Building- And District-Level Resilience With Solar PV And Storage: Insights From Swedish Prosumers

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Abstract

To ensure energy efficiency and resilience, building prosumers must maintain energy supply during disruptions while minimizing environmental impact. This study examines the resilience of three solar-applied building prosumers: a single-family home, a multi-family building, and a commercial property in Västerås, Sweden. It evaluates (1) the impact of PV and battery integration and load prioritization on outage resilience, (2) seasonal variations in resilience for individual buildings in high-latitude region, and (3) district-level performance to assess aggregation effects on system resilience. One-day power outages are simulated for each season, with loads classified as critical or non-critical. System performance is measured using load coverage rate, which quantifies the robustness of building systems in withstanding disruptions. The results show that load prioritization significantly enhances resilience, particularly for multi-family buildings during heating season, ensuring occupant habitability and survivability. The role of PV and battery sizing in improving resilience varies by season, with battery capacity playing a key role during winter outages. The benefits of energy sharing at the district level are limited, but can be advantageous for multi-family buildings with a lower PV-to-load ratio. This study provides insights into the role of PV and storage systems as resilience strategies for buildings and districts in cold-climate regions.

Keywords: renewable energy, solar, buildings, prosumers, urban energy systems, resilience

1. Introduction

Energy security is becoming increasingly critical as extreme weather events and cyber threats pose growing risks to centralized power systems. One essential aspect of energy security is resilience, which ensures continuous energy supply under normal conditions and maintains critical functions during disruptions (IRENA, 2024). The International Energy Agency (2015) defines a resilient energy system as “ *the capacity of the energy system and its components to cope with a hazardous event or trend, to respond in ways that maintain its essential functions, identity, and structure as well as its capacity for adaptation, learning and transformation. It encompasses the following concepts: robustness, resourcefulness, recovery”*. In the context of building energy systems, resilience depends on technical reliability, which is influenced by system stability, energy flexibility, and the dependable operation of heating, cooling, and electrical systems (Rios et al., 2002). During the disruptive events, an infrastructure may experience different phases consisting of initial condition, disturbance progress, post-disturbance degradation, and restorative stage (Li & Mostafavi, 2024; Panteli et al., 2017). Figure 1 illustrates these phases in the resilience trapezoid and the corresponding capabilities an infrastructure should exhibit during disruptions.

Each phase of the resilience trapezoid maps to a system capability: withstanding, short-term absorption, recovery/restoration, and longer-term adaptation. The four core resilience attributes, robustness, redundancy, resourcefulness, and rapidity (Panteli & Mancarella, 2015), align with these capabilities. Robustness is the capacity to endure disruptions without loss of function; it focuses on pre-event resistance and corresponds to withstanding (Shafiei et al., 2025). Robustness can be reinforced by redundancy, which provides alternative operational paths during failures (Nan & Sansavini, 2017). In practice, buildings often rely on fossil-based backup (e.g., diesel generators) to maintain electricity and heat immediately after an outage, improving continuity but conflicting with sustainability goals. Given that the building sector accounts for nearly one-third of global CO_2 emissions (IEA, 2023), addressing sustainability alongside resilience is imperative.

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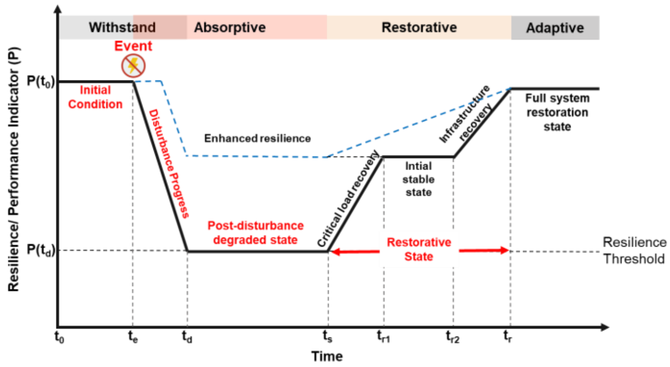


Figure 1: The resilience trapezoid illustrates the different phases an infrastructure may experience during a disruption, with figures adapted from Panteli et. al. (2016) and Umunnakwe et. al. (2021)

In Sweden, most residential and commercial buildings remain dependent on the centralized grid, making them vulnerable to outages. Enhancing the role of prosumers, entities that both produce and consume electricity and/or heat, is a key strategy for improving resilience in buildings and broader energy systems (Oprea & Bâra, 2024). By producing electricity and heat onsite from renewable sources, prosumers support the shift toward decentralized energy infrastructure, enhancing flexibility, reducing reliance on centralized grids and imported fuels, and ensuring continuity of essential services during disruptions (Iria & Soares, 2023; Oprea & Bâra, 2024; Yang et al., 2023).

