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ASSESSING THE IMPACT OF ELECTRIC VEHICLES ON ENERGY DEMAND IN HIGH-RISE RESIDENTIAL BUILDINGS

Abstract. Electric vehicle charging in high-rise residential buildings increases daily electricity consumption, but the magnitude of its impact on electrical infrastructure is primarily determined by the coincidence of charging. This study evaluates this impact in terms of the energy balance, maximum 15-minute active power, available power headroom, and the timely provision of the energy required for mobility. Drawing on official Azerbaijani statistics and international scientific literature, a reproducible computational model is developed for a hypothetical building with 120 apartments and 80 parking spaces. Immediate charging, simultaneous charging of all vehicles at 22:00, and managed charging aligned with the building load are compared. Under the baseline assumptions, supplying each of 64 vehicles with 8 kWh of electricity per day increases the building's daily consumption from 1475 kWh to 1987 kWh, or by 34.7%. Immediate charging increases the total peak load from 120 kW to 259.8 kW; coordinated control meets the same energy demand while maintaining the maximum at 120 kW. When high daily mileage and an increased building load are assumed together, the physical limitations of control also become apparent. The article proposes assessing power headroom jointly with energy provision, serving residents on the basis of energy provision by their departure time, and allocating a reserve according to forecast error. The results represent an analytical computational model based on explicit assumptions, rather than measurements conducted in an actual building in Baku.

Keywords: electric vehicle, energy demand, peak load, managed charging, energy flexibility.

Allocating space for electric vehicle charging in a residential building is not equivalent to ensuring that the building's electrical system is ready for charging. A garage may have sufficient vacant space, yet charging that coincides with evening household consumption may create a capacity shortfall in the incoming supply line or in the wider network served by the transformer. Therefore, determining only the number of devices to be installed is insufficient for a design decision. The times at which vehicles connect, the amount of energy they require, and the building load during those hours must be examined together [1].

According to the International Energy Agency's 2026 report, global sales of electric passenger cars exceeded 20 million in 2025 and accounted for approximately one-quarter of new car sales. This figure includes plug-in hybrids alongside battery electric vehicles; it does not represent their share of the existing vehicle fleet [7]. The implication for residential buildings is clear: charging demand should be incorporated into the building's energy plan in advance, rather than addressed through individual requests as they arise. Transport statistics in Azerbaijan also require a differentiated approach. The State Statistical Committee's 2025 compendium reports 570 electric passenger cars at the end of 2022, 3115 in 2023, and 5941 in 2024. The increase between the latter two figures is 90.7%, according to the author's calculation. Of the 66 385 hybrid passenger cars at the end of 2024, only 9749 were separately identified as plug-in hybrids. Including all hybrids in the charging load would overestimate demand. Nor can the charging load of a specific building be derived directly from the size of the national vehicle fleet [3]. In high-rise buildings, elevators, water pumps, lighting in common areas, ventilation, and apartment consumption may share the same electrical supply path in addition to the charging load. The type of heating and cooling system substantially changes the load profile.

Scientific foundations and the assessment gap. The same daily energy consumption can impose different power requirements on the electricity network. For example, delivering 8 kWh of energy within 1 hour or distributing it over 8 hours may yield the same metered consumption, but the loading of the line will differ. Richardson et al. (2012) demonstrated that controlling charging power through linear programming in a low-voltage network can improve the utilization of existing infrastructure [11]. This approach also supports combining energy demand with its time constraints at the building level.

Sorensen et al. (2021a) jointly analyzed charging reports and meter data in a multifamily residential setting. Their associated dataset contains 6878 charging sessions from 97 users, with connection and disconnection times and the energy delivered recorded [14]. Such data reveal an important distinction: energy is not transferred throughout the entire period during which a vehicle is parked. The intervening idle time provides an opportunity to shift charging to another hour. However, it would be inappropriate to treat this user behavior as a measured indicator for Baku.

A subsequent building study in Norway reported a peak load reduction of up to 45% in optimized computational models. The result was influenced by the tariff, photovoltaic generation, bidirectional energy exchange, and the location of the billing meter [15]. This percentage is not a universal savings benchmark. Differences in baseline loads and charging windows cause the same control method to produce different results.

