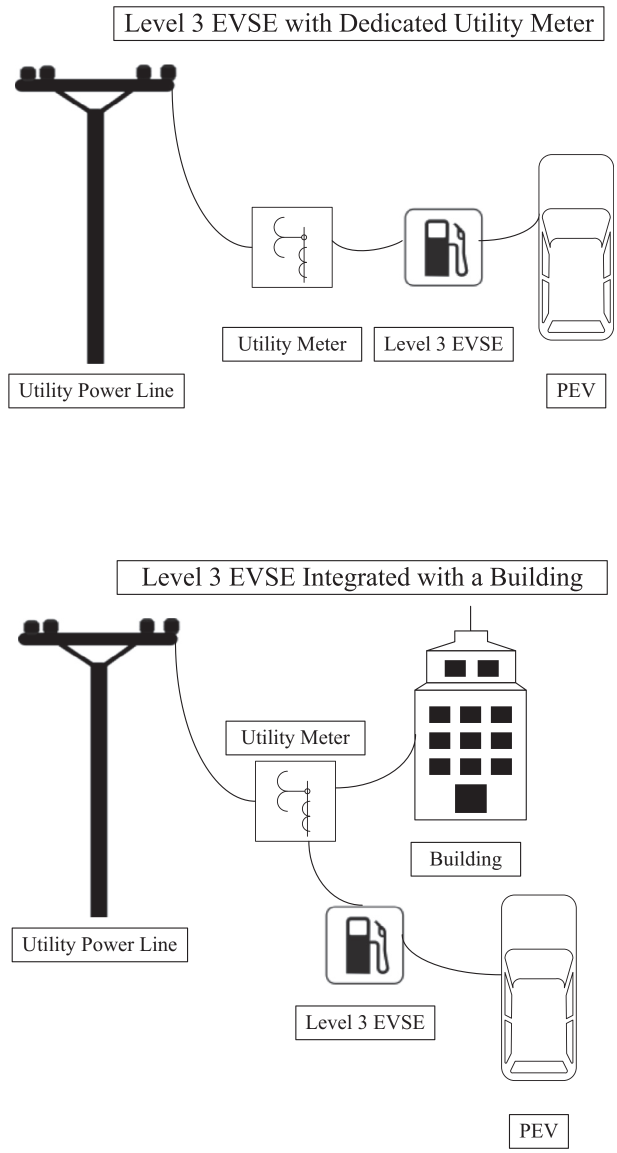

Fig. 1. Schematic of Level 3 EVSE when (a) serviced through a dedicated utility meter, and (b) integrated with a building.

under different operating strategies. Finally, Sections 5 and 6 present the analysis of the results and the conclusions respectively.

2. Methods

The models and methods used in this work consist of a set of PEV traffic (Section 2.1) and Level 3 EVSE operation models (Section 2.2) originally presented in [55], building energy models based on real building energy data [57] filtered using the method described in [58] (Section 2.3), utility rate models applicable for PEV refueling and commercial or industrial buildings developed in [55,59,60] (Section 2.4), and a method of allocating cost between the PEV refueling load and the building (Section 2.5).

2.1. Travel model

Due to a lack of Level 3 refueling data for common types of travel, the probabilistic travel model developed in [55] is adopted to produce a set of PEVs that travel to a public Level 3 EVSE refueling station. First, vehicle sales data is used to produce a probability density function that predicts the types of PEVs arriving at the EVSE station [61]. Using the randomly selected PEV models, the characteristics of the vehicles, such as battery size [62] and vehicle range [63] are known.

Then, probability density functions based on the 2009 National Household Travel Survey data are used to predict the vehicle miles traveled from the origin of travel to the final destination (including any travel occurring in between the origin and selected final destination), the day of travel, time of arrival, and time spent at the destination (or dwell time) [56]. Since the most common trips performed to a public location are for shopping and work, only these two types of travel are considered in this work. For a detailed description of the travel model, please refer to [55].

2.2. Level 3 refueling station operation model

The Level 3 refueling station operation models used in this work are the same as those used in [55]. The two operation models are "conventional parking" and "valet parking". Conventional parking occurs when a PEV is allowed to pull into an EVSE equipped parking spot only if that spot is available at the time of arrival. If the spot is not available, the PEV driver moves on to another spot. Once a PEV driver has pulled into an open spot, the PEV remains in the spot until the dwell time of the driver at the destination is complete.

Under valet operations, if an EVSE equipped parking spot is available at time of arrival, the PEV driver pulls into the spot and begins refueling. However, once refueling is complete, a mechanism exists (e.g., valet driver, person who moves the charging cord, automated switch, multiplexed EVSE, autonomous vehicles) to remove the vehicle from the charger. If a driver arrives when the EVSE equipped spot is occupied, a queue is formed with the unfueled PEVs, which are allowed to begin refueling once the prior PEV has been refueled.

The conventional and valet parking models attempt to span the various systems and strategies that have been adopted by public EVSE operators. Instead of attempting to capture a single system, these two operating strategies can be used to determine the range of electricity costs that can be expected by public Level 3 EVSE. For both strategies, a PEV can only be refueled if arriving with below an 80% state of charge. Refueling is complete when the PEV battery reaches 80% state of charge or the driver leaves, whichever comes first.

2.3. Building energy model

The primary interest of this study is to determine the difference in cost as a result of refueling PEVs using Level 3 EVSE integrated with a building. No two buildings are identical in either load dynamics or quantity of electricity consumed. Prior work has also shown that the cost of electricity for a building located within the service territory of Southern California Edison is highly correlated with the building electrical load factor (average electrical demand divided by maximum electrical demand) [60]. In order to produce robust cost results, the building energy model must span the range of load factors and building sizes that can be found in the built environment.

Prior work has led to the capture of at least a years' worth of building energy demand data in 15 min increments for 39 buildings throughout Southern California [57]. These buildings can be classified as public, commercial, educational, hotel, and industrial buildings, and do not capture typical residential building behavior. Ten buildings from the set of 39 were selected that span high and low load factors for this work. These ten buildings were then filtered using the k-medoids clustering method described in [58] to produce a summer and winter month of representative building energy demand. Since the study is interested in the cost of electricity, and the typical billing period for a utility is one calendar month, only a single summer and winter month of filtered data is required for each building. The filtered summer and winter month power data are shown in Figs. 2 and 3 respectively. Note that the demand profiles for summer and winter were built using data from the respective seasons only, with the season being defined by the utility as described in Section 2.4. As a result, the summer and winter months for each building differ from each other.

The filtered data is then normalized to an average electrical demand of 100 kW, 500 kW, 1000 kW, and 2000 kW average demand to account for a variety of building sizes. This creates four groups of building data ranging from small to large, while removing any effects created within each building size caused by slightly different total energy consumption. These four sets of building data were used to evaluate the effects of integrating Level 3 EVSE with a building on the cost of electricity. The selected buildings are used to model typical public, commercial, or industrial buildings, and is not intended to capture the behavior of residential buildings.

2.4. Utility rate model

The utility model in this work is based on Southern California Edison (SCE) rates. Since public EVSE being integrated with commercial building loads is being evaluated in this work, the applicable SCE rates are TOU-EV-3 [64] and TOU-EV-4 [65] for PEV refueling and TOU-8 [66] for buildings and the aggregated building and PEV refueling load. TOU-8 contains two separate rate structure, rate A and rate B, of which a customer can choose to take service under either rate. This work assumes that the customer will always select the lower cost option between rate A and B. All rates have seasonal time of use energy charges and non-time of use demand charges. Only TOU-8-B has time of use demand charges during the summer. TOU-8 is only applicable to buildings with maximum demand greater than 500 kW. However, the rates appli-

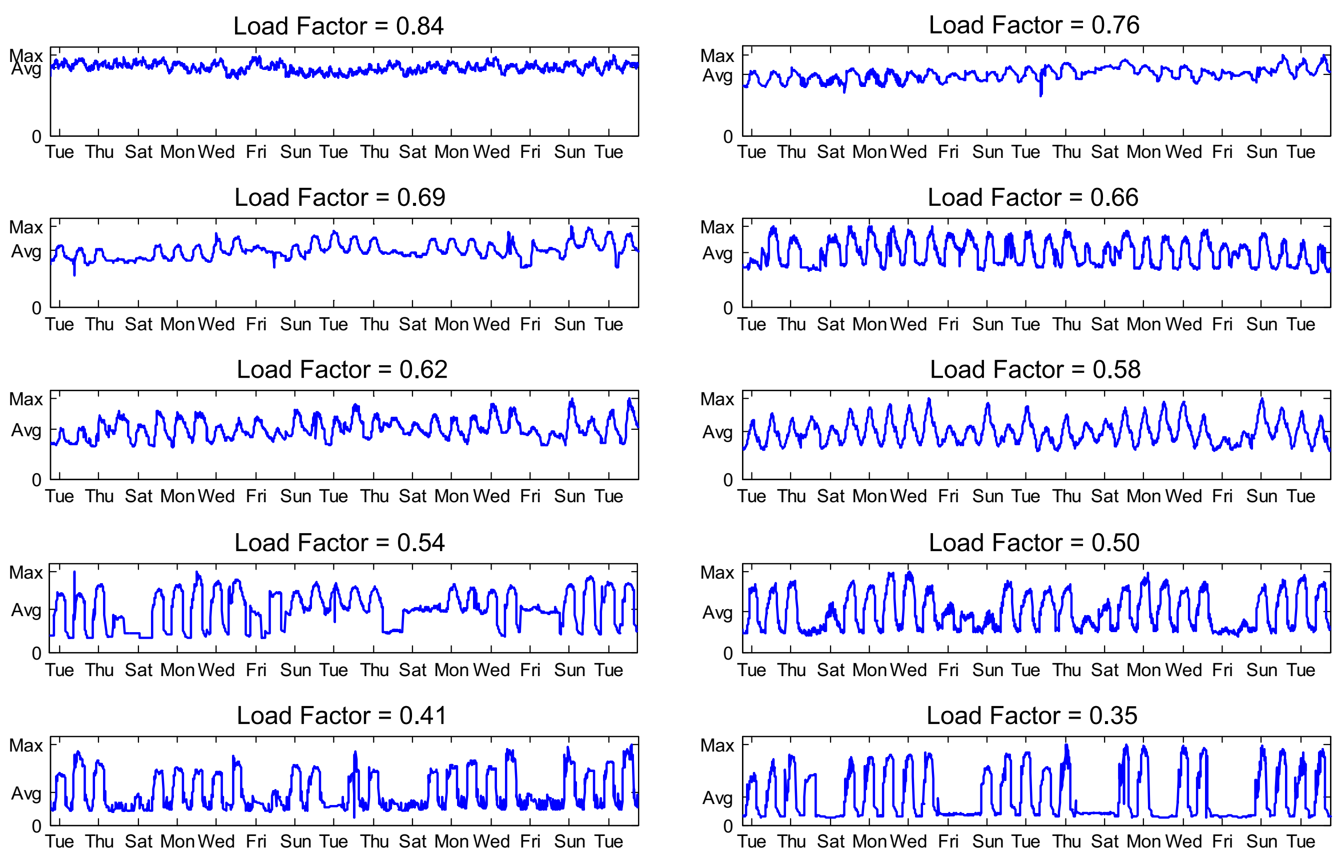

Fig. 2. Representative electrical demand during the summer for the 10 buildings evaluated.