Solar photovoltaics (PV) currently represent the fastest-growing renewable energy technology in Europe, and are a defining feature of modern energy prosumers (European Commission, 2025) and offering a practical solution for enhancing energy security and reducing emissions (Skandalos & Karamanis, 2025). However, the mismatch between solar production and demand, particularly during evening peaks, limits system reliability. Pairing PV with battery storage enables load shifting, increases self-consumption, and provides backup power, strengthening both building- and district-level resilience (Erba & Barbieri, 2022). Sweden's Risk Preparedness Regulation and the Steering of Electricity (STYREL) framework prioritize certain consumers, particularly essential societal functions such as hospitals and emergency services, for electricity supply during disruptions and power shortages that may cause outages in parts of the network (Energimyndigheten, 2020). As a result, most households and offices receive lower priority (Ramboll, 2023), underscoring the need for independent and resilient energy solutions. Achieving this in cold climates requires optimal PV-battery sizing as the redundancy sources, load prioritization, and attention to seasonal variation, factors often overlooked in research. This study assesses the resilience in terms of robustness of solar-based prosumer systems in three building types in Västerås, Sweden: a single-family home, multi-family housing, and a commercial facility. It focuses on:

- Evaluating the potential improvements in outage resilience from PV and battery integration and load prioritization in individual buildings.
- Examining seasonal variations in energy resilience.
- Assessing aggregated district-level system performance and its impact on resilience.

Findings aim to inform strategies for developing solar-powered, resilient, robust, and climate-adaptive energy systems in northern urban areas.

2. Data and Method

2.1 Case Study

This study utilizes measured electricity and district heating consumption data from three building types in Västerås, Sweden: 57 single-family houses (SFH), one multi-family building (MFH) comprising 42 households, and one commercial office building. For the multi-family and commercial buildings, electricity and heating demand data were adjusted to represent the year 2019 using a data-driven method based on records from other years. In contrast, the single-family house data are based on actual measurements from 2019. The year 2019 was selected because its weather conditions closely resemble the typical climate of Västerås, making it a more suitable reference year compared to other available years.

All scenarios use a standardized system configuration, as detailed in Table 1, with the same photovoltaic (PV) module, Trina Solar Vertex S TSM-405 DE09.08, applied to all building types, with a module efficiency (η_{sys}) is 21.1% (Trina Solar, 2021). PV capacity is determined by optimizing the available roof area for each building. For single-family houses, it is assumed that all buildings have similar roof areas, based on the most representative house in the dataset. Hourly PV production is modeled using tilted irradiance at time t ($G_T(t)$) calculated with the Hay and Davies model (Duffie et al., 2020). Global and diffuse irradiance data are used to calculate the beam irradiation and input in the model. Global and diffuse irradiance data from the Standardize and Verify Energy Performance in Buildings SVEBY climate dataset for 2019 (SVEBY, 2022) are used to compute beam irradiation, adjusted for a south-facing roof (azimuth 120°) with a 30° tilt. The power produced by the PV system at time t or $P_{PV}(t)$ is calculated in eq. 1 as:

$$P_{PV}(t) = G_T(t). A. \eta_{sys} \quad \text{(eq. 1)}$$

where η_{sys} is the module efficiency (21.1%), A is the roof area in m^2 defined for each scenario in Table 1. The $P_{PV}(t)$ is expressed in *Watt* (W) and $G_T(t)$ in *W/m²*.

Battery system capacity is designed to correspond with annual PV production, aiming to maximize the use of available roof area. Battery sizing is based on the Relative Battery Capacity (*RBC*) ratio proposed by Nyholm et al. (2016), which compares battery energy capacity to annual PV generation. Practical *RBC* values typically range from 2.5 to 4, as larger ratios offer diminishing returns in terms of self-consumption and self-sufficiency (Nyholm et al., 2016). Accordingly, battery capacities in this study meet the practical *RBC* threshold and are scaled similarly across all building types for comparability. Table 1 also outlines the battery systems used in each scenario, based on Tesla's storage solutions: Powerwall 2 for single-family houses and Powerpack for multi-family and commercial buildings (https://www.igen-energy.com/tesla-battery-storage/).

The battery model used in this study is based on the work of Fachrizal et al. (2022), where battery storage is treated as a load. In this approach, the battery power is positive during charging and negative during discharging. The model has been adapted to suit the conditions of this study, with the assumption that the battery starts fully charged (i.e., at maximum State of Charge, SOC) and operates with a Depth of Discharge (DoD) of 80%. Using eq. 2 below, the battery power $P_B(t)$ is modeled as:

$$P_B(t) = \begin{cases} \min\left(P_{PV}(t) - P_L(t), P_{B,max}\right) if\ P_L(t) \le P_{PV}(t), \\ \max\left(-\left(P_{PV}(t) - P_L(t)\right), -P_{B,max}\right) if\ P_L(t) > P_{PV}(t) \end{cases} \quad \text{(eq. 2)}$$

where P_{PV} refers to on-site PV power production at time t, $P_L(t)$ is the building's electricity load at time t, and $P_{B,max}$ is the maximum battery charging. All variables are coverted to and expressed in kilowatts (kW).