Shifting load to nighttime does not, in itself, constitute coordinated control. In a field experiment, Bailey et al. (2025) found that time-of-use prices shifted charging toward low-price hours while also creating new synchronized peaks. Powell et al. (2022) demonstrate the effects of charging location and timing at the wider electricity system level. The schedule that produces the lowest peak for a building may not automatically be the schedule with the lowest

emissions for the overall energy system. Local capacity constraints and system needs should be assessed as separate signals [4, 5].

Another issue concerns charging losses. In tests involving 38 vehicle models, Sevdari et al. (2023) showed that current modulation generated additional losses in some cases and altered reactive power behavior. Thus, continuously allocating very low power to all vehicles is not always the most energy-efficient option. A practical system may alternate charging among selected vehicles at an appropriate power level.

The system boundary is the common electrical connection point of the building and its associated garage. The baseline load includes the apartments and common building services. It is assumed that all daily vehicle energy needs are met at this connection point. Each vehicle requiring charging has access to a connection point; physical queuing among a limited number of shared chargers is not modeled. A photovoltaic system and a stationary battery are excluded from the baseline calculation.

Table 1 – Initial parameters of the hypothetical building and charging demand

Parameter	Baseline assumption	Status
Building size	20 stories, 120 apartments	Computational model assumption
Parking and charging outlets	80 spaces; an outlet for each active EV	Computational model assumption
Daily energy without charging	1475 kWh	Total of the profile in the appendix
Maximum power without charging	120 kW	Maximum of the profile in the appendix
Allocated power and reserve	180 kW and 15 kW	Operating limit of 165 kW
Charger upper limit	7.4 kW / vehicle	Identical in all modes
Daily mileage and battery consumption	40 km; 0.18 kWh/km	Computational model assumption
Charging efficiency	90%	Constant coefficient
Grid energy per vehicle	8 kWh / day	Calculated from mileage
Arrival and departure	17:00–22:00; departure at 07:00	Arrival distribution in the appendix
Managed charging window	22:00–07:00	9 hours
Time step	15 minutes	96 intervals / day

Electric vehicle shares of 10%, 30%, 50%, and 80% are defined relative to the 80 parking spaces. These correspond to 8, 24, 40, and 64 vehicles, respectively. These shares do not refer to the number of apartments or to the vehicle fleet in Baku. The 20 stories describe the building; the load is not mechanically multiplied by the number of stories. Two buildings of the same height may have different loads because of differences in the number of apartments, heating systems, and common service equipment.

Energy balance and power constraint. Daily charging energy is calculated from the number of vehicles, daily mileage, battery-side energy consumption per unit distance, and charging efficiency:

$$E_{EV} = \frac{N \cdot d \cdot e}{\eta} \quad (1)$$

Here, N is the number of vehicles requiring charging, and d is daily mileage; e denotes battery-side energy consumption, while η denotes grid-to-battery transfer efficiency. Under the baseline assumption, the result for one vehicle is 40 km × 0.18 kWh/km ÷ 0.90 = 8 kWh. This result should not be confused with the 7.2 kWh added to the battery. The power rating indicated on the charger is not the amount of energy consumed in one day. In any time interval, total active power is the sum of the building load and the power supplied to the vehicles:

$$P_{grid}(t) = P_{building}(t) + \sum_{i=1}^{N} p_i(t) \quad (2)$$

The model assumes an allocated active power capacity of 180 kW and an additional operating reserve of 15 kW. The upper limit for planning is therefore 165 kW. This is neither a regulatory requirement nor the nameplate rating of a specific transformer. When converting transformer capacity from kVA to kW, the power factor and the share of other consumers must be considered separately. The headroom available for charging at a given time is expressed as follows:

$$H(t) = max\{0, P_{allocated} - R - P_{building}(t)\} \quad (3)$$

When a vehicle is disconnected, its charging power must be zero. When it is connected, the power must not exceed the limit accepted by the charger and the vehicle, and the required energy must be supplied by the departure time. Merely reducing the peak while allowing a vehicle to leave in the morning without the required energy does not constitute successful control. Following the calculation of total power, phase current, voltage drop, cable ampacity, and protection selectivity must be checked separately. IEC 61851-1 and IEC 60364-7-722 provide the relevant framework for equipment and installation requirements; no assumption is made here regarding the legal status of their application in Azerbaijan [6].

Charging modes compared. In Mode A, a vehicle starts charging at up to 7.4 kW immediately upon arrival and stops after receiving 8 kWh. Only the remaining energy is accounted for in the final partial interval. Accordingly, the maxima in the tables represent 15-minute average power. Instantaneous switching events are not modeled separately at this time resolution.

