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RESIDENTIAL ELECTRICITY DEMAND STRUCTURE IN MULTI-APARTMENT BUILDINGS: IMPLICATIONS FOR ROOFTOP PHOTOVOLTAIC AVAILABILITY AND URBAN ENERGY RESILIENCE

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Abstract. The Urban energy systems face increasing pressure to decarbonise while maintaining security of supply and resilience to external disruptions. Rooftop photovoltaic (PV) systems on multi-apartment residential buildings offer a promising pathway to increase locally available renewable electricity in dense urban environments. However, reliable assessment of PV contribution requires a statistically robust understanding of residential electricity demand patterns at high temporal resolution.This article presents the first stage of a multi-layer study assessing the technical viability of rooftop PV deployment in multi-apartment buildings in Riga, Latvia, with a focus on energy availability and resilience. The object of the study is residential electricity demand in apartment buildings. Using hourly smart-meter data from a representative sample of 198 apartments (3.1 million observations), the study analyses whether households with different annual electricity consumption levels exhibit systematically different diurnal or seasonal demand structures once scale effects are removed. Electricity demand profiles were normalised by annual consumption and analysed using functional analysis of variance with permutation-based inference. The results show that mean hourly electricity consumption ranges from 0.09 kWh h^{-1} in the lowest consumption group (<1000 kWh yr^{-1}) to 0.44 kWh h^{-1} in the highest group (>3000 kWh yr^{-1}), while dispersion also increases markedly. However, after normalisation, neither diurnal nor seasonal load-shape functions differ statistically across consumption groups. The tests do not reject equality of diurnal profiles ($p = 0.24$) or seasonal profiles ($p = 0.30$). These findings demonstrate that higher residential electricity consumption in multi-apartment buildings reflects scale effects rather than distinct daily routines or seasonally concentrated usage. An assumption about winter-dominated electric heating in high-consumption apartments is not supported at a statistically significant level. From a practical perspective, the results support the use of representative, scalable demand profiles in subsequent modelling of rooftop PV generation, energy flows, and local energy availability, providing a robust foundation for resilience-oriented urban energy assessments.

Keywords: Rooftop photovoltaic systems, Multi-apartment residential buildings, Load profile analysis, Residential electricity demand.

JEL Classification: Q01, Q47, O18

1. Introduction

The transition towards a decarbonised and resilient energy system is a central objective of the European Union (EU) energy and climate policy. The European Green Deal and subsequent strategic frameworks aim to achieve climate neutrality by 2050 and substantially increase the share of renewable energy in final energy consumption by 2030 (European Climate Law, 2021). In response to recent geopolitical disruptions in Ukraine and following energy market volatility, particularly in Eastern Europe, the EU has further emphasised the need for energy security, diversification of supply, and resilient energy infrastructure that can withstand external shocks while maintaining affordability and sustainability (European Commision, 2025).

Distributed renewable energy technologies, particularly photovoltaic (PV) systems, are recognised as key enablers of these policy goals (Directive 2009/28/EC, 2009). Solar PV deployment has accelerated rapidly in

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recent years, with 22.4% of solar generation becoming one of the primary source of renewable electricity in the EU in 2025 (Eurostat, 2025). Initiatives such as REPowerEU explicitly call for the accelerated deployment of solar PV to reduce dependence on fossil fuel imports and enhance energy security (REPowerEU Plan, 2022).

In the context of urban residential energy systems, multi-apartment buildings account for a substantial share of electricity demand in Europe, particularly in Eastern European Countries like Riga, where 92% of residents live in multi-apartment housing(Central Statistical Bureau of Latvia, 2021). According to the EEA Greenhouse Gas Inventory, around 40% of energy in the EU is consumed in buildings, and 20% of that is electricity.(European Environment Agency, 2025). In Latvia, around 1740 GWh of electricity is consumed by households (Central Statistical Bureau of Latvia, 2025), which represents 26.7% of all electricity consumption in Latvia.

Researchers have recognised this high potential of the rooftops for PV energy production, and studies for PV integration in the urban context have been carried out, particularly in Northern countries. Extensive research has been done in Sweden. (Yang et al., 2020) assessed rooftop solar potential at both municipal and national scales in the Swedish context, identifying a substantial theoretical contribution of rooftop PV to national electricity supply. (Kanters & Horvat, 2012) quantified the urban rooftop solar potential of buildings in Lund, Sweden, and demonstrated that urban solar power can make a meaningful contribution to increasing the share of renewable electricity in cities. However, the study primarily focused on estimating technical power potential and did not explicitly consider electricity demand patterns or interactions with the wider electricity network.

The study by (Ruan et al., 2023) investigates rooftop photovoltaic deployment in an urban residential context by combining building-level PV potential estimation with electricity demand considerations to improve system sizing and self-consumption outcomes. The analysis focuses on quantifying technical generation potential and evaluating PV system performance under different deployment scenarios, primarily from an energy yield and utilisation perspective. While the study acknowledges the importance of electricity demand for PV optimisation, it treats demand in an aggregated or representative manner, and it does not explicitly examine the statistical structure of residential load shapes.