Table 1: PV and battery system characteristics implemented in this study.

Case Study	Photovoltaic (PV) System			Battery System	
	Number of Modules	Covered roof area (m^2)	Total power capacity (kW$_p$)	Total capacity (kWh)	Charging and Discharging efficiency (%)
Single-family House	30	60	12.7	40.5	95
Multi-family House	220	440	93	280	93.5
Commercial Building	436	872	184	550	93.5

Table 1: PV and battery system characteristics implemented in this study, continued.

Case Study	Annual Electricity Load (kWh/year)	Annual PV Production (kWh/year)	P/L
Single-family House	13529	12518	0.92
Multi-family House	155010	89525	0.58
Commercial Building	153725	177200	1.15

All buildings in this study are assumed to be fully electrified, utilizing electric heating systems with air-source heat pumps (ASHP). Accordingly, the heating demand is modeled using air-to-water heat pumps based on the coefficient of performance (COP) model proposed by Ruhnau et. al. (2019), applied to the total heating load, including space heating and domestic hot water (DHW), derived from district heating measurement data. The COP is calculated using a quadratic regression fitted to German manufacturer data across varying temperature conditions as in eq. 3 below:

$$\Delta T = T_{sink} - T_{source},$$

$$COP = 6.08 - 0.09.\Delta T + 0.0005.\Delta T^2 \quad \text{(eq. 3)}$$

Here, T_{source} represents the ambient air temperature, obtained from SVEBY's 2019 climate dataset used for standardized building energy calculations (SVEBY, 2022). T_{sink}, the heat sink temperature for water heating, is assumed to be constant at 50°C (Ruhnau et al., 2019).

To simulate realistic disruptions, a one-day power outage scenario is modeled based on the Swedish Electricity Act, which states that power outages should not exceed 24 hours (Energimyndigheten, 2020). This scenario is used to evaluate the resilience performance of buildings within that regulatory limit. The outage day is selected based on typical seasonal conditions, and it is assumed that the battery is fully charged at the onset of the outage. During normal operation, all buildings are connected to the centralized grid to meet their overall energy demand.

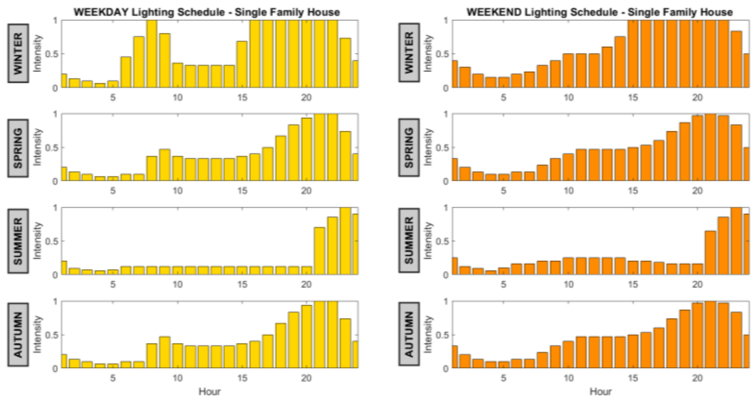
2.2 Load Categorization and Prioritization

Resilience during power outages depends on identifying and securing critical loads, as buildings must be able to independently meet essential energy needs when on-site generation is insufficient. According to ASHRAE guidelines (2003), this study defines critical loads as those required for thermal comfort, air quality, and essential life-support functions during emergencies. Based on these criteria, critical loads are defined to include space heating, ventilation, cooking (stove and freezer), lighting, and phone charging for safety and communication. Prioritizing these loads is crucial to ensuring functionality and safety during disruptions. Table 2 presents the critical loads and the typical energy requirements for appliances used in these activities, based on the Swedish Building Regulations (BBR) (Boverket, 2019) and SVEBY guidelines (SVEBY, 2012). The values in the SVEBY guideline are based on electricity use measurements from 400 single-family and multi-family buildings in Sweden, conducted as part of the *400 Housing Measurement* Project (Mätprojektet 400 bostäder), which is managed by the Swedish Energy Agency (Zimmermann, 2009). It is assumed that the buildings are equipped with mechanical exhaust and supply air ventilation systems with heat recovery (FTX systems), which are currently the most common in Swedish households, according to the Swedish National Board of Housing, Building and Planning (Boverket, 2024). This study focuses on calculating critical loads for single-family and multi-family buildings only.

Table 2: Electricity requirements for different types of equipment designated as critical loads.