In Mode B, all vehicles begin charging simultaneously at 22:00. This is a computational model of an uncontrolled common timer. The mode does not assume an existing nighttime discount for residential consumers in Azerbaijan; its purpose is to examine the physical consequences of a synchronized start.

In Mode C, more energy is allocated to intervals with lower building loads between 22:00 and 07:00. A level L is selected to flatten the total load as far as possible, and the charging power in each interval is determined by the following rule:

$$P_{EV}(t) = min\{N \cdot P_{max}, max[0, L - P_{building}(t)]\} \quad (4)$$

Here, Pmax is the upper limit of 7.4 kW per vehicle. The value of L was determined through a bisection search that ensures that the sum of power multiplied by time over the charging window equals the required energy. The 165 kW limit is applied separately; any energy shortfall is reported if demand cannot be met within this limit. In the baseline computational model, where all vehicles have the same 07:00 departure time and the same energy requirement, equal allocation of aggregate power also satisfies the individual energy requirement. In practical implementation, intermittent alternation may be necessary because of minimum charging currents and discrete current steps. Thus, Mode C is an ideal scheduling benchmark, rather than a test result for an operational controller.

The calculation covers 96 intervals from 12:00 to 12:00 on the following day. The hourly baseline load is held constant over each set of four intervals. The arrival distribution and all baseline load values are provided in the appendix. In Modes A and B, power is not automatically curtailed when the upper limit is reached: the demand that would arise in the absence of control is explicitly represented. Exceeding this limit is not interpreted as the protective device tripping at that exact moment.

Energy consumption and maximum load. As the number of electric vehicles increases, additional daily energy rises linearly under the selected assumption of constant daily mileage. The energy requirement is 64 kWh for 8 vehicles, 192 kWh for 24 vehicles, 320 kWh for 40 vehicles, and 512 kWh for 64 vehicles. Changing the timing of charging does not eliminate the increase in energy consumption. Since all three modes operate at the same efficiency in the model, daily energy consumption is also identical.

The power outcome, however, differs.

Table 2 – Results of different charging modes under the same energy demand

EV share / count	Additional energy kWh/day	Energy increase %	A peak kW	B peak kW	C peak kW
10% / 8	64	4.3	132.2	120.0	120.0
30% / 24	192	13.0	169.0	237.6	120.0
50% / 40	320	21.7	205.8	356.0	120.0
80% / 64	512	34.7	259.8	533.6	120.0

Note. Source: author's calculations. A — immediate charging; B — simultaneous charging at 22:00; C — managed charging aligned with the building load. The peak is the maximum 15-minute average active power of the entire building. Energy demand is fully met in all modes.

Although the total installed charging power is 473.6 kW in the case of 64 vehicles, not all vehicles operate at maximum power simultaneously under immediate charging. Because arrival times differ, the total building peak is 259.8 kW. This value is 116.5% higher than the baseline peak. When the simultaneous start rule at 22:00 is applied, a charging load of 473.6 kW is added to the 60 kW building load at that time, producing a demand of 533.6 kW. Thus,

a common starting time chosen with good intentions worsens the situation in this computational model.