Table 1
Electrical energy and demand charges for TOU-EV-3, TOU-EV-4, and TOU-8 rate structures for Southern California Edison for 2015.

	Rate	TOU-EV-3	TOU-EV-4	TOU-8-A	TOU-8-B
Energy charges ($/kW h)	Summer On-Peak	0.36386	0.29033	0.40067	0.13711
	Summer Mid-Peak	0.17469	0.12248	0.13597	0.08308
	Summer Off-Peak	0.09485	0.05356	0.05938	0.05938
	Winter On-Peak	0.16221	0.10763	N/A	N/A
	Winter Mid-Peak	0.14291	0.09402	0.08487	0.08487
	Winter Off-Peak	0.10374	0.06244	0.06473	0.06473
Demand charges ($/kW)	Summer On-Peak	N/A	N/A	N/A	23.74
	Summer Mid-Peak	N/A	N/A	N/A	6.55
	Summer non-TOU	N/A	13.2	14.88	14.88
	Winter non-TOU	N/A	13.2	14.88	14.88

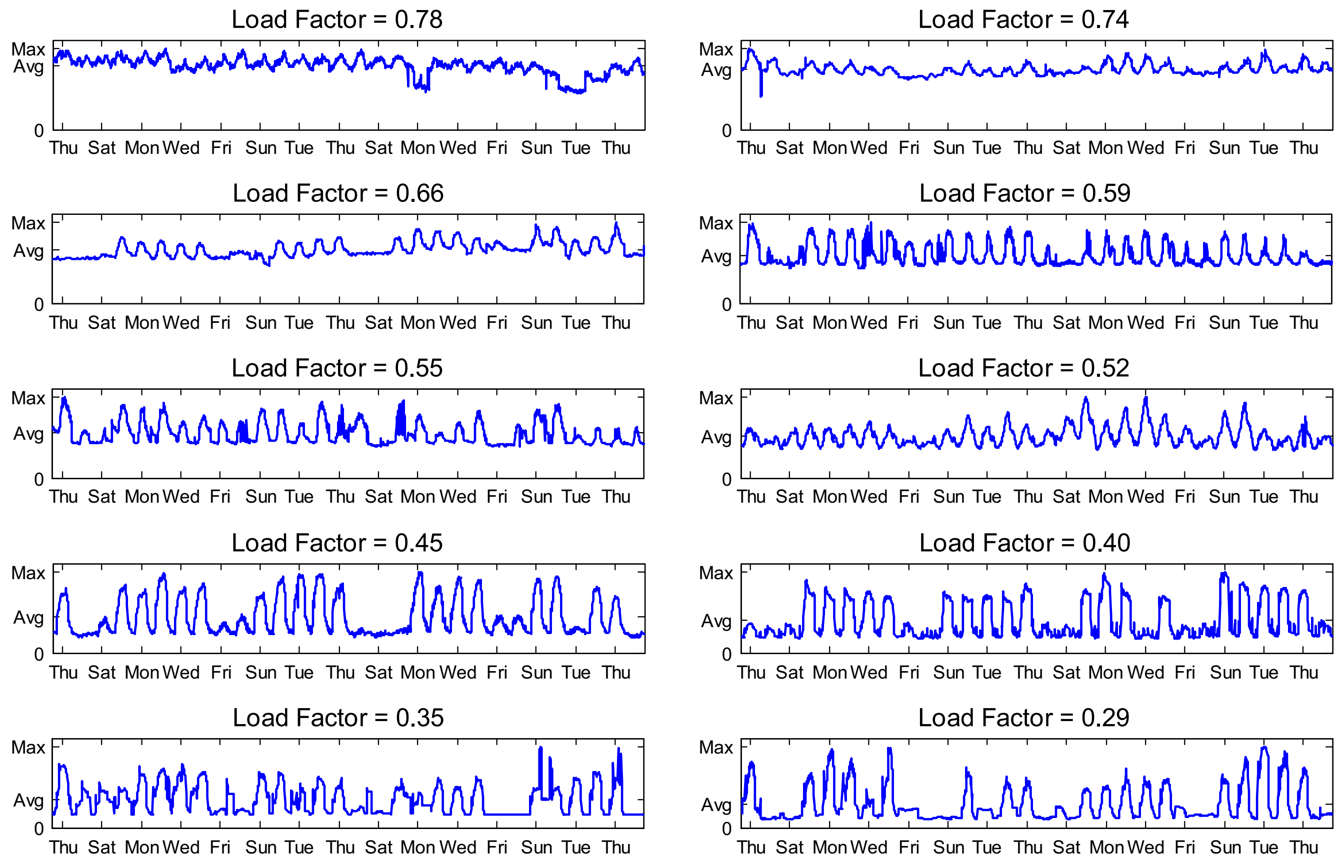

Fig. 3. Representative electrical demand during the winter for the 10 buildings evaluated.

cable to smaller buildings are similar with minor difference in actual charges.

For all rates, summer is defined as June 1st through October 1st and winter is all other time. TOU-EV-3 and TOU-EV-4 define summer and winter on-peak hours as from 12:00 p.m. to 6:00 p.m., mid-peak as 8:00 a.m. to 12:00 p.m. and 6:00 p.m. to 11:00 p.m., and off-peak hours as all other time and weekends. TOU-8 defines summer on-peak hours as from 12:00 p.m. to 6:00 p.m., mid-peak as 8:00 a.m. to 12:00 p.m. and 6:00 p.m. to 11:00 p.m. and off-peak as all other time and weekends. TOU-8 defines winter mid-peak as 8:00 a.m. to 9:00 p.m., off-peak as all other time and weekends, and does not use an on-peak charge. Prior to integration with a building, Level 3 EVSE is typically billed under TOU-EV-4. Applicable SCE rates are shown in Table 1.

2.5. Cost allocation

When EVSE is integrated with a building, the total cost is determined using the model described in Section 2.4 using TOU-8. The total cost, however, can be allocated between the PEV refueling and building demand. While the building and EVSE operators may not cooperate to continuously minimize total electricity cost, the building and EVSE operators may agree to cooperate such that each individual pays for their fair share of the electrical utility bill.

The method used to determine a fair allocation for this work is the Shapley value [67]. While the Shapley value can be calculated for each individual PEV driver, as seen in [55], the purpose of this work is to determine if, in aggregate, EVSE integration with a building leads to lower electricity costs for PEVs. As a result, the Shapley value is calculated for the building and the aggregated PEV refueling load.

The Shapley value is calculated using Eq. (1). In Eq. (1), N represents a coalition of n participants (EVSE and the building). S is any coalition of the participants that form a subset of N. The function $v(S)$ is the characteristic function, which determines the cost incurred by subset S. For this work, the characteristic function is either the energy or demand charge incurred by coalition S. Using these definitions, the Shapley value, or the allocation of participant i, is φ_i.

$$\varphi_i(i) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(n - |S| - 1)!}{n!}(v(S \cup \{i\}) - v(S)) \quad (1)$$

The Shapley value calculates the weighted average of the marginal cost contribution of customer i (either the building or a PEV driver) when combined with any other group of customers. If the PEVs are aggregated into a single load, the Shapley value can be found directly using Eq. (1). While the rate that is applicable to the aggregated PEV and building load is determined by the utility, the Shapley value will show any value created by EVSE integration and assign the cost fairly. For example, if PEVs experience a lower cost of energy due to integration, the building should experience a benefit due to providing access to the lower cost utility rate. Or, if the combination of the building and EVSE loads occurs without increasing maximum utility demand, both parties should experience a cost reduction as a result of splitting a pre-existing demand charge.

Note that the cost allocation method used in the current work only separates shared costs between involved parties. For this particular study, any potential savings or losses generated due to EVSE integration will only be realized if the building and EVSE operator agree to split costs according to the method outlined above. The current work does not address the question of pricing, only cost allocation.

3. Baseline building cost of electricity

An important aspect of this study is to determine the effect of EVSE integration on the building cost of electricity. Using the utility rate model presented in Section 2.4, the baseline cost of electricity (or cost of electricity when no PEVs are refueled at the buildings) can be determined. The effect of EVSE integration will be measured by how the baseline energy and demand charge costs change. The summer energy costs and baseline rate selected (either TOU-A or TOU-B) for the ten buildings are presented Table 2. The winter energy costs under SCE rates for the ten buildings are presented in Table 3. Note that both tables show that the cost of electricity becomes more expensive as load factor decreases and that TOU-B is the less expensive rate for buildings with a medium to high load factor, and TOU-A is less expensive for buildings with a low to medium load factor.

Table 3
Baseline cost of electricity during the winter for the ten winter building loads tested

Load factor	Winter cost of electricity ($/kW h)	Winter energy charge ($/kW h)	Winter demand charge ($/kW h)
0.78	0.1018	0.0764	0.0254
0.74	0.1033	0.0763	0.027
0.66	0.1066	0.0764	0.0302
0.59	0.1106	0.0768	0.0338
0.55	0.1131	0.077	0.0361
0.52	0.1157	0.0771	0.0386
0.45	0.1216	0.0772	0.444
0.4	0.1278	0.0781	0.0497
0.35	0.1371	0.0772	0.599
0.29	0.1454	0.0773	0.0681

4. Level 3 EVSE results

This work assumes that there are two primary scenarios under which Level 3 EVSE can be installed in the built environment: (1) the EVSE is not integrated with a building and receives electrical service through a dedicated utility meter, and (2) the EVSE is integrated with a building and both share the same utility meter. The first scenario was examined in [55] and shows energy and demand charges versus PEV traffic levels. The current work is primarily concerned with determining if the second scenario can provide any cost savings compared to the first scenario. The general shape of the trends in energy and demand charges versus time for both the integrated and non-integrated cases does not change. Therefore, instead of presenting energy and demand charges results versus PEV traffic levels before and after building integration, the cost results in this section are shown in terms of a cost difference between the two competing scenarios. For all cost difference plots, a positive difference indicates that EVSE integration with a building increases cost, whereas a negative difference indicates that EVSE integration reduces cost. The PEV cost difference is created by the utility charges when the EVSE is integrated with a building minus the utility charges created when the EVSE is not integrated with a building (which are also the same utility charges presented in [55]). The building cost difference is created by the utility charges produced when the EVSE is integrated minus the utility charges when the building has no integrated EVSE (the costs for this scenario are presented in Section 3).

Since the shopping and work trips are randomly generated using the NHTS data, the models described in Section 2 are run multiple times for a given number of PEV trips per month. The results of each individual run are then averaged to results presented in this section. The number of simulations performed at each number of PEV trips per month increased until the average result of all simulations at that traffic level experienced marginal changes. The number of trips considered ranges from 50 to 10,000 trips per month. The exact number of tested trips per month is as follows: from 50 to 1000 in increments of 50, 1100 to 2000 in increments of 100, 2200 to 4000 in increments of 200, 4500 to 8000 in increments of 500, and both 9000 and 10,000. Scenarios with one, two, four, and eight EVSE integrated with a building are considered. EVSE power levels considered are 44 kW and 120 kW. Due to a difference between winter and summer utility costs, the results are separated by season. Note that during the summer, either rate A or rate B can be selected as the utility rate. It is assumed that the lowest cost rate will always be used, resulting in the possibility of a switch in utility rate as a result of EVSE integration. In reality, the building operator would have the option to remain on the original, but more expensive, utility rate.