Activities	Appliance	Single-family house	Dwelling unit in a multi-family building
Cooking	Stove	510 kWh/year	390 kWh/year
	Freezer	1020 kWh/year	720 kWh/year
Air quality	Ventilation System	Specific Fan Power (SFP) = 1.5 kW/(m^3/s) Outlet airflow = 0.35 l/s	
Safety	Lighting	1275 kWh/year	630 kWh/year
Communication	Phone Charging	Fast Charging = 0.02 kW/unit (assume 2 units per dwelling and one hour charging per day per unit)	

Cooking activities and lighting are occupant-driven aspects that exhibit dynamic and uncertain behavior. To account for this variability, measured data from the *400 Housing Measurement* Project are utilized to derive average daily schedules for lighting and cooking activities in both single-family and multi-family dwellings. To assess the impact of seasonality on resilience, distinct lighting schedules for each season were defined, as illustrated in Figure 2, Figure 2(a) for single-family houses and Figure 2(b) for multi-family buildings. The average daily lighting schedule from the project is applied to spring and autumn, as these patterns closely align with the daylight hours typical of those seasons. For summer and winter, however, the lighting schedules were adjusted to reflect seasonal variations in daylight. In winter, full lighting usage begins at 3 PM, corresponding to the average onset of dusk, and gradually decreases starting at 8:30 AM. In contrast, during summer, full lighting begins at 9 PM, coinciding with twilight. Seasonal differences also influence the total energy consumption for lighting. Winter requires significantly more electricity due to shorter daylight hours, while summer demands the least. These seasonal lighting profiles are based on empirical data from the *400 Housing Measurement* Project.



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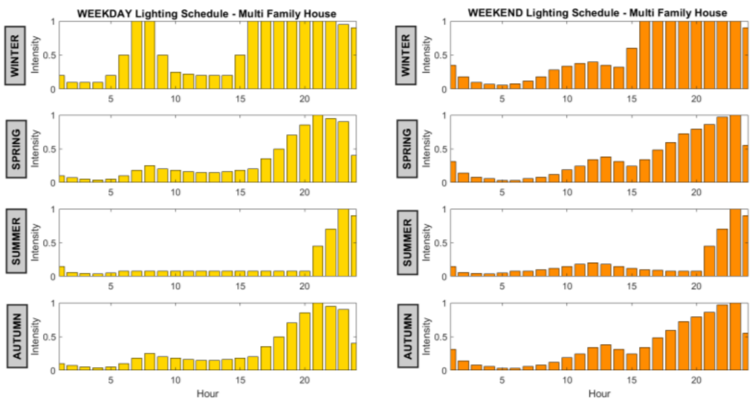
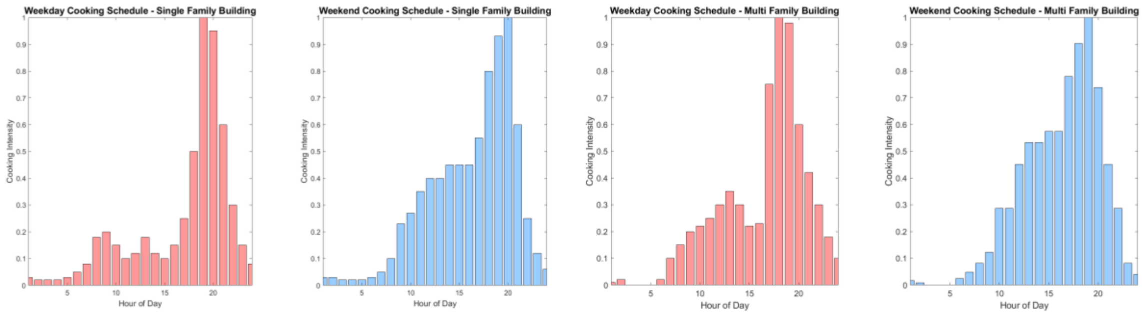


(b)

Figure 2: Lighting schedules for (a) single-family and (b) multi-family buildings during weekdays (yellow bars) and weekends (orange bars) across different seasons, adapted from the lighting data of the *400 Housing Measurement* Project (Zimmermann, 2009).

For cooking activities, it is assumed a consistent schedule across all seasons. However, weekday and weekend patterns were differentiated, as illustrated in Figure 3, where Figure 3(a) for single-family buildings, and Figure 3(b) for multi-family buildings.



(a) (b)

Figure 3: Cooking activity schedules for (a) single-family and (b) multi-family buildings during weekdays (light red) and weekends (light blue), based on data from the *400 Housing Measurement* Project. (Zimmermann, 2009).