Similarly, in recent years, several studies have addressed the deployment of rooftop photovoltaic (PV) systems in multi-apartment buildings in Latvia, primarily from a technical–economic and regulatory perspective. For example, (Mutule et al., 2025) analyse the feasibility of PV energy communities in residential apartment buildings in Latvia, focusing on technical connection options, legislative frameworks, and economic viability under different participation scenarios. Their work employs representative hourly consumption profiles to evaluate net metering and net settlement schemes, and demonstrates that economic outcomes are susceptible to electricity prices, tariff structures, and regulatory uncertainty. The emphasis of this study is therefore on institutional design, cost allocation, and investment attractiveness of PV communities, rather than on a detailed empirical analysis of underlying household demand structures.

A related line of work by (Borodiņecs et al., 2024), focuses on optimising PV system sizing and self-consumption based on observed electricity demand in apartment buildings. While this study recognises the importance of demand profiles for PV optimisation, it largely relies on aggregate or averaged load representations and treats differences in household consumption primarily in terms of magnitude, with limited statistical examination of whether temporal usage patterns differ systematically across consumption levels.

In contrast to existing studies, this article focuses explicitly on the empirical structure of residential electricity demand in multi-apartment buildings. Using high-resolution empirical data and functional statistical methods, the study examines whether differences in annual electricity consumption are associated with systematically different diurnal or seasonal demand patterns after controlling for scale effects. By establishing whether representative demand profiles can be robustly applied across consumption levels, the analysis provides a statistically validated foundation for subsequent modelling of rooftop PV generation, energy availability, and resilience at building and city scales. This demand-centric perspective complements prior PV-oriented research and addresses a critical prerequisite for reliable assessment of distributed solar energy in dense urban housing.

2. Methods

2.1. General Approach

This article is the first part of the study to assess the technical viability of rooftop photovoltaic (PV) deployment on multi-apartment residential buildings in Riga, Latvia, with a specific focus on energy availability and its potential contribution to local energy resilience.

The full analysis will be structured around four methodological layers. First, aggregated residential electricity demand within multi-apartment buildings is analysed. This modelling is conducted at high temporal resolution to capture diurnal and seasonal variability, which is critical for evaluating energy availability during grid disturbances. Second, the existing residential building stock will be characterised at the level of building typologies that dominate Riga's urban fabric. This characterisation will reflect differences in construction period, height, roof geometry, and typical dwelling density, enabling a representative assessment of rooftop PV potential across the city rather than for isolated case studies. Third an energy flow modelling layer will be employed to quantify the temporal interaction between on-site PV generation. Finally, scenario-based aggregation will be used to scale individual building results to the city level, allowing the estimation of cumulative PV energy availability across Riga's multi-apartment housing stock. This will enable an assessment of how distributed rooftop PV could contribute to decentralised energy supply during periods of stress on centralised infrastructure.

This focus this article is on the first layer – analysis on the residential electricity demand.

2.2. Electricity Demand Analysis Framework for Multi-Apartment Buildings

Electricity demand is modelled at the level of individual dwellings and then aggregated to the building scale. This bottom-up formulation is necessary because the subsequent PV availability analysis will be constrained by the roof-area-to-dwelling ratio, and because multi-apartment buildings distribute any rooftop generation across a large number of households. The demand model therefore combines (i) an empirically anchored annual consumption magnitude, (ii) a smooth seasonal component, (iii) an empirically derived intra-day shape differentiated by workdays and weekends, and (iv) stochastic variability, while preserving annual energy consistency by constructing annual consumption bands and calibrating to Riga statistics

Annual consumption as the primary driver of household heterogeneity

Let E_i denote the annual electricity consumption of dwelling i (kWh/year). Empirical residential electricity statistics for Riga show that households are well described by discrete annual consumption bands, with the majority of dwellings concentrated between approximately 500 and 2000 kWh/year and a rapidly declining share at higher consumption levels (Figure 1). In the model, each dwelling is assigned an annual consumption value drawn from these empirical bands, such that the synthetic population reproduces the observed statistical distribution.

This annual consumption value defines the total energy budget of the dwelling and represents the dominant source of heterogeneity between households.

Hourly electricity consumption data were obtained from *Sadales Tīkli*, the Latvian electricity distribution system operator (DSO), covering a 24-month observation period spanning three calendar years. From this dataset, a representative subset of 198 apartments was extracted for which complete hourly measurements were available for at least one full calendar year. Apartments with incomplete annual records were excluded to ensure the integrity of functional demand profiles.