4.1. Shopping travel

4.1.1. Winter season and 44 kW EVSE

Results from [55] showed that approximately 28% of all Level 3 compatible PEVs used for shopping trips will arrive with less than an 80% state of charge. The minimum and maximum number of trips tested per month (50–10,000 PEV trips per month) correspond to 14 and 2787 trips that can be serviced using Level 3 EVSE respectively.

During the winter, EVSE integration with a building creates access to lower cost of electricity during the on-peak and mid-peak, but increases energy costs during off-peak. In general, most shopping trips result in an arrival occurring during on-peak or mid-peak, resulting in an overall reduction in energy cost for PEVs when integrated into the building, as seen in Fig. 4 for one, two, four, and eight 44 kW EVSE operated using conventional and valet parking. For these scenarios, Fig. 4 shows the difference in energy charge as a result of integrating Level 3 EVSE with a building. Since the energy cost at any given moment is determined by time of use

Table 2
Baseline cost of electricity and SCE rate selected during the summer for the ten winter building loads tested.

Load factor	SCE rate	Summer cost of electricity ($/kW h)	Summer energy charge ($/kW h)	Summer demand charge ($/kW h)
0.84	B	0.1619	0.0842	0.0777
0.76	B	0.1714	0.848	0.0866
0.69	B	0.179	0.0846	0.0944
0.68	B	0.1936	0.0869	0.1067
0.66	B	0.1873	0.0877	0.0996
0.58	A	0.1973	0.1629	0.0344
0.54	A	0.2004	0.163	0.0374
0.5	A	0.2069	0.167	0.0399
0.41	A	0.2225	0.1736	0.0486
0.35	A	0.2371	0.18	0.0571

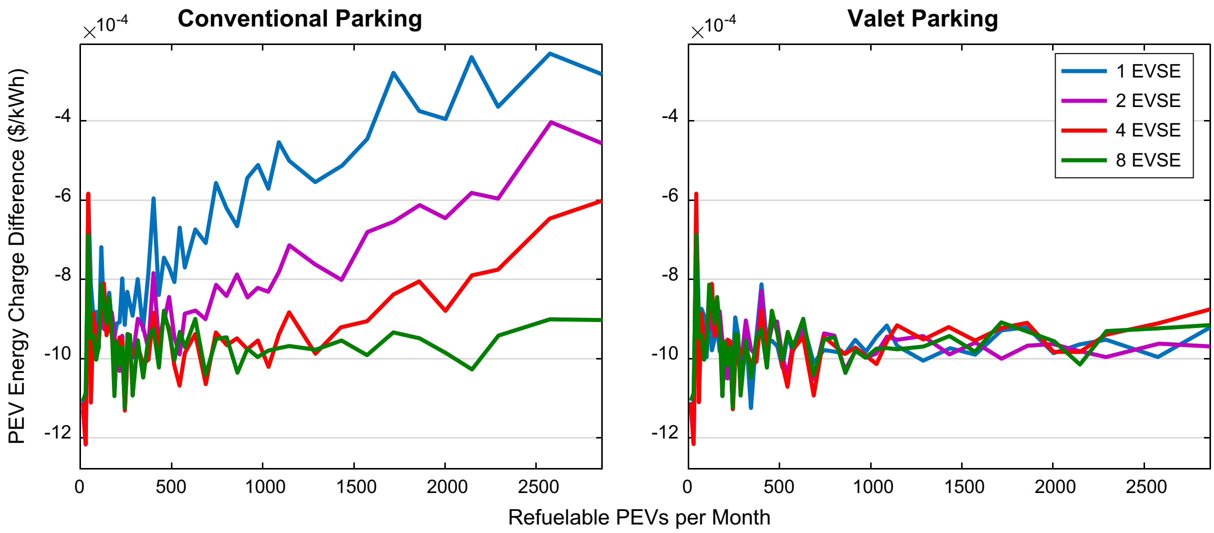

Fig. 4. Difference in energy charges for refueling PEVs performing shopping travel using one, two, four, and eight 44 kW EVSE for both conventional and valet parking during the winter.

energy charges, the difference in energy cost created by EVSE integration with a building does not depend upon the current energy demand of a building, but rather the time of day. Therefore, the difference in energy cost for EVSE operation is independent of building demand shape or size, and only changes depending upon the parking management strategy and the number of EVSE installed.

Under conventional parking, energy charge savings tend to decrease as PEV traffic increases. Examining a single EVSE reveals that as PEV traffic increases more vehicles arrive early in the morning, increasing the purchase of off-peak electricity. Despite being the lowest cost of electricity during the day, EVSE integration leads to a slight increase in the energy charge during off-peak for PEVs, reducing any savings generated during the middle of the day. As more EVSE are installed, the effect of early arriving PEVs is reduced, and more electricity is purchased during on-peak and mid-peak. Under valet parking, the mechanism to switch in queued PEVs once early arriving PEVs are finished refueling offsets the effect of early arriving PEVs across all numbers of installed PEVs considered.

The difference between the TOU-EV-4 and TOU-8 mid-peak energy cost is $0.00915 per kW h. According to Fig. 4, the savings produced by EVSE integration for PEVs are much lower than $0.009 per kW h. Since the EVSE has access to lower cost electrical energy through the building, the building receives compensation for every kW h delivered to a PEV. The building is compensated by the EVSE operator, resulting in smaller savings for refueling PEVs, but also in lower building energy charges. Fig. 5 shows the difference in building energy charge for a 100 kW average demand building. As PEV traffic increases, the total energy delivered to PEVs increases, also increasing the building energy charge savings. For both conventional and valet parking and all numbers of EVSE tested, any scenario that leads to an increase in energy delivered to PEVs increases energy charge savings for the building. Note that the energy charge for the building is determined for every kW h consumed by the building. Even at the highest PEV traffic levels tested and 8 EVSE operated using valet parking (or the scenario under which the most energy was delivered to PEVs), the energy delivered to PEVs is approximately 15% of the total energy delivered to a building with a 100 kW average demand. As a result, energy charge savings for the building are small, with the largest energy charge savings resulting in a total savings of approximately $14.50 per month. Increasing building size increases the number of kW h by which this total savings is divided by when determining the energy charge, reducing the savings per kW h virtually to zero.

Unlike energy charges, the difference in demand charges due to integration depends heavily upon the building load profile and size. The difference in demand charge cost for the EVSE integrated with a building is shown for all ten winter building loads set to a 100 kW average demand in Fig. 6 for a single 44 kW EVSE. As suggested by the results presented in the prior work [55], the integration of EVSE with a building leads to large demand charge cost reductions when PEV traffic is low. At low PEV traffic levels, high demand charges can be created by a single or handful of refueling events that use a relatively small amount of electrical energy. By splitting this high demand charge with a building, PEV demand charges are significantly reduced. These savings are diminished as PEV traffic increases because, as shown in [55], when the PEV traffic increases, the demand charge cost prior to integration decreases, resulting in a smaller demand charge per kW h. In general, it appears that demand charge savings are small for buildings with the high load factors (or consistent electrical demand). Integration with lower load factor buildings may reduce demand charge costs, but not always. The building with the largest reduction to demand charges is the 0.35 load factor building, not the 0.29 load factor building. Under conventional operation, integration with a building nearly always results in savings. However, under valet operation, integration with a building increases demand charge costs for PEVs at low to moderate traffic levels except for the 0.35 and 0.59 load factor buildings. These results show general trends, but also highlight the challenges associated with building load-shape, which can exacerbate or diminish the effects of PEV refueling on demand charges (e.g., whether or not building peaks coincide with PEV refueling peaks and whether or not they are in mid-peak or on-peak periods).

Fig. 7 shows the average increase to maximum utility demand when a single 44 kW EVSE is integrated with the ten buildings. Fig. 7 essentially has the same shape as Fig. 6 for all buildings studied. The buildings for which PEV refueling and maximum building demand do not coincide experience the smallest maximum utility demand increase, and realize greater savings. The peak demand for the 0.35 load factor building is created by a single peak demand occurring during the last Sunday of the month, as seen in Fig. 3. Since refueling during this small time period does not consistently coincide with the refueling of PEVs, integration occurs without

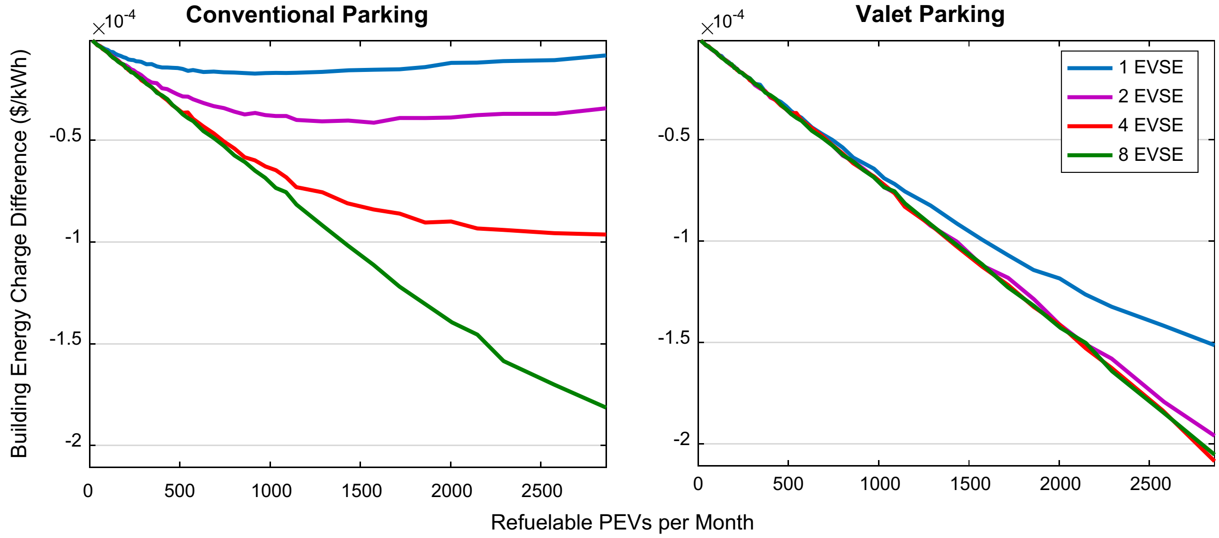

Fig. 5. Difference in building energy charges for a 100 kW average monthly demand as a result of integration one, two, four, and eight 44 kW EVSE using conventional and valet parking operation during the winter.