2.3 Resilience Performance Assessment

The impact of renewable energy and storage system integration as a redundancy measure on building- and district-level resilience is evaluated by analyzing the Load Coverage Rate (*LCR*) across various PV and battery configurations for each prosumer type. The focus is on the robustness dimension of resilience, defined as the ability to maintain normal operations immediately after a disruption (withstanding/absorptive phases), while excluding restorative and adaptive phases. During a disruption where an external electricity supply is not available, LCR is adopted from the self-sufficiency ratio (Luthander et al., 2015). The difference is that conceptually, the self-sufficiency ratio has the battery charged from local generation only. However, in the LCR for resilience assessment, it was assumed that the battery was prepared for disruptions regardless of where the energy comes from, thus fully charged before the outage event. The LCR during the disruption in this study is defined as the ratio of electricity demand met by on-site PV generation and battery storage to the total electricity load (eq. 4):

$$P_{lc,t} = \min\left(P_{l,t}, P_{PV,t} - P_{B,t}\right),$$

$$LCR = \frac{\sum_{i=1}^{N} P_{lc,i}\Delta t}{\sum_{i=1}^{N} P_{l}\Delta t} \qquad \text{(eq. 4)}$$

where $P_{lc,t}$ refers to the covered load at time t, $P_{l,t}$ is the electricity load at time t, $P_{PV,t}$ is on-site solar PV production, and $P_{B,t}$ is the battery charging power, where a negative value of the variable means the battery is discharging. A robust energy system is characterized by a LCR close to or equal to 1, indicating that the system can fully meet the electricity demand of the building.

LCR is evaluated at both individual building and aggregated district scales across meteorological seasons: Winter (December–February), Spring (March–May), Summer (June–August), and Autumn (September–November). Scenarios include: (i) individual single-family house (SFH); (ii) aggregated SFHs; (iii) individual multi-family housing (MFH); (iv) individual commercial building (COM); and (v) mixed-district aggregation (SFH+MFH+COM with energy sharing). To ensure representativeness, the single-family house *LCRs* were averaged across the 57 buildings. In aggregated cases, buildings are assumed to deploy comparable redundancy (PV–battery) as summarized in Table 1, enabling power exchange within the community to support unmet loads during outages.

3. Results

3.1. Load Prioritization and Seasonality Impact on the Resilience of Individual Buildings

This section examines how load prioritization during outages and seasonal variability affects resilience. Figure 4 plots a single-family home’s PV generation and demand profiles under a one-day outage across the four seasons. Early in the day, the battery visibly sustains both critical and total loads in all seasons, most notably in winter and autumn when PV output is limited. As solar generation ramps up, PV covers the load and (when available) re-charges the battery to serve later hours. In winter, PV production is generally insufficient to recharge the battery and PV mainly meets critical loads at midday, while the already-depleted battery cannot

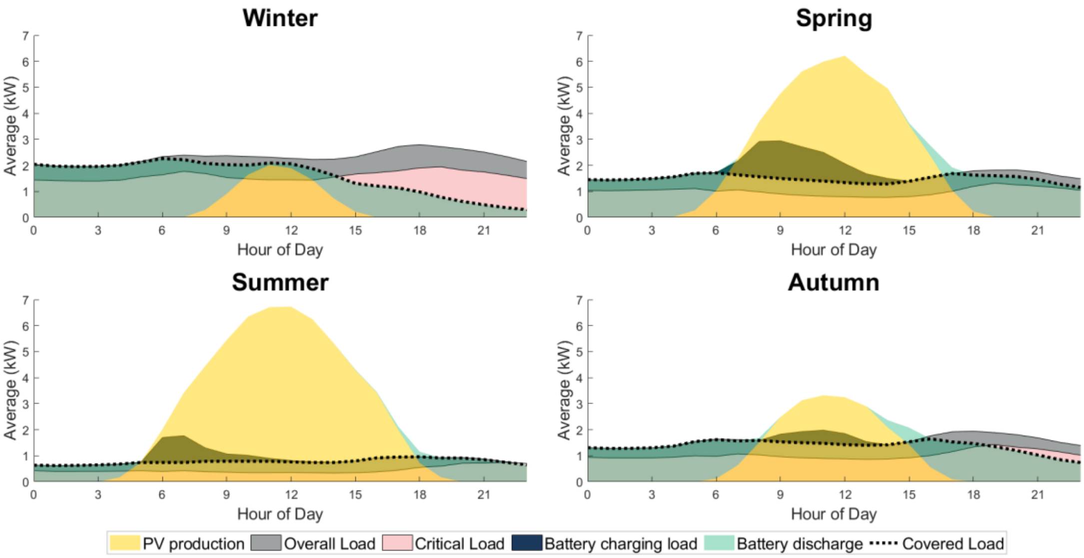


Figure 4: Electricity production and consumption profiles for a single-family house during a one-day power outage, including PV generation, total load, critical load, battery charging and discharging, and the portion of the load covered by PV and battery discharge across different seasons.

sustain critical demand overnight. In autumn, modest excess PV allows partial recharging, reducing, but not eliminating, late-day shortfalls (typically in the final 4 hours). Attempting to serve all loads in winter and autumn increases vulnerability. Hence, prioritizing critical loads can materially improve resilience by reserving PV and battery discharge for evening and night. By contrast, summer PV is ample to meet all loads throughout the day, and in spring the designed system meets all critical loads and nearly all total load.