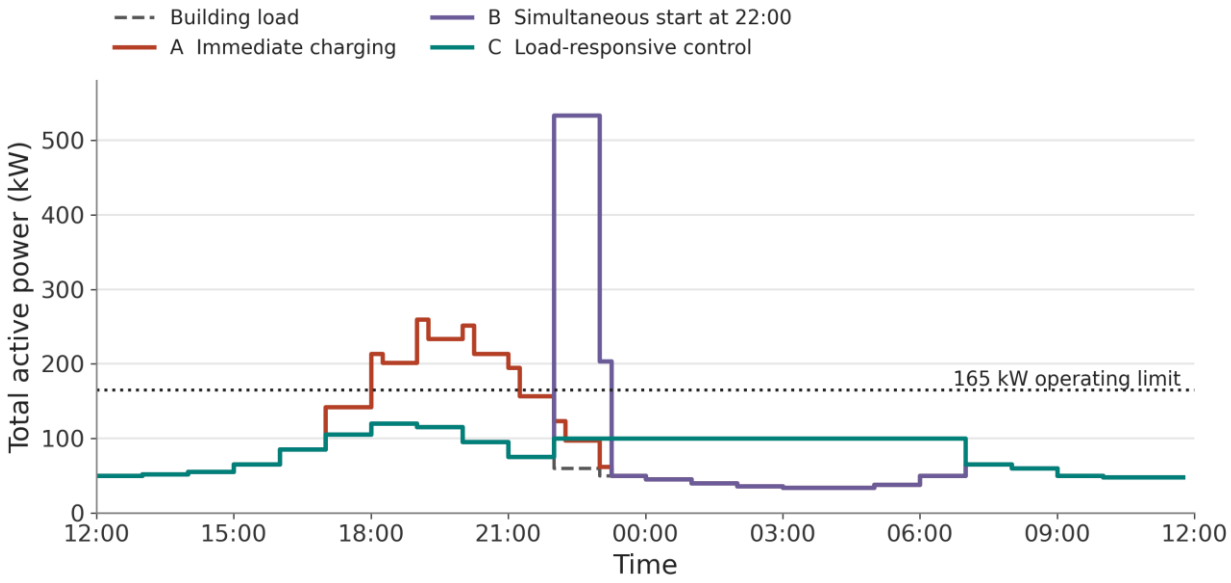


Figure 1 – Building load and charging modes for 64 vehicles

Note. Source: author's calculations. The curves represent 15-minute average power. In A and B, the portions above the limit represent unconstrained demand, rather than actual delivered supply.

In Mode C, the 512 kWh required by 64 vehicles is delivered between 22:00 and 07:00. Since the building's baseline consumption during this window is 387 kWh, the combined load is leveled at approximately 99.9 kW. The evening peak of 120 kW without charging remains the daily maximum. The peak is 53.8% lower than in Mode A. This percentage represents a reduction in the total building peak, rather than electricity savings.

The duration of limit exceedance provides a more precise explanation of the result. With 24 vehicles, Mode A exceeds the 165 kW limit in only one 15-minute interval; with 64 vehicles, this duration reaches 3.25 hours. In Mode B, the exceedance duration for 64 vehicles is 1.25 hours, but the maximum is higher. Considering only the number of hours of exceedance is also insufficient: duration and magnitude must be assessed together.

The baseline building load factor, defined as the ratio of average power to maximum power, is 0.512. With managed charging for 64 vehicles, this indicator increases to 0.690; under immediate charging, it falls to 0.319. Distributing the same daily energy more evenly improves the utilization of available capacity. A separate thermal and electrical model is required to determine the precise effects on transformer life and cable losses.

In an additional check, reducing the charger power for 64 vehicles from 7.4 kW to 3.7 kW lowers the Mode A peak from 259.8 kW to 239.8 kW, but extends the duration of exceedance of the 165 kW limit from 3.25 hours to 4 hours. This occurs because charging

sessions last longer and overlap with those of vehicles arriving later. A lower-power charger may be a useful option, but it does not replace coordination over time.