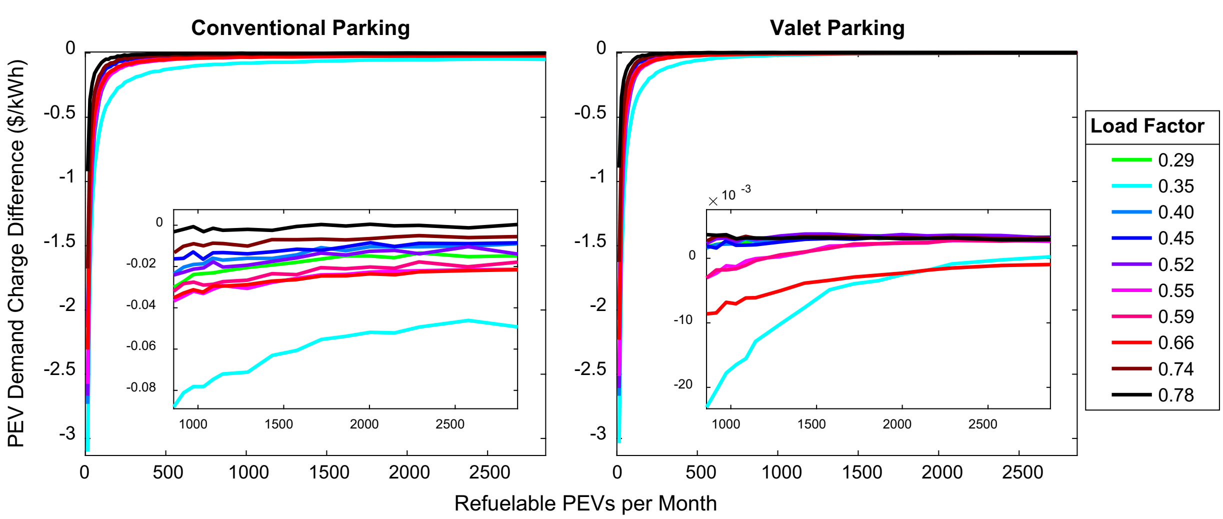

Fig. 6. Winter demand charge cost difference for a single 44 kW EVSE integrated with a 100 kW average demand building.

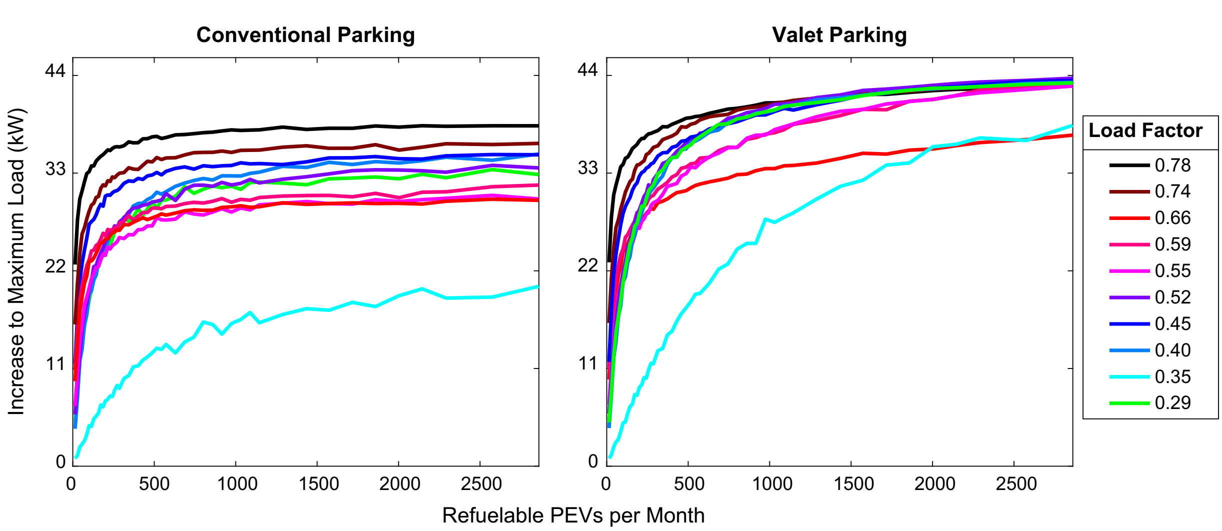

Fig. 7. Increase to the 15 min average maximum building demand for conventional and valet parking during the winter for a single 44 kW EVSE.

consistently increasing maximum utility demand. The increase to maximum load for each building is smaller under conventional parking because under valet operations, vehicles are queued and subsequently refueled. Since most buildings examined have a peak demand around or near the middle of the day, any chance of avoiding the coincidence of peak building demand and the refueling of PEVs is eliminated under valet operation and with moderate to high PEV traffic levels.

The building demand charges are also affected as a result of EVSE integration. Fig. 8 shows the difference in building demand charge when all ten winter building profiles are set to a 100 kW average demand and a single 44 kW EVSE is integrated. Similar to Fig. 6, the shape of each building in Fig. 8 mirrors the result shown in Fig. 7. Under conventional parking, the savings range from small for the 0.78 load factor building, to nearly $0.02 per kW h for the 0.35 load factor building. Under valet parking, large savings are experienced at low PEV traffic levels, but these savings quickly disappear for most buildings as traffic increases. Beyond approximately 500 PEVs per month, demand charges increase for the building because the integration of EVSE with a building increased the demand charge rate for the EVSE from $13.20 per kW to $14.88 per kW. While the EVSE at these levels experiences higher demand charges, a portion of the increased demand charge cost for the EVSE is assigned to the building. Comparing Figs. 6–8 show that the EVSE and buildings either experience a cost reduction or slightly increase together. Since maximum savings for both the EVSE and building come from the sharing of demand charges, any increase to maximum utility demand decreases demand charge savings. As a result, demand charge savings are greatest when PEV traffic is low, since maximum utility demand experiences the smallest increase at this traffic level.

Fig. 9 shows the demand charge difference for the refueling of PEVs when one, two, four, or eight 44 kW EVSE are integrated with the 0.52 load factor building. The results for the nine other buildings are similar to the results presented in Fig. 9 for this 0.52 load factor building, with the primary difference being the magnitude of the demand charge difference.

Under conventional parking, increasing the number of EVSE from one to two leads to a reduction in demand charges for the EVSE. The additional EVSE allows for an increase in number of PEVs refueled. However, since only two EVSE are available, the chance that two vehicles will arrive during the same 15 min window to unoccupied EVSE is low, especially at high PEV traffic levels, reducing the chance of both EVSE operating at the same time, when building demand is high. As the number of EVSE increase to four or eight, the chances of multiple PEVs arriving to open spots increases, resulting in an increase in peak EVSE demand, and a reduction in demand charge savings.

Under valet operations, the additional EVSE allow for arriving PEVs to gain access to being refueled quicker than with only a single EVSE. While the aggregated EVSE load increases, the refueling of each individual PEV occurs closer to the time of arrival. As a result, the sustained refueling load created by one or two EVSE at high PEV traffic levels is replaced is eliminated with four or eight EVSE. Similar to conventional parking, the higher level of demand produced by multiple PEVs refueling at the same time must be coupled with a high building demand in order for demand charges to increase.

Similar to the results presented in Fig. 8, the impact of EVSE integration on building demand charge cost depends on the sharing of the demand produced by the EVSE, but also by changing the utility rates applicable to the refueling of PEVs. Under conventional parking, a larger reduction in building demand charge cost is realized when multiple EVSE are installed under both conventional and valet operations, as seen in Fig. 10. The increase in the number of EVSE results in the sharing of a larger portion of the building demand charge, reducing building cost.

Under valet parking, the addition of multiple EVSE reduces demand charge by eliminating sustained PEV refueling typical of a single EVSE used to satisfy a large number of PEVs. The level to which additional EVSE helps reduce cost depends upon the PEV traffic level. When two EVSE are adopted, savings are realized until approximately 1500 Level 3 eligible PEVs arrive at the building each month. At this level of traffic, the two EVSE are fully utilized during the day, demanding 88 kW consistently during on-peak and mid-peak periods. Unless the building peak demand occurs off-peak, demand charges will be increased beyond the 44 kW increase associated with a single EVSE, resulting in a demand charge cost increase for the building. Adopting additional EVSE allows for the PEVs to be refueled faster, increasing EVSE load at the point of arrival, but eliminating the consistent load associated with valet operations when PEV traffic is high.

The prior results were based on integration with a 100 kW average building demand. So far, the largest source of savings comes from the integration of EVSE with a building without increasing the maximum utility demand. Since the size of the tested EVSE (44 kW) is comparable to the size of the tested buildings (100 kW), savings can only be guaranteed at extremely low PEV

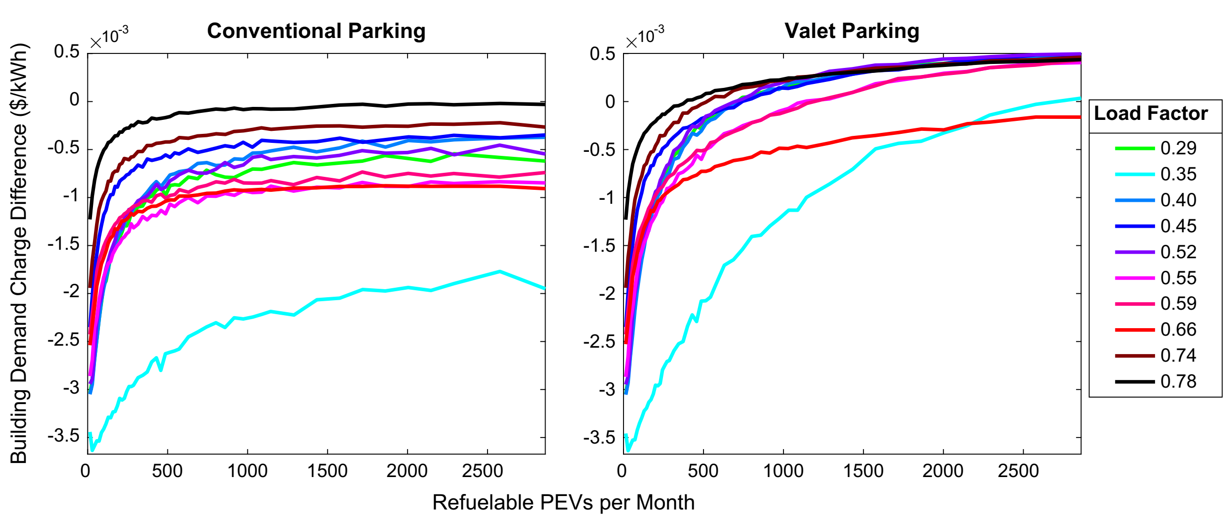

Fig. 8. Winter building demand charge cost difference for a single 44 kW EVSE integrated with a 100 kW average demand building.