Figure 5 compares springtime hourly profiles for (a) a single-family house and (b) a multi-family building. Despite relatively abundant solar, neither building can meet total load overnight. In the single-family house, however, the designed system sustains critical loads while in the multi-family building, critical demand is unmet once solar wanes. This underscores the value of load prioritization by allocating limited PV + battery power to life-safety and essential services can preserve habitability for the full 24-hour outage. The need is especially acute in multi-family buildings, where a smaller PV-to-load ratio, constrained by roof area per dwelling, makes covering all loads infeasible without strict prioritization.

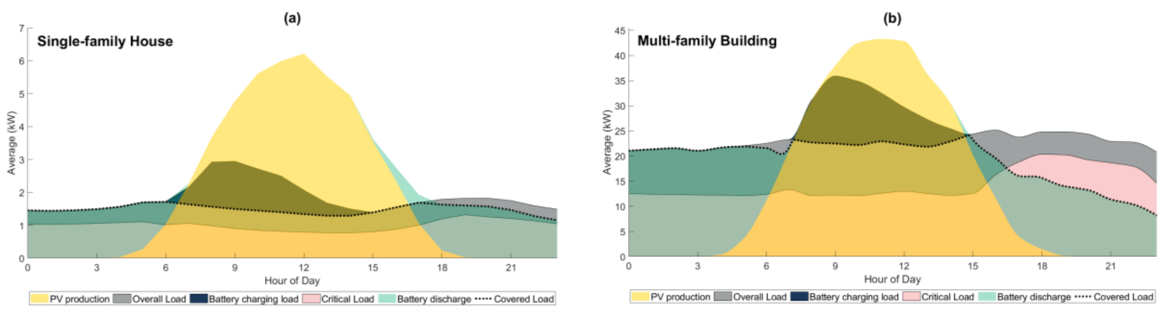
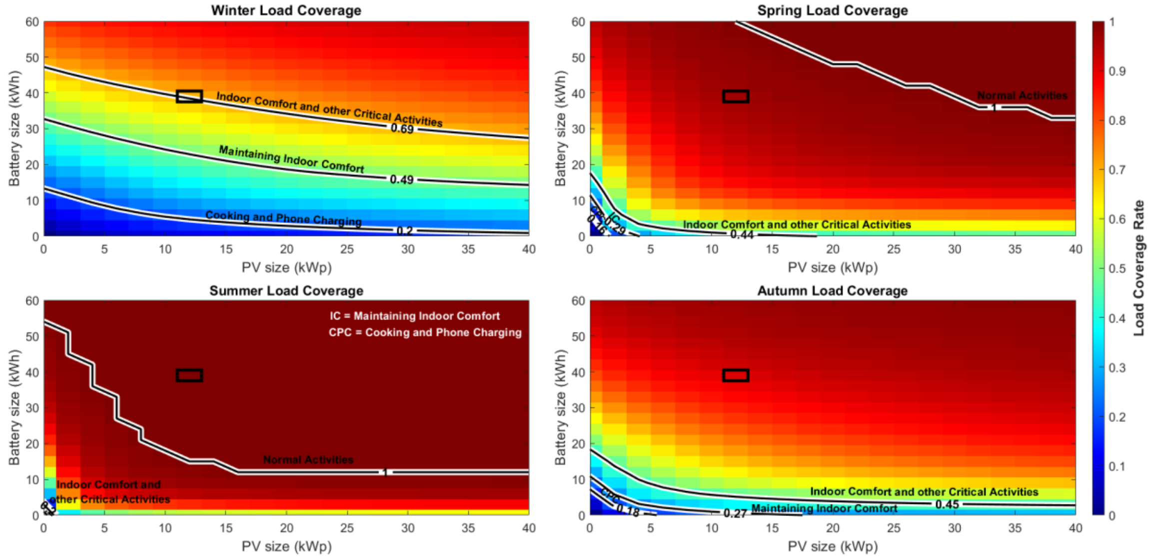