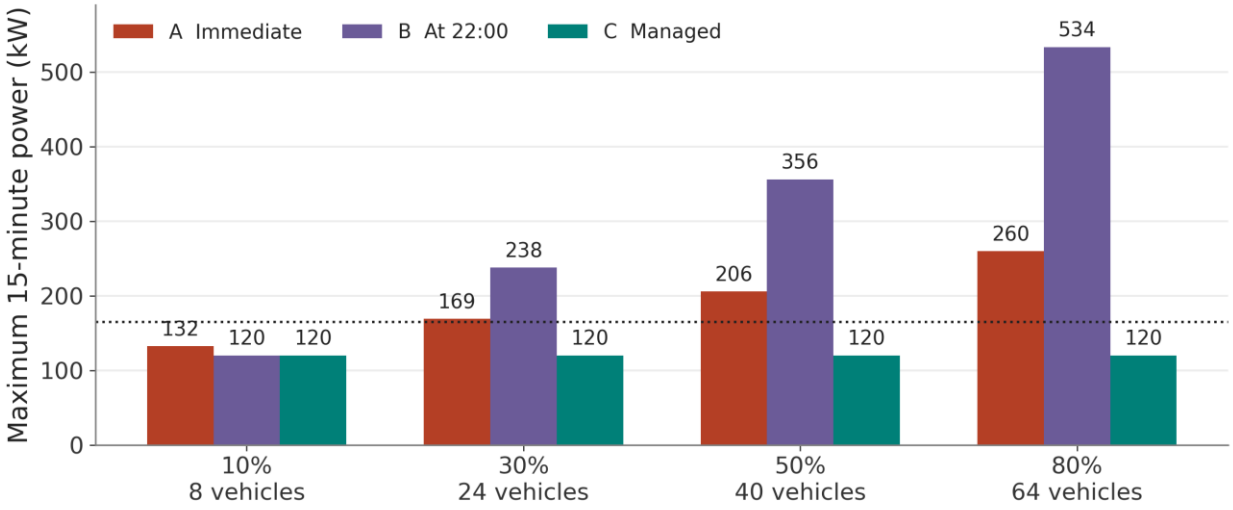


Figure 2 – Changes in total peak power as the electric vehicle share increases

Note. Source: author's calculations. The numbers above the bars are rounded to whole kW; exact values are provided in Table 2. The dotted line represents the 165 kW limit.

The physical limit of control. The power headroom available overnight must also be calculated in energy units. Under the baseline profile, it is theoretically possible to deliver 1098 kWh of charging energy over 9 hours within the 165 kW operating limit. This requires all vehicles to remain connected throughout that window, a sufficient number of charging outlets, and the absence of other electrical constraints. The value of 1098 kWh is the upper bound of energy provision only under these conditions.

A sensitivity analysis was conducted for 64 vehicles by varying daily mileage, consumption, efficiency, and connection duration. A 25% increase in the building load is treated as a test of possible additional heating and cooling loads, rather than as an observation measured in a particular season.

Table 3 – Sensitivity analysis of demand and the power limit for 64 vehicles

Computational model	d / e / η	Building load / window	Demand kWh	Shortfall kWh	C peak kW
Low mileage	20 / 0.16 / 0.93	×1.00 9 hours	220.2	0.0	120.0
Baseline	40 / 0.18 / 0.90	×1.00 9 hours	512.0	0.0	120.0
High mileage	60 / 0.20 / 0.87	×1.00 9 hours	882.8	0.0	141.1
High mileage and building load	60 / 0.20 / 0.87	×1.25 9 hours	882.8	0.0	151.8
Maximum-load case	80 / 0.22 / 0.87	×1.25 9 hours	1294.7	293.5	165.0
Short window	60 / 0.20 / 0.87	×1.00 7 hours	882.8	4.8	165.0

Note. Source: author's calculations. d — km/day; e — kWh/km; η — efficiency. The 9-hour window refers to 22:00–07:00, and the 7-hour window to 00:00–07:00. The 165 kW operating limit is maintained in all scenarios. Values are rounded to 0.1 units.

In the high-mileage scenario, each vehicle travels 60 km per day and consumes 0.20 kWh/km on the battery side, with an assumed efficiency of 87%. Total demand increases to 882.8 kWh. When the building load remains unchanged, the Mode C peak is 141.1 kW. If the building load also increases by 25%, the maximum reaches 151.8 kW and remains below the 165 kW limit. However, the 120 kW result achieved in the baseline scenario is no longer maintained.

The maximum-load case combines 80 km of daily mileage, consumption of 0.22 kWh/km, 87% efficiency, and a 25% higher building load. Energy demand is 1294.7 kWh, while the available overnight energy capacity is 1001.3 kWh. An energy shortfall of 293.5 kWh remains by morning; only 77.3% of the required energy is supplied. Compliance with the peak limit does not mean that the service is fully provided in this case. Possible solutions include extending the charging window, charging part of the energy elsewhere, or increasing supply capacity.

A short charging window is also consequential. When all charging in the 60 km daily mileage scenario is compressed into the 00:00–07:00 interval, available energy capacity falls to 878 kWh, resulting in a shortfall of 4.8 kWh. Although this difference may appear small, it violates the criterion of fully meeting daily demand. Collecting information on late connections and early departures is therefore as important as calculating the design capacity.