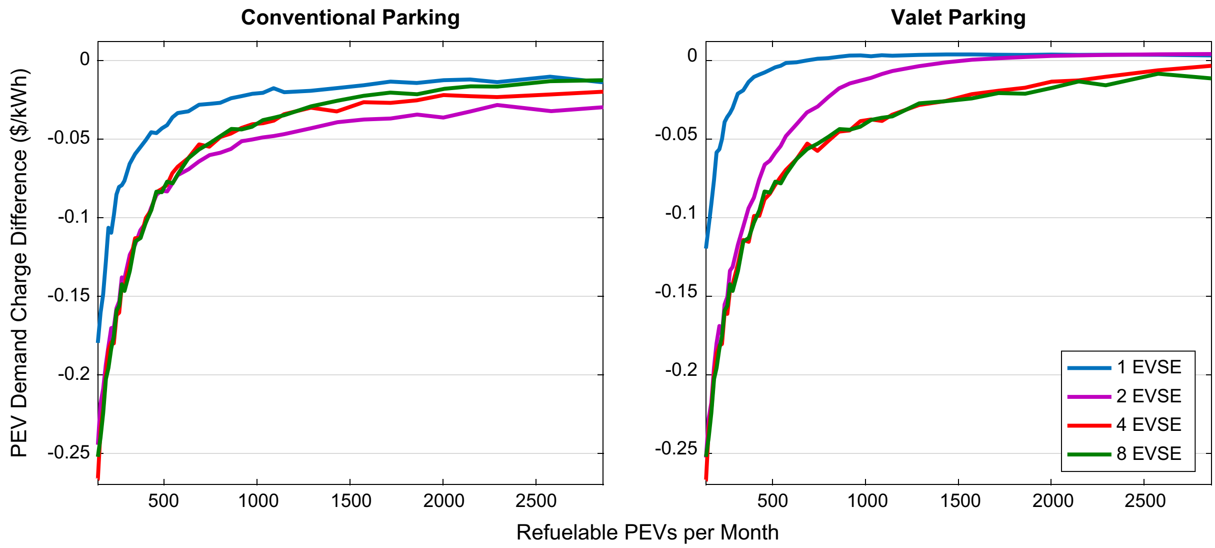

Fig. 9. Winter demand charge difference for one, two, four, and eight 44 kW EVSE operated using conventional and valet parking while integrated with the 0.52 load factor building demand profile normalized to 100 kW average demand.

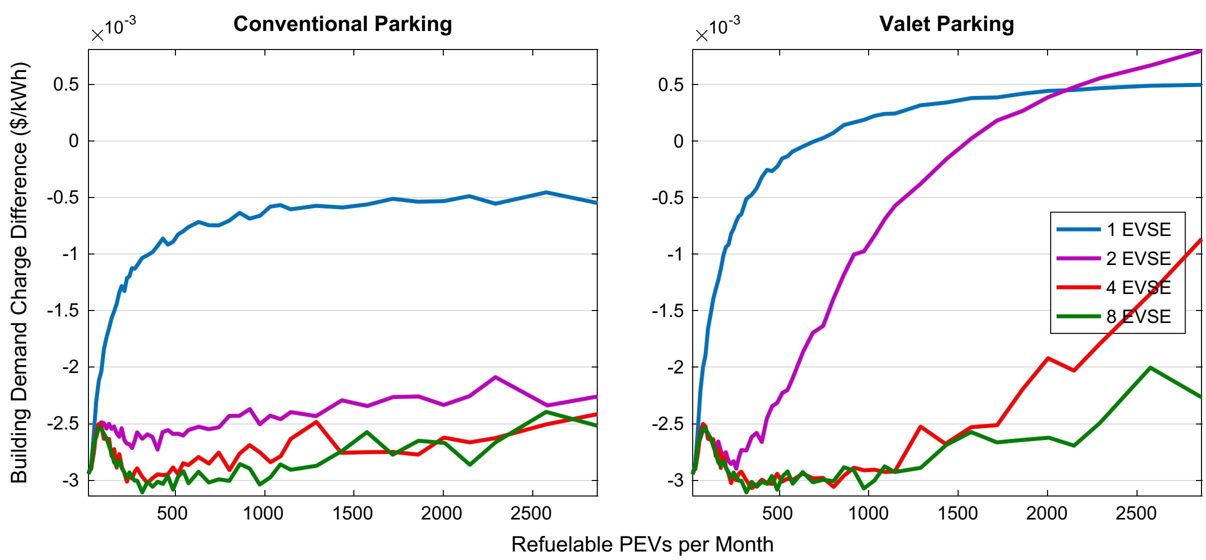

Fig. 10. Winter building demand charge difference for one, two, four, and eight 44 kW EVSE operated using conventional and valet parking while integrated with the 0.52 load factor building demand profile normalized to 100 kW average demand.

traffic levels. As PEV traffic increases, significant savings seem to be maintained only by chance under conventional parking and never under valet parking (unless the maximum building demand occurs during the night). The chance of reducing cost as a result of EVSE integration can be increased by selecting larger buildings. Fig. 11 shows the demand charge difference for a single 44 kW EVSE integrated with a 100 kW, 500 kW, 1000 kW, and 2000 kW average demand 0.52 load factor building. The results for all other buildings have similar results as the 0.52 load factor building.

By integrating the EVSE with a larger building, the absolute difference between the maximum and normal building demand becomes greater than for the 100 kW average demand buildings. During periods of normal building demand (or when building demand is not near or at the maximum), EVSE operation is less likely to increase maximum utility demand. If EVSE operation does occur during peak building demand, the increase to maximum utility demand is smaller unless EVSE operation perfectly coincides with the maximum building demand. As a result, under conventional parking, the integration of EVSE with a larger building always results in increased demand charge savings. The largest increase in savings comes from shifting from a 100 kW to 500 kW average building demand. Integration with larger buildings continues to reduce demand charge costs, but not at the same rate. Under valet parking, savings are increased for low to moderate PEV traffic. However, as PEV traffic increases from moderate to high, consistent EVSE operation occurs, and the benefit of being integrated with a large building disappears since the 44 kW EVSE demand is present throughout the day.

Fig. 12 shows the demand charge savings generated for the 0.52 load factor building with an average demand of 100, 500, 1000, and 2000 kW when a single 44 kW EVSE is integrated. While producing greater savings for the EVSE under conventional parking, the benefit provided by the building to the PEVs is fixed by the size of the integrated EVSE. As a result, if the EVSE can be integrated without increasing maximum utility demand, the total savings provided to the building is the same for a 500 kW, 1000 kW, and 2000 kW

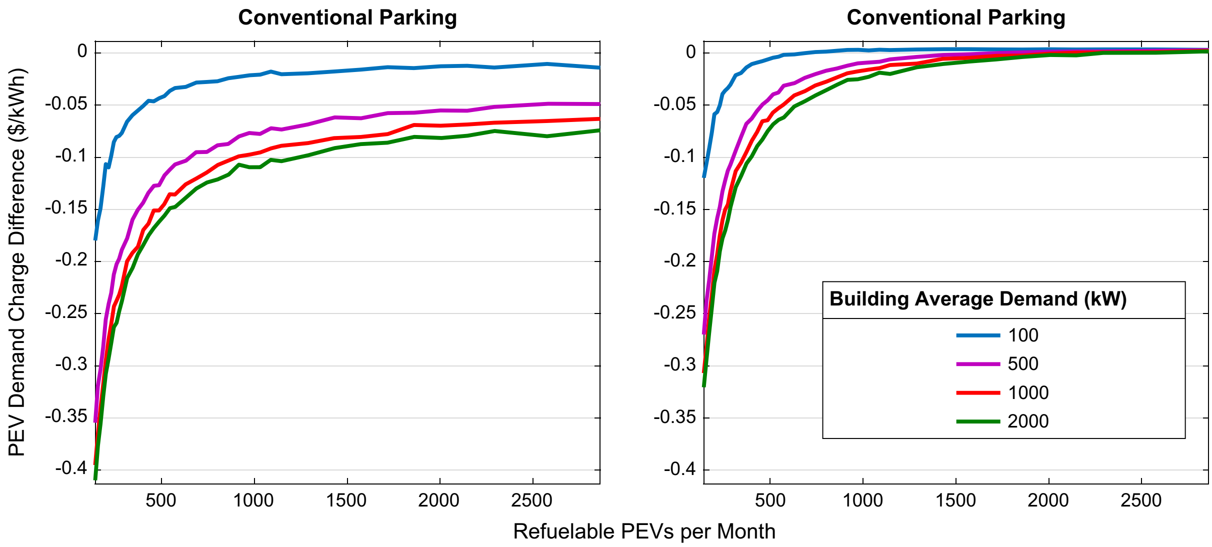

Fig. 11. Demand charge difference for a single EVSE integrated with the 0.52 load factor building with an average monthly demand of 100, 500, 1000, and 2000 kW during the winter.

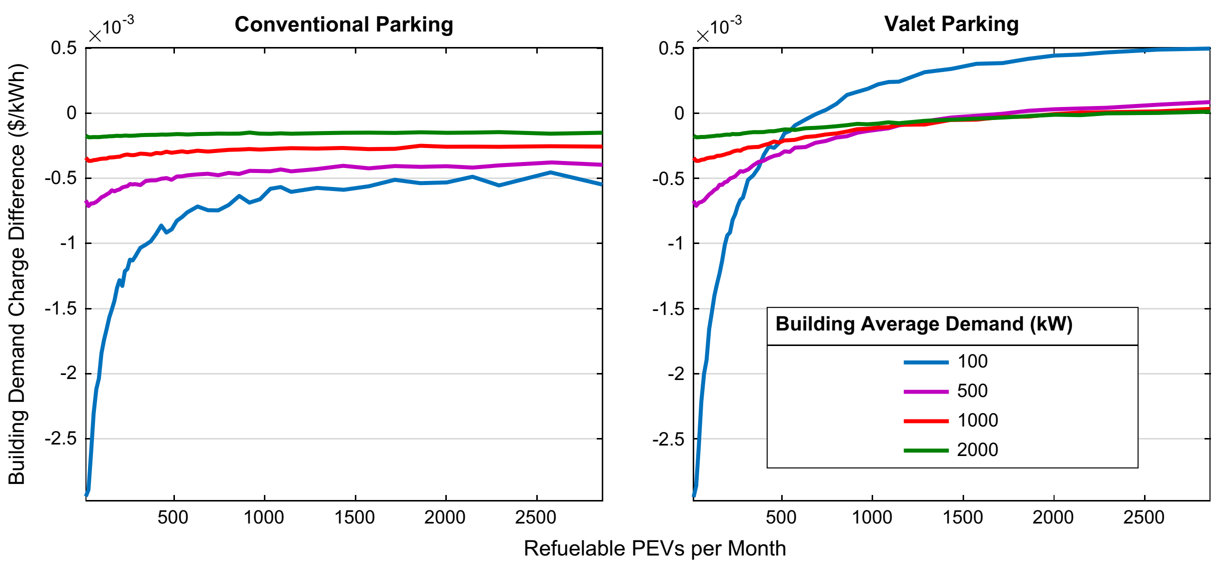

Fig. 12. Building demand charge difference for a single EVSE integrated with the 0.52 load factor building with an average monthly demand of 100, 500, 1000, and 2000 kW during the winter.

building. However, on a dollar per kW h basis, the savings are divided by a larger and larger total quantity of energy, reducing the savings per kW h as the building size increases.

Under valet operations, the building demand charges are increased for the 0.52 load factor building with an average demand of 100 kW. Increasing the building size nearly eliminates the cost increase, but the consistent EVSE demand associated with valet parking always increases the building demand charges.