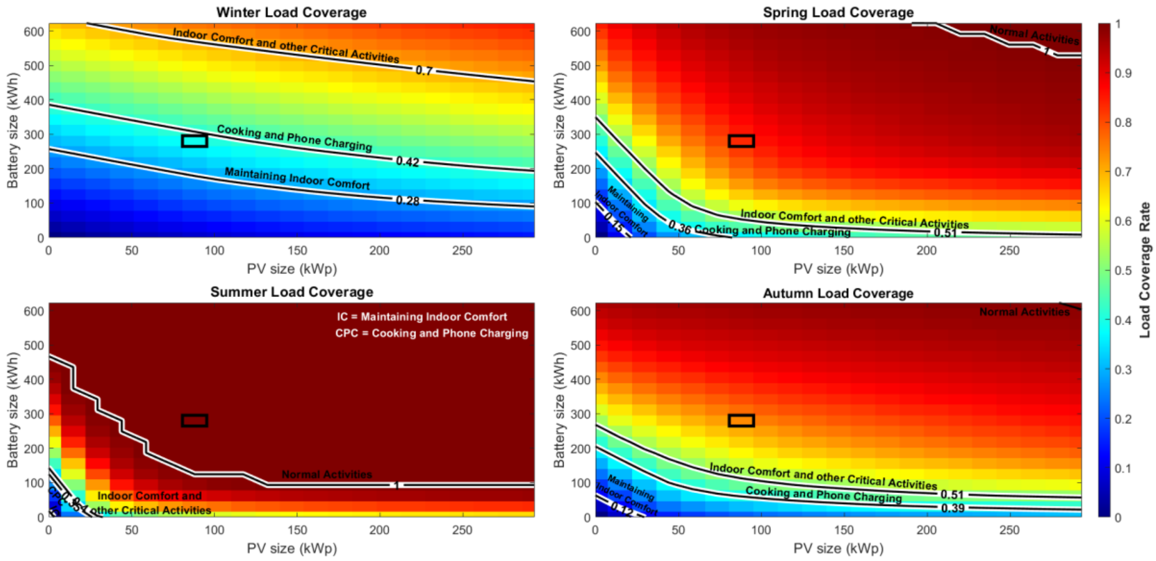
Figure 5: Comparison of electricity consumption and production profiles during a power outage in spring for (a) single-family houses and (b) multi-family buildings.

3.2. The Role of PV-Battery Integration in Individual Buildings Resilience

Figure 6 further emphasizes the importance of load prioritization and illustrates the impact of PV-battery integration on the system's robustness in supplying electricity to households after an outage begins. To assess resilience, daily average load coverage ratio (LCR) maps are used for both single-family and multi-family buildings. Each heatmap shows LCR as a function of PV and battery sizing across seasons, revealing how



(a)



(b)

Figure 6: Seasonal variation in building resilience represented by the Load Coverage Rate (LCR) for different PV and battery sizing configurations in (a) single-family and (b) multi-family buildings. The black rectangle indicates the default PV and battery sizing for each building type. Black and white contour lines represent the LCR thresholds required to meet electricity demands for specific critical and non-critical activities.

storage and PV jointly shape resilience. Color scales indicate the achieved LCR while black-white isolines mark the coverage required for activity tiers: "critical" (cooking, phone charging, maintaining indoor comfort, here cooking aggregates stove, lighting, and ventilation) and "normal" (all critical plus non-critical uses such as dishwashing, laundry, and entertainment). The black rectangle denotes the default PV–battery configuration for each building.

Seasonal LCR maps reveal clear variation in resilience across the two buildings. The slope of the black-white activity isolines diagnoses redundancy contributions in which steep slopes, which is visible in spring–summer–autumn, indicate PV-driven gains in LCR, whereas the gentler winter slope shows limited PV benefit. On the other hand, battery capacity is the resilience driver in winter. With the default design, the MFH can sustain indoor comfort in winter (its space-heating need is comparatively lower than other critical uses), but cannot cover all critical activities for a 24-h outage which limits the buildings occupant for cooking and phone charging activities. Meanwhile, SFH (Fig. 6a) reaches approximately 70% LCR for critical loads yet remains short of normal operation. The MFH (Fig. 6b) would require more than double its default battery capacity, at the same PV, to meet all critical loads over a winter day.

In spring, PV's contribution is pronounced. For the SFH (Fig. 6a), around 20 kWp PV alone (no additional storage) is sufficient to meet critical functions during a 24-h outage, with the default PV it already exceeds 80% total-load coverage, and doubling PV approaches full normal-load coverage. Where roof area limits PV expansion, increasing battery capacity can backfill to reach full coverage. For the MFH in spring, the default PV with roughly half the default battery can satisfy critical loads without the need to compromise on cooking, having lower indoor temperature, and other critical component.

In autumn, PV yields diminish relative to spring or summer, reducing its leverage on resilience for both buildings. By contrast, abundant summer irradiance enables the designed systems to cover all loads: PV effects remain evident up to 15 kWp (SFH) and 135 kWp (MFH), after which returns flatten. Overall, winter resilience depends on battery capacity, while PV's role is more superior for the other season, guiding season-specific sizing priorities.

3.3 Aggregation Impact on Resilience

This section evaluates the resilience effects of aggregation or energy sharing relative to individual operation, where prosumers use only on-site resources. Figure 7 reports overall load coverage across outage durations for both individual and aggregated scenarios, focusing on winter, the season of highest demand. To align with commercial operating hours, outages are assumed to begin at 06:00.