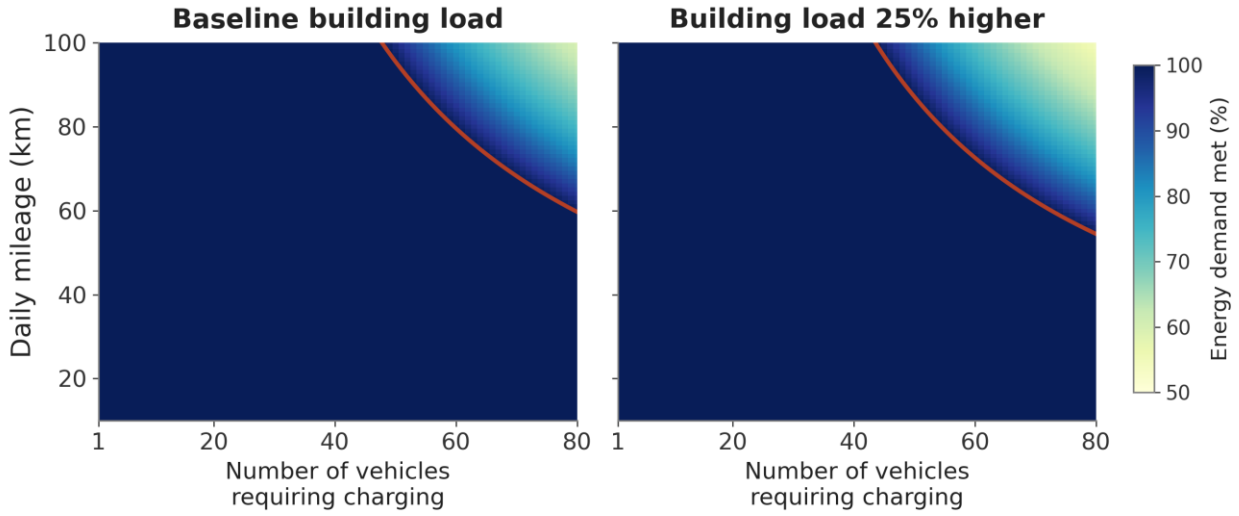


Figure 3 – Boundary of overnight energy provision by vehicle count and daily mileage

Note. Source: author's parametric calculation. In both panels, consumption is 0.20 kWh/km, efficiency is 87%, the charging window is 9 hours, and the limit is 165 kW. The red curve marks the boundary at which demand is fully met; energy shortfalls occur above and to the right of it.

Joint planning of power headroom and energy provision. A charging capacity passport based on annual and seasonal measurements is proposed for each building. The passport should specify not only the allocated power capacity but also the energy available by hour, the minimum phase headroom, and the level of service that can be provided to residents. The designer first determines how many vehicles require how much energy by which departure time, and then compares this demand with the capacity of the existing line. This sequence prevents the sum of nominal charging powers from being interpreted directly as a requirement for a new transformer.

The passport should retain two separate results: capacity for an average day and capacity for a high-demand day. A successful result for an average day does not demonstrate that the equipment is sufficient under all conditions. The existence of scenarios in which the energy needs of 64 vehicles are either fully met or subject to a 22.7% shortfall under the same 165 kW limit illustrates this distinction concretely.

Departure-time-based service and equitable allocation. Rather than promising residents a constant 7.4 kW throughout the night, it is advisable to offer a service such as "8 kWh of energy by 07:00." Residents specify their required energy and departure time. The controller identifies urgent sessions based on the relationship between the remaining energy and the remaining time, and then allocates power among them. This also prevents unsupported promises that a vehicle will be fully charged: the battery's initial state and the user's actual needs may differ.

Allocation should not be based solely on a first-come, first-served principle. Daily service shortfalls for residents who return late would undermine trust in the system. The

proposed rule consists of a minimum energy provision announced in advance, priority for sessions approaching their departure time, and a limited reserve for urgent requests. If total physical capacity is insufficient to meet demand, the shortfall should be communicated as early as possible, rather than at the end of charging. This service rule represents a subsequent implementation stage beyond the model's assumption of identical energy requirements and departure times; it has not been tested separately here.

Forecast-error-based reserves and local control. Although a fixed reserve of 15 kW is a transparent assumption for the initial scenario, it may not be optimal for every hour in an actual building. The pilot project should develop a one-interval-ahead building load forecast and collect errors for which the actual load exceeds the forecast. The proposal is to update the operating reserve using the greater of the minimum specified for the equipment and a reserve based, for example, on the 95th percentile of these positive errors. The 95th percentile is an initial design choice, not a safety guarantee; consecutive abrupt changes must be examined separately.

Scheduling and local protection must operate at different timescales. The energy schedule may be updated in 15-minute steps, but operational monitoring of incoming power and electrical protection must rely on faster measurements. Charging is reduced when an elevator or pump starts; priority building services are not interrupted to sustain charging. In the event of a communication failure, a previously tested, restricted local mode is applied instead of allowing all devices to revert automatically to maximum power.