4.1.2. Summer season and 44 kW EVSE

The primary difference between summer and winter seasons is the option to select between two different rates, TOU-8-A (A, high energy charges, preferred by low load factor buildings) or TOU-8-B (B, high demand charges, preferred by high load factor buildings). Assuming that the lowest cost rate is always selected, the integration of an EVSE load may result in a rate switch. For all buildings that originally operated under rate A, no switch to rate B occurred during any simulation. For such a switch to occur, EVSE operation would need consume on-peak and mid-peak electricity without increasing maximum utility demand. Unless some form of refueling control is implemented that also accounts for current building demand, maximum utility demand always increases, as seen in Fig. 7 for a single 44 kW EVSE, blocking any switch from rate A to B.

The switch from rate B to A, however, does occur for buildings with an average demand of 100 kW. Fig. 13 shows the percent of simulations for the five buildings that originally selected rate B where EVSE integration resulted in the combined building and EVSE load that ended up selecting rate A. Fig. 13 shows that nearly all simulations performed with two EVSE results in a rate switch for all five buildings. This result is consistent when installing more than two EVSE, with a rate switch occurring consistently under both conventional and valet operations. This rate switch occurs because the additional PEV refueling load increases the on-peak and mid-peak demand charges associated with rate B without a corresponding increase in peak electricity consumption. Under

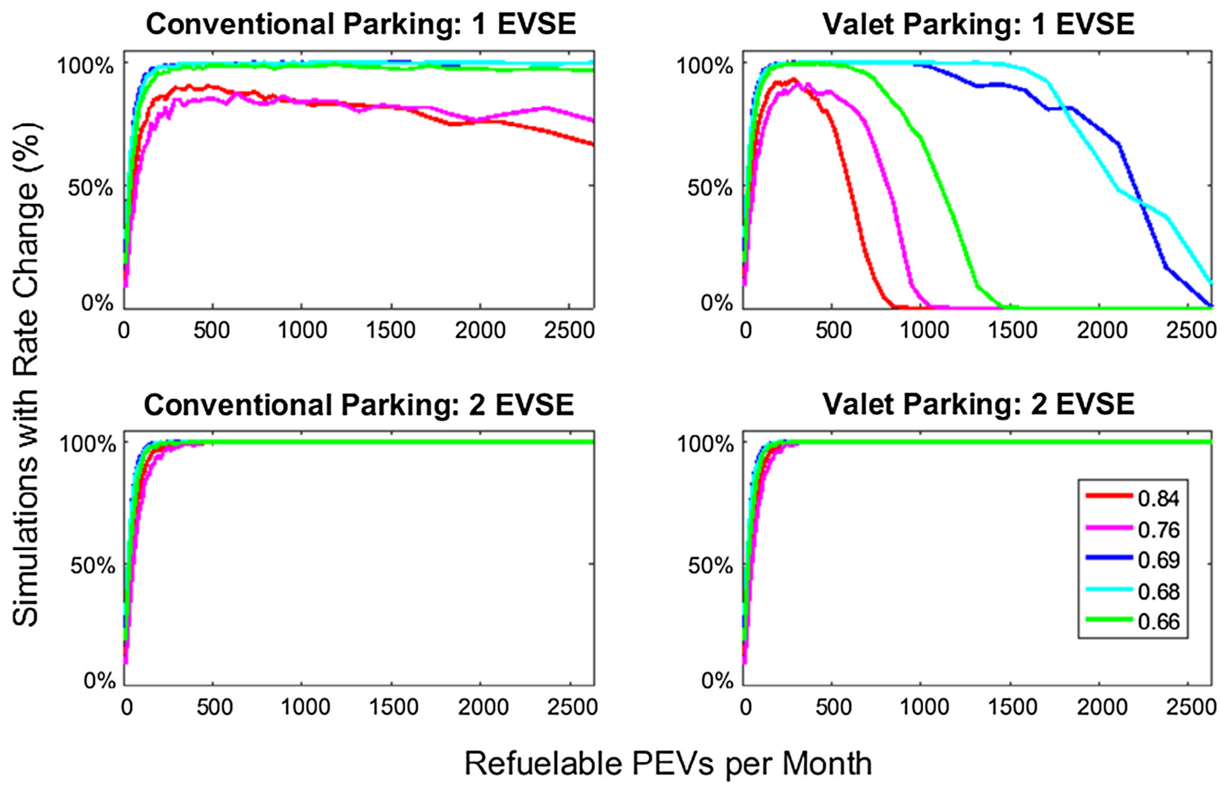

Fig. 13. Percent of simulations in which a rate switch from B to A occurred for the five buildings with a 100 kW average monthly demand that originally took service under rate B during the summer for one and two 44 kW EVSE.

these conditions, it is less expensive to switch to a rate that has higher on peak energy charges than to remain on the current rate with higher on- and mid-peak demand charges.

Referring back to Table 2, there is a clear transition from buildings that automatically take service under rate A and B. A building with a load factor close to one finds the lowest cost electricity under rate B. As load factor decreases, electricity costs increase, and the cost difference between rate A and B decreases, until rate A eventually provides lower cost electricity for low load factor buildings. When EVSE is integrated with a building, the load factor typically decreases, especially for relatively small buildings (∼100 kW). Fig. 13 shows that the higher load factor buildings (0.86, and 0.76) experience a rate change less frequently that the other buildings (0.96, 0.68, and 0.66) when a single EVSE is integrated with the building. While the integration of EVSE typically results in a lower load factor load, high load factor buildings require a greater increase to maximum utility demand than lower load factor buildings for a rate switch to occur. Under conventional operation of a single EVSE, a rate switch occurs frequently, even at low PEV traffic levels. However, high load factor buildings experience a rate switch less frequently.

Under valet operations, the 100 kW buildings also experience a rate switch at low PEV traffic levels. Fig. 7 shows that, when valet operations occur, maximum utility demand increases by nearly the size of the EVSE at low traffic levels, resulting in a decrease to load factor occurring at low traffic levels. However, once this maximum utility demand has been established, increasing PEV traffic results in subsequent refueling operation that does not contribute to a higher utility demand. The increase in energy consumption without an increase in maximum power demand begins to balance out any demand charge increases, resulting in a reduction of instances where a rate switch occurs. The PEV traffic levels where the chance of a rate switch occurring decreases at low to moderate traffic levels for high load factor buildings, and moderate to high PEV traffic levels for the lower load factor buildings.

Since a rate switch is the result of an increase to maximum utility demand, the instances when PEV refueling results in an increase to maximum utility demand can be determined. By separating PEVs between vehicles that contribute to an increase in maximum utility demand sufficient to cause a rate switch and vehicles that do not sufficiently increase maximum utility demand can be determined. By separating between these two sets of vehicles, the cost contributions of the two sets of refueling demand to electricity costs can be determined. The results show that vehicles that are not responsible for increasing maximum utility demand during a simulation when a rate switch occurs experience similar energy and demand charges to vehicles refueled at the same building in a simulation where a rate switch does not occur.

The cost to refuel PEVs when such behavior contributes to an increase in maximum utility demand is comprised of the portion related to purchasing electricity at that moment, as well a portion of the overall cost impact experienced by all other members due to the rate switch. In particular, this includes a portion of the change in building energy costs. If the refueling of these particular PEVs results in a cost difference due to a rate change for the building, the PEVs that are responsible for increasing maximum utility demand will share in either the savings or cost increase. In the specific case studied in this work, the buildings that experience a rate change originally took service under rate B due to access to an overall lower cost of electricity. The change from rate B to A reduces demand charge rates for the building, but increases energy charge rates. The difference in utility costs for the five buildings can be seen in Fig. 14, which shows the difference in energy, demand, and total costs versus PEV traffic level for both conventional and valet parking. Fig. 14 shows that the combined effect on energy and demand charges results in an overall increase in cost

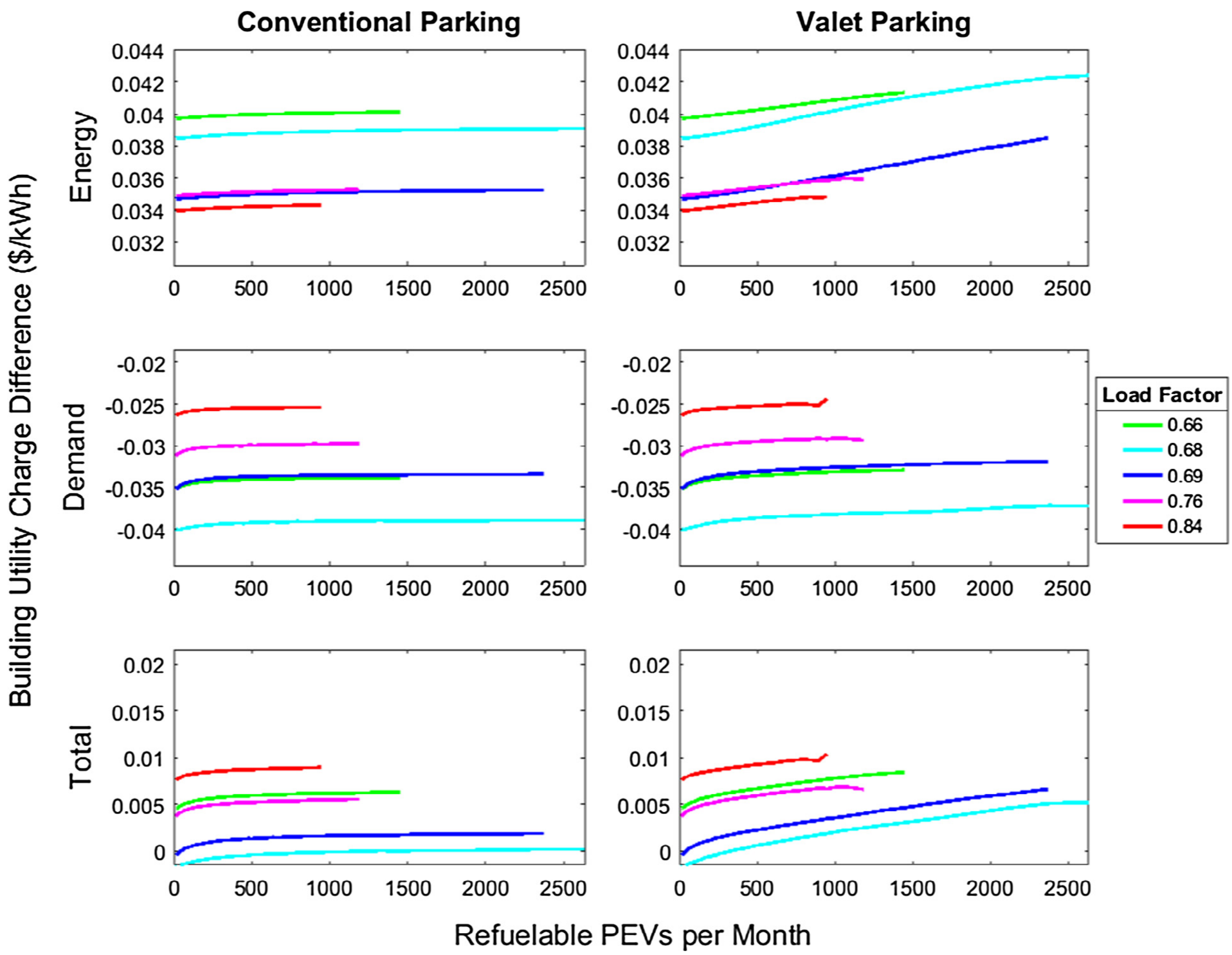

Fig. 14. Building demand, energy, and total charge difference when a rate switch occurs from B to A.

for all five 100 kW buildings across all levels of PEV traffic, under both refueling scenarios. This overall cost increase is shared by the responsible PEVs, which experience an increase in cost of $25 per kW h at the lowest traffic levels tested, to between $1 and $2 per kW h under conventional parking, and $0.20 per kW h under valet at the highest traffic levels tested. Note that a portion of this cost increase is due to the changing of utility charges for other groups, such as the building.