Across all cases, systems can sustain at least 9 h of outages without unmet load. For longer outages, multi-family housing becomes supply-limited, while commercial buildings, with optimized rooftop PV and low night-time occupancy, maintain coverage for up to 18 h and serve as the most robust system in the scenarios, aided by night periods with minimal load that preserve stored energy for daytime operations. Aggregation provides little benefit for single-family houses in winter because scarce solar yields leave no surplus to share. By contrast, mixed-building aggregation (SFH + MFH + COM) enables overall load coverage to around 15 h at the district level. Multi-family building resilience improves through imports from commercial buildings, albeit with a modest trade-off in the resilience margin of the better-supplied peers. In short, aggregation in winter reallocates limited redundancy rather than creating new supply. Aggregation benefits are heterogeneous, strongly favoring load profiles with persistent deficits particularly multi-family building.

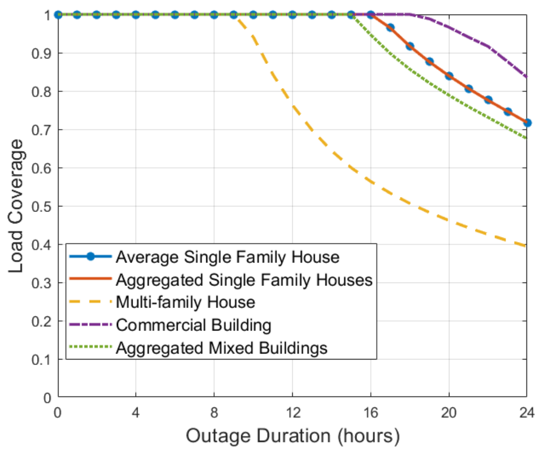


Figure 7: Resilience performance of different prosumer building systems at both individual and district levels, assessed by calculating the Load Coverage Rate (LCR) for various outage durations during winter.

4. Discussion

Based on the results, load prioritization in households located in high-latitude regions is crucial to ensure the survivability and habitability of building occupants, especially during disruptions or power outages in winter. Prioritizing loads becomes an optimal strategy for occupants, as their systems are not initially designed to handle prolonged disruptions. Research conducted in several U.S. cities shows that prioritizing loads and adapting occupant behavior during power outages can increase the load coverage ratio during extreme events by up to 22.9%, without the need to oversize PV and battery systems (Jiang et al., 2026). Similarly, load management through prioritization of critical over non-critical loads in prosumer households has been shown to alleviate electricity poverty in rural communities using stand-alone photovoltaic-battery systems (Ayodele et al., 2017).

Furthermore, during winter, energy sharing does not significantly enhance the resilience of single-family buildings. This is because each household tends to focus on maximizing its own power availability, assuming all homes have similarly sized PV and battery systems based on available roof area. A study by Huang et al. (2022), which focuses on optimizing energy sharing in energy communities across several countries, found that in a Swedish city, the performance of energy sharing was relatively lower than in countries at lower latitudes. This is due to the seasonal imbalance in PV production, low in winter and abundant in summer. As a result, buildings tend to be in the same energy state simultaneously by either all have sufficient energy or all lack it, reducing opportunities for energy sharing. Furthermore, the study indicates that energy sharing performance in residential districts can be improved by ensuring a sufficient Renewable Energy Source (RES) capacity ratio, ranging from 0.4 to 1.1, and by incorporating larger centralized storage capacity within the community (Huang et al., 2022).

This study utilized a limited dataset, particularly for multi-family and commercial buildings. Future work should include a broader range of buildings with diverse power production and consumption profiles to yield more representative results and explore additional scenarios. It would also be valuable to conduct economic and environmental assessments on different PV and battery storage sizing configurations, various energy management and sharing strategies, as well as alternative renewable energy sources. This would help identify the most effective approaches for enhancing the robustness and resilience of buildings and district energy systems.

5. Conclusion

This study conducts a resilience assessment of three types of prosumer buildings, a single-family home, a multi-family building, and a commercial building, in Västerås, Sweden, under a one-day power outage scenario. It evaluates the role of load prioritization in individual buildings, the integration of photovoltaic (PV) and battery systems, and energy sharing within a district-level setup. The results show that load prioritization is beneficial for ensuring that backup systems can cover critical loads, thereby maintaining occupant survivability and habitability during outages in heating-dominated seasons. The impact of PV sizing on building resilience is limited in winter but more evident in other seasons. In contrast, battery sizing plays a crucial role in enhancing resilience during winter outages. The study also explores how energy sharing at the district level affects the resilience of individual buildings and the overall energy community. Findings indicate that aggregation has limited impact on the resilience of single-family buildings in winter, as households typically lack excess energy to share. However, multi-family buildings benefit from aggregation due to their limited PV production and shorter outage durations, which make it feasible to cover their overall load. Commercial buildings can support energy sharing by distributing their PV generation to other buildings, enabling the entire district to meet its energy needs during a 15-hour outage. These findings offer valuable insights into the implementation of PV and battery storage strategies to improve the resilience of individual buildings and energy districts during disruptions such as power outages.

6. Acknowledgments

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