The distribution of single-phase chargers across phases must also be recorded. Compliance with the total active power limit does not rule out overloading an individual phase. A practical controller must therefore comply with the most restrictive of the limits imposed at the building's incoming supply, on the phases, and on individual charging circuits.

Phased infrastructure deployment. In a new building, cable routes, meter space, a communication channel, and provision for expansion in the distribution board should be allocated from the outset. The chargers themselves can be installed in phases according to confirmed demand. In an existing building, the first step is to measure the incoming load and garage circuits, rather than to purchase devices. Parking rights, metering, and billing arrangements must also be resolved alongside the technical design; official guidance for multifamily buildings specifically emphasizes these organizational issues [16].

An open communication protocol is useful for reducing supplier dependence, but the actual operation of the relevant function in the device must be verified. Open Charge Alliance (2025) indicates support in OCPP 2.1 for advanced charging management, distributed energy resources, and bidirectional energy flows. ISO 15118-20 defines information exchange between the vehicle and charging equipment, including messages for bidirectional transfer [8]. Reference to these standards does not establish that a vehicle is capable of exporting energy. Procurement should require the scope of certification, the response to power limits, and communication-loss testing in addition to the protocol name.

Solar panels and a stationary battery should be added following a separate techno-economic comparison. In a high-rise building, roof area does not increase in proportion to the

number of apartments and vehicles; moreover, daytime generation may not coincide with nighttime charging. A more justified sequence is to assess unused time flexibility in the first stage and then incorporate additional energy assets into the calculation. Vehicle-to-building energy export should likewise not be recorded as a saving without accounting for battery degradation, warranty conditions, and resident consent.

Tariffs and the investment decision. In Azerbaijan, the price of electricity purchased by charging stations must be distinguished from the price of the service provided to drivers. The annex to Tariff Council Decision No. 19 of December 29, 2024, specifies 12.5 qapiks/kWh for electricity supplied to the “other” non-residential group, including charging stations that sell electricity to vehicles. This figure must not be equated with the final service price charged to drivers by the station [2].

From January 1, 2026, a fixed monthly tariff of 1 manat also applies to residential and single-phase non-residential consumers, while a tariff of 3 manats applies to three-phase non-residential consumers [2]. The subscriber category and metering arrangement under which the garage will be supplied must be determined for the actual project. The increasing block tariff applicable to an apartment meter must not be conflated with billing through a separate charging meter within the same model.

If each of the 64 vehicles in the example receives 8 kWh every day, 15 360 kWh of charging energy is required over 30 days. At an assumed price of 0.125 manat/kWh, the energy component is 1920 manats. Assuming a separate three-phase non-residential subscription, the total including the fixed tariff would be 1923 manats. Equipment, communication, maintenance, additional infrastructure losses, and the operator’s service fee are not included in this amount. If the same energy is purchased at the same fixed unit price, this energy component does not differ among Modes A, B, and C. Calculating direct tariff savings from control requires a separate price differential or contractual mechanism.

The principal component of the investment comparison is the infrastructure reinforcement that can be deferred through control. The controller, metering, communication, and operating costs of the managed option must be compared with the discounted costs of the alternative involving additional cables, a distribution board, and a transformer. If reinforcement is merely postponed, its full cost is not counted as a permanent saving. Specifying a particular payback period without local price quotations and technical conditions is not justified.

Verification program in an actual building and limitations. The proposed pilot should begin with 4–6 weeks of measurements at the incoming supply and on individual phases, with subsequent monitoring covering different seasons. Records of connection, disconnection, required energy, and delivered energy are collected from the chargers. Resident identifiers are pseudonymized; names and apartment owners’ personal information are not required for the calculation. Weekdays, weekends, and high-load days are examined

separately. The difference between the departure time stated in a survey and the actual disconnection time must also be measured.

Table 4 – Indicators proposed for joint monitoring in the pilot

Indicator	Unit of measurement	Implication for decisions
Maximum incoming load and exceedance	kW; minutes	Compliance with the power limit
Sessions fully supplied by departure	% of sessions	Reliability of the energy service
Unmet energy	kWh; % of demand	Effect of peak reduction on service
Current and voltage by phase	A; V	Local electrical constraints
Measured charging efficiency	Battery/grid energy, %	Effect of modulation losses
Data completeness and communication loss	%; minutes	Operational performance of control
User interventions	Count; % of sessions	Acceptance of the rules

Note. Source: author's pilot project proposal. All acceptance criteria must be agreed before the project in accordance with the technical conditions and service agreement. If battery data are unavailable, efficiency is measured in a separate test.