It is important to note that the only time a rate switch occurred during the simulations is when the size of the installed EVSE was comparable to the size of the average building demand. At the 500 kW average demand building size, rate switching did not occur consistently (>20%) unless four or more EVSE were adopted, valet operations occurred, and PEV traffic was high. At 1000 kW average demand, rate switching occurred during less than 3% of the simulations when eight EVSE was tested using valet operations at high PEV traffic levels. At 2000 kW average demand, rate switching does not occur.

When a rate switch does not occur, the difference in utility charge during the summer behaves exactly as it did in the winter. Differences in energy charges depend on whether the applicable rate is A or B, with energy cost increasing by approximately $0.03 per kW h under rate A, and decreasing by between $0.035 and $0.025 per kW h under rate B. The difference for building energy charges depends upon the amount of energy delivered to the PEVs, with the maximum amount of energy (i.e., when multiple EVSE are adopted, valet operations occur, and PEV traffic is high) is either a $0.005 per kW h increase under rate A or a $0.0045 per kW h decrease under rate B.

Demand charges under TOU-A during the summer are exactly the same as during the winter. Under TOU-B, an on-peak demand charge of $23.74 per kW and mid-peak demand charge of $6.55 per kW exist. If EVSE integration were to lead to an increase in the on-peak, mid-peak, and non-TOU maximum utility demand by one kW, the effective demand charge rate would be $45.17 per kW. This value represents the maximum possible demand charge incurred during EVSE integration with a building. Depending upon the combination of the building and EVSE load, maximum utility demand may not increase, resulting in a splitting of the current demand charges only.

Fig. 15 shows the change in demand charges when integrating a single EVSE into both a 100 kW and 500 kW average demand building for combinations that only operate under rate B. When integration with a 100 kW building demand is simulated, a large increase to maximum demand can be expected, resulting in a consistent increase to demand charge cost. If the increase to maximum utility demand can be reduced, and increase to demand charges can be reduced, even producing savings at low PEV traffic levels. As PEV traffic increases, the summer demand charge cost for EVSE is always increased as a result of integration.

Increasing the building load to 500 kW eliminates any large increase to demand charges at low PEV traffic levels. However, as traffic levels increase, demand charges become sufficiently expensive that the increase to building demand outweighs the benefit of

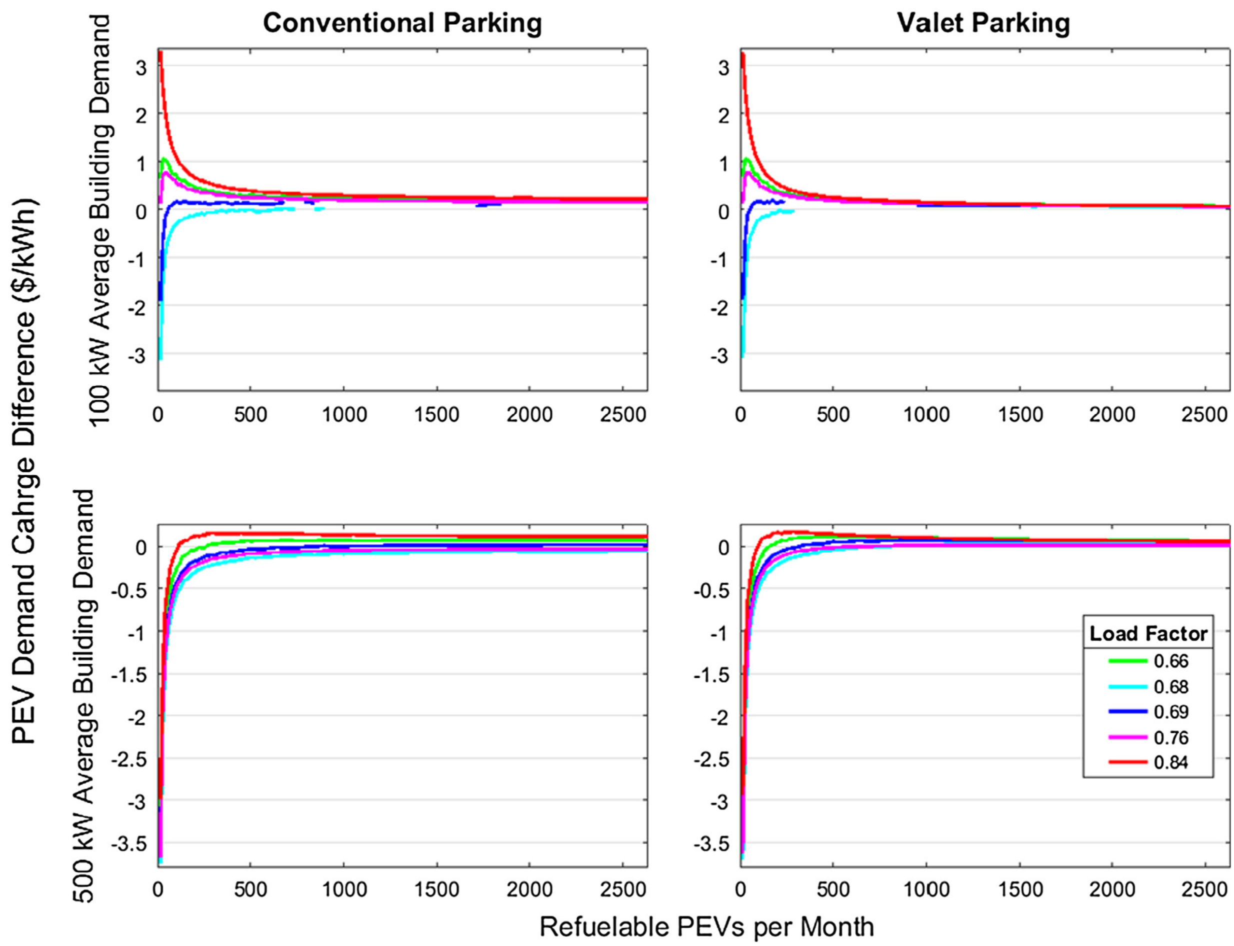

Fig. 15. Difference in PEV demand charges during the summer when a single EVSE is integrated with a 100 kW and 500 kW average demand building operated using either conventional or valet parking when rate B is least expensive.

sharing previously established demand charges, and PEV demand charges increase for three of the five buildings considered.

Increasing building size results in a smaller increase to maximum utility demand, reducing any PEV demand charge increases. However, if more than a single EVSE is installed, PEV demand charge cost increases. Even at the largest building level tested (2000 kW), PEVs still experience an increase in demand charges as a result of EVSE integration. For the integrated case the change in PEV demand charge obviously has an effect on building demand charges as well, with building demand charges either increasing or decreasing with PEV demand charges.

4.2. Work travel

Three major differences exist between work and shopping travel: (1) dwell time at work is considerably longer than while shopping, (2) drivers arrive frequently in the early morning, and (3) more vehicle miles are traveled to work than shopping, resulting in an increase in eligible PEVs for Level 3 refueling. The differences between work and shop travel are primarily manifested in the energy charge difference. EVSE integration with a building to refuel PEVs used for work travel experience similar increases and decreases in demand charges for both PEVs and buildings as for shopping travel.

Due to an increase in early arrivals associated with work travel, off-peak electricity consumption increases. Under winter rates, it is more expensive to purchase electricity through the building than if the EVSE had a dedicated utility meter. Fig. 16 shows the difference in energy charges for a PEV when one, two, four, and eight 44 kW EVSE are integrated with a building. Under conventional parking, early arriving PEVs purchase off-peak electricity and remain in the parking spot for an extended time, blocking the use of the EVSE during periods when electricity is less expensive through the building than through standalone EVSE. This behavior persists as PEV traffic increases, resulting in an increase in energy cost. Increasing the number of EVSE does not reduce electricity charges since the newly installed EVSE are consistently occupied early in the morning.

Adopting valet operation allows for later arriving PEVs to refuel using on-peak and mid-peak electricity, reducing the PEV energy charge. Eventually, as PEV traffic increases, the savings generated during on-peak and mid-peak counteract the loss produced during off-peak, resulting in an overall cost reduction. However, if more EVSE are adopted, the PEVs are refueled closer to the time of arrival (typically early in the morning, during off-peak), resulting in an increase in the purchase of off-peak electricity, increasing PEV energy costs.

As with shopping, building energy charges either increase or decrease alone with PEV energy charges. Fig. 17 shows the difference in building energy charges associated with work travel when one, two, four, or eight 44 kW EVSE are integrated with a 100 kW average demand building during the winter. In general, and under the studied rates, the integration of EVSE into a building results in an increase in energy charges for a building during the winter.

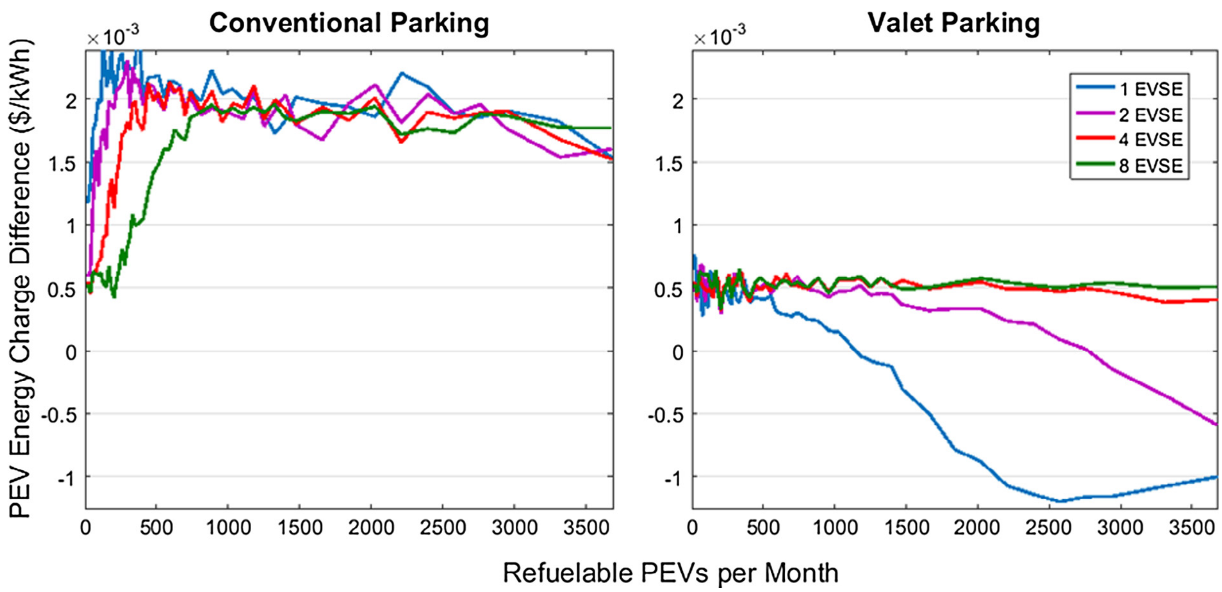

Fig. 16. Difference in energy charges for refueling PEVs performing work travel using one, two, four, and eight 44 kW EVSE for both conventional and valet parking during the winter.