To measure the benefits of control, comparisons must use the same energy demand and building load. Instead of deliberately creating uncontrolled loading in an actual building, recorded sessions are calculated under Modes A and B in a safe digital replay. The actual managed result is compared with this benchmark. In this way, changes in weather and the number of users are not presented as effects of control [9].

The model's limitations define the boundaries of applicability of the results. Daily mileage and arrival times are deterministic, and their values have not been estimated from local observation [10]. Charging vehicles with the same amount of energy every day does not fully capture the effects of less frequent but larger sessions. The interaction between single-phase and three-phase devices, harmonics, reactive power, reductions in charging power as battery state of charge increases, and the thermal behavior of cables have not been modeled. This model does not account for the dependence of energy losses on power; losses are represented by a constant coefficient.

Furthermore, the calculation assumes perfect knowledge of the building load. Forecast error and user overrides of control may alter the actual result. Maintaining the limit at the building's incoming supply does not guarantee the problem-free operation of the entire low-voltage network to which the building is connected. Therefore, the 53.8% peak reduction is a result of this model, rather than a generalized empirical estimate for buildings in Baku.

Conclusion. The impact of electric vehicles on a high-rise residential building must be assessed separately in terms of the increase in daily kWh and the increase in maximum kW. In the hypothetical building with 120 apartments, the baseline energy demand of 64 vehicles increased daily consumption by 34.7%. Meeting the same demand through immediate

charging produced a peak of 259.8 kW, while a common nighttime timer produced a peak of 533.6 kW. Load-responsive allocation delivered all the energy within a 9-hour window under the known baseline profile while maintaining the daily maximum at 120 kW.

Control does not remove the physical limit of supply capacity. In the maximum-load case, where daily mileage and the building load increased together, the 165 kW limit was respected, but an energy shortfall of 293.5 kWh remained by morning. Project success must therefore be measured both by compliance with the limit and by the timely fulfillment of user demand [12, 13].

The principal implementation proposal is to express each building's charging capability in terms of energy provision based on measured load. Providing residents with energy by their departure time, allocating reserves according to forecast error, monitoring phases, and deploying infrastructure in stages can be integrated within this framework. Seasonal measurements in an actual building will determine how much reinforcement expenditure this approach defers and what level of service it provides.

Input data for reproducing the calculation. The baseline load is assumed to remain constant within each hour. The hourly total of the power values shown in Table 5 is 1475 kWh, and the total for the 22:00–07:00 window is 387 kWh. This profile, the arrivals in Table 6, and the requirement of 8 kWh per vehicle are sufficient to reproduce all the main results. Power values are expressed in kW and energy in kWh.

Table 5 – Baseline building load without charging by starting hour

Time	kW	Time	kW	Time	kW
00:00	45	08:00	60	16:00	85
01:00	40	09:00	50	17:00	105
02:00	36	10:00	48	18:00	120
03:00	34	11:00	48	19:00	115
04:00	34	12:00	50	20:00	95
05:00	38	13:00	52	21:00	75
06:00	50	14:00	55	22:00	60
07:00	65	15:00	65	23:00	50

Note. Source: author's synthetic load profile. For example, the value in the 18:00 row refers to the 18:00–19:00 interval.

Table 6 – Hourly arrivals of vehicles requiring charging

Total EVs	17:00	18:00	19:00	20:00	21:00	22:00
8	1	1	2	2	1	1
24	2	4	6	6	4	2
40	3	7	10	10	7	3
64	5	11	16	16	11	5

Note. Source: author's scenario distribution. Each vehicle arrives once, requires 8 kWh, and departs at 07:00 the following day.

For reproduction of the calculation, each hour is divided into four 15-minute intervals. In Mode A, an energy balance of 8 kWh is initialized for each vehicle, and the power allocated

in each interval is the smaller of 7.4 kW and the remaining energy divided by 0.25 hours. In Mode B, the same procedure begins at 22:00 for all vehicles. In Mode C, the level L is sought such that the energy delivered during 22:00–07:00 equals demand; at each step, the sum of the building load and charging power is constrained to remain at or below 165 kW. If capacity is insufficient to meet demand, the difference is recorded as unmet energy. Energy conservation, the power constraint, and final remaining balances were checked separately in the results.

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