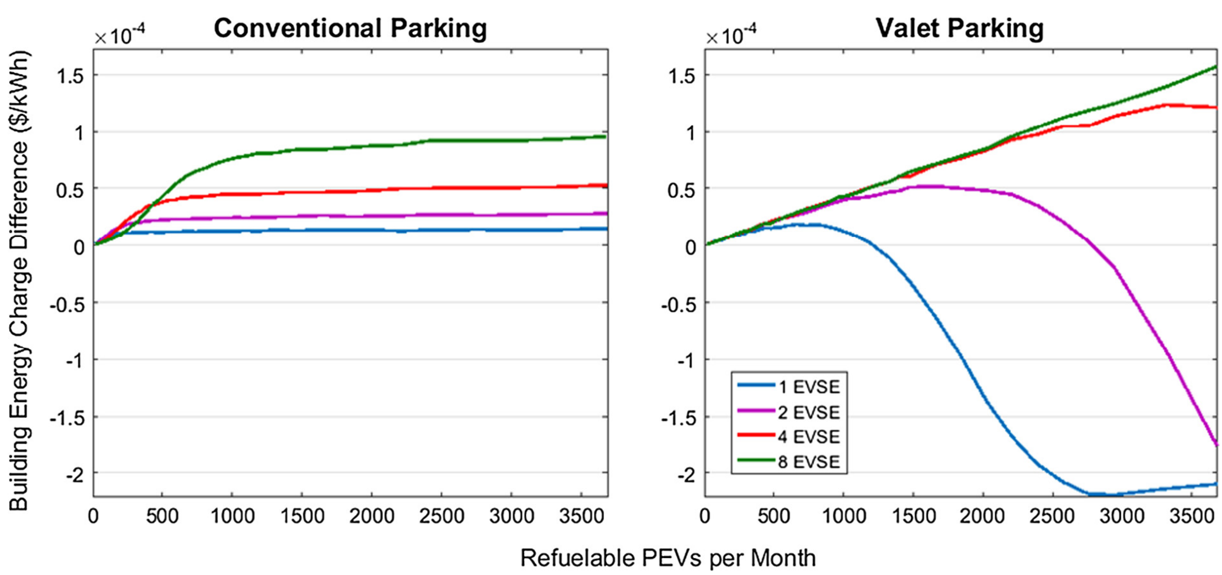

Fig. 17. Difference in building energy charges associated with work travel for a 100 kW average monthly demand as a result of integration one, two, four, and eight 44 kW EVSE using conventional and valet parking operation during the winter.

However, the increase in energy charge is almost insignificant. The maximum increase to building energy cost equates to a total increase in cost of approximately $10.80 per month.

Demand charge savings for work travel are similar to shopping travel, where the combination of EVSE and building that experiences the greatest savings is the one which has the smallest increase to maximum utility demand as a result of EVSE integration. An increase in off-peak refueling associated with work travel can result in peak refueling demand occurring during a time when building demand is low. However, under conventional parking, only a fraction of eligible PEVs can be refueled under work parking. Under conventional parking, additional EVSE must be installed as PEV traffic increases, or sustained refueling will occur throughout the day, resulting in a consistent increase in maximum utility demand. Note that the adoption of additional EVSE would occur when a single EVSE is still capable of meeting the majority of the refueling demand.

4.3. Difference between 44 kW and 120 kW EVSE

Level 3 EVSE encompasses a range of EVSE up to 240 kW [5]. Using a higher power EVSE results in faster refueling, shrinking the time it takes to refuel a PEV. While this may be desirable in certain applications, such as range extension, prior work has shown that an increase in EVSE power to refuel PEVs used for common types of travel increases demand charges, but may not improve access to an EVSE station, especially if conventional parking is implemented [55]. From the perspective of building integration, the high demand charges associated with increasing EVSE power may be reduced by the sharing of demand charges with a building. However, the current work has shown that the building selected for integration needs to be sufficiently large relative to the size of the EVSE for this benefit to be realized, particularly during the summer.

If a 120 kW EVSE were to be integrated with a 100 kW building, PEV demand charges are effectively doubled. This increase in demand charges can be sufficiently large enough to eliminate any cost benefit to building integration, increasing cost for both the EVSE and building when savings existed when using 44 kW EVSE. Savings can still be preserved if the integration of 120 kW EVSE occurs with larger buildings, however, the benefit of building integration is reduced. Under the summer rates used in this paper, the integration of 120 kW EVSE nearly always increases demand charge cost for PEVs and the building under rate B. Under Southern California Edison Rates, the integration of 120 kW EVSE also leads to an increase in the switching of rates in larger buildings, especially when multiple EVSE are adopted.

5. Analysis

The quantitative results presented in this work are applicable to Southern California or any other region with similar electrical utility rate structures. Qualitatively, this work illustrates the benefits and potential challenges of integrating Level 3 EVSE with a building. By far, the greatest potential benefit is the sharing of demand charges between the EVSE and a building, reducing electricity costs for both parties. The greatest challenge, however, is achieving integration without substantially increasing the combined utility demand beyond what was already present with the building. Without instituting any additional control beyond what has been described in this work, this means that integration with medium to low load factor buildings that have a high average electrical demand present the most attractive candidates for EVSE integration. However, from the perspective of the building, the cost benefit is relatively small for large buildings, as the demand for which charges will be split becomes a smaller portion of the overall demand created by the building. It is likely that some other benefit will need to be provided to a large building for widespread EVSE adoption to occur, particularly if EVSE operation could potentially result in a rate switch.

If integration is to occur with smaller buildings for which the financial benefit is relatively greater, additional EVSE controls must be implemented to ensure that integration does not increase the maximum utility demand (i.e., prevent PEV refueling from coinciding with maximum building demand). With additional controls, EVSE integration may be able to occur such that the maximum benefit is realized, the demand charge is split, and maximum utility demand is not increased.

For the particular scenarios presented, EVSE integration resulted in increased demand charge cost for the EVSE if maximum utility demand was to be sufficiently increased. If the reverse situation was to occur, where integration with a building were to result in access to lower demand charges, then integration will always produce cost savings. However, the benefit will be muted if the difference between standalone and integrated demand charges is relatively small, and utility demand is increased.

Energy charge savings can be produced through integration. However, unless a substantial difference between standalone and integrated energy charges exists, the benefit is primarily provided to the PEVs, with the building experiencing a marginal benefit.

Unless additional EVSE controls are implemented, EVSE integration may provide too much risk under current electrical rates. Although the splitting of demand charge costs created by EVSE integration can provide significant savings for the EVSE operators and a smaller building, the potential of erasing this benefit by increasing maximum utility demand, and by causing a rate switch, appear to discourage integration with the buildings for which this would be beneficial. While the results in this particular work are specific to Southern California Edison, other major utilities, such as Florida Power and Light, Georgia Power, and Xcel Energy, have multiple rates for commercial and industrial customers that have similar structures and differences between rates as those of SCE.

It is apparent that robust controls are necessary to achieve EVSE integration with a building that results in cost savings. While physical mechanisms that block EVSE operation during periods of high building demand could be implemented, another method of control could be through the cost charged to a customer who is refueling their PEV at the building. Alerting the customer to the actual cost associated with refueling a vehicle during a period of high building demand may be sufficient to prevent the refueling of a vehicle at the wrong time. In addition, optimization of building energy procurement may allow for the building and EVSE to work together such that the building energy and EVSE demand is always met without increasing cost for either parties.

It is important to note that the benefit of EVSE integration is greatest when PEV traffic is low to moderate at a conventionally operated station. If PEV traffic is high, then valet operations provide the best access to the EVSE, while also achieving the lowest cost. In this scenario, the cost benefit of EVSE integration to the PEV customers is small, and the potential for increasing cost discourages integration with a building. Under this scenario, it appears that, in terms of keeping utility costs low, EVSE integration should not occur. Also, valet operation (which leads to the lowest cost to refuel a PEV, as shown in [55]), typically leads to increased cost in the current analysis, suggesting that EVSE integration should not happen if PEV traffic levels increase.

Finally, it important to reiterate that the approach taken in this work provides the most optimistic scenario for Level 3 EVSE. If a PEV driver arrives at a Level 3 equipped station, and has reduced the vehicle battery state of charge below 80%, then they will attempt to refuel their vehicle, regardless of access to lower cost refueling options through Level 1 or 2 EVSE, or if sufficient state of charge is present prior to refueling such that all remaining trips are viable, and the driver can wait until the end of the day to refuel at home. It is predicted that, if a more realistic scenario were to be considered, the actual number of customers using the Level 3 EVSE would decrease, and the cost to refuel would increase, but the benefit of building integration may increase.

6. Summary and conclusions

This work examines the cost implications of integrating public Level 3 EVSE into real buildings operating under real electric utility rate structures. Models that simulate the travel patterns, building demand, and subsequent refueling of Level 3 compatible PEVs are developed and combined with utility rate models to determine the cost of supplying electricity to a Level 3 refueling station in Southern California. Two types of Level 3 refueling station operations were considered (conventional and valet parking). Potential savings created by EVSE integration are providing access to PEVs to lower cost energy and the sharing of demand charges between a building and PEVs. The main findings of this analysis are:

- EVSE integration provides more benefit to PEVs than buildings. Since the cumulative PEV refueling load is small compared to a 100 kW average monthly demand building, the benefits of sharing demand charges can reduce PEV demand charge cost by up to 50%. Cost reductions for a building are much lower, with risks possibly outweighing any cost savings benefit. Energy charge savings exist only if building rates are lower than PEV refueling rates, and do not depend upon building dynamics or size. Otherwise, energy cost for both the building and PEVS is increased.

- The dynamics and size of the building electricity consumption have a large effect on overall demand charge cost reductions. Maximum cost benefit is realized when the maximum building and refueling demand do not coincide. As a result, high load factor buildings provide little to no cost benefit, and low load factor buildings may provide savings if peak building demand does not coincide with peak PEV travel times. Integration with larger buildings reduces the chance of coincidence of PEV refueling with maximum building demand. However, relative to total building utility costs, potential savings shrink as building size increases.
- Installing multiple EVSE can produce increased savings under conventional operation but tend to reduce or eliminate savings under valet parking. Increasing EVSE power always reduces savings and leads to an increase in cost more frequently than lower power EVSE.
- If a small building may select utility service from multiple rates, EVSE integration can result in a rate switch, which always increases building electricity costs. Such a switch can be traced back to a small number of PEVs that refuel when building demand is high, for which cost to refuel is high (>$1 per kW h).

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