Zero-valued observations were retained and treated as valid measurements, reflecting periods of negligible or absent electricity use that are common in residential smart-meter datasets. The subset was selected using distribution-preserving sampling based

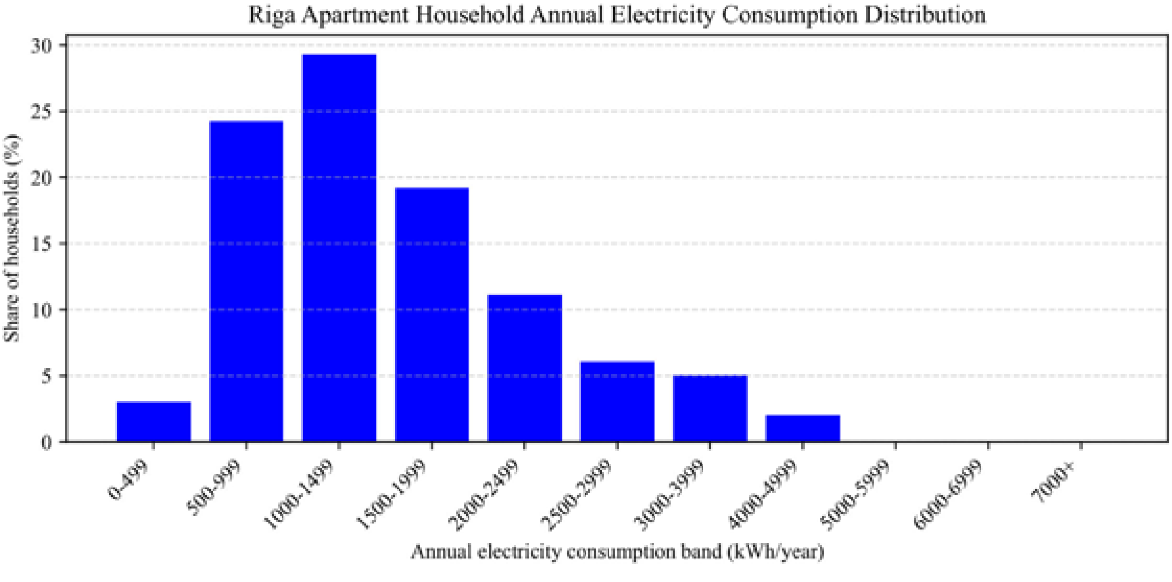

Figure 1. Riga Apartment Household Annual Electricity Consumption Distribution

Source: (Latvia Statistics Bureau, 2020) on annual electricity consumption, such that the empirical distribution of annual demand in the subset matches the national distribution reported in official household electricity surveys (Latvia Statistics Bureau, 2020).

Normalisation of Apartment-Level Electricity Demand Profiles

Apartments were grouped ex-ante into four annual consumption bands (<1000 kWh, 1000–2000 kWh, 2000–3000 kWh, >3000 kWh), reflecting standard segmentation used in residential electricity demand studies and allowing interpretation in terms of household size, appliance stock, and usage intensity

To isolate behavioural differences in electricity use from differences in absolute consumption levels, all analyses were conducted on *normalised* demand profiles.

For each apartment i, hourly electricity consumption $E_{i,h}$ was normalised by the apartment's total annual electricity demand E_i^{ann}, such that

$$\tilde{E}_{i,h} = \frac{E_{i,h}}{E_i^{\text{ann}}} = \frac{E_{i,h}}{\sum_{h=1}^{8760} E_{i,h}} \tag{1}$$

where h denotes the hour of the year. This transformation ensures that the sum of hourly values for each apartment equals unity and that the resulting profile represents the *relative allocation of electricity use over time.* Consequently, all remaining variation reflects differences in timing, load concentration, and daily or seasonal structure, rather than scale effects associated with total energy use.

Normalisation was performed at the *individual apartment level prior to any aggregation.* This ordering is critical, as averaging raw consumption profiles before normalisation would suppress within-group heterogeneity and implicitly assume identical temporal behaviour across apartments, an assumption that is explicitly tested rather than imposed in this study.

Each apartment-year was therefore treated as one realisation of a stochastic electricity-use process, yielding a set of normalised hourly demand functions grouped by annual consumption band. Group-level average profiles were computed solely for descriptive and visual purposes, while all statistical inference was based on the full set of apartment-level normalised profiles.

Diurnal behavioural load-shape analysis

To characterise behavioural electricity-use patterns within a typical day, the normalised hourly profiles were aggregated by hour of day. For each apartment i, a 24-dimensional diurnal load-shape function was constructed as

$$x_i^{\text{day}}(h) = \sum_{d=1}^{D} \tilde{E}_{i,(d,h)}, h = 0, \dots, 23, \tag{2}$$

where d indexes days in the year. The resulting function represents the share of annual electricity consumption occurring in each hour of a typical day and is invariant to both total demand and seasonal effects.

This representation isolates systematic daily timing behaviour driven by occupancy patterns, routines, and activity scheduling, and is therefore interpreted as a behavioural load-shape profile. Group-level mean diurnal profiles were computed for descriptive purposes only, while all statistical inference was based on apartment-level functions.

Differences between consumption groups were assessed using one-way functional analysis of variance (functional ANOVA), testing the null hypothesis that the group-specific mean diurnal load-shape functions are identical over the 24-hour domain.

Seasonal appliance-driven load-shape analysis

To capture longer-term seasonal structure associated with appliance stock and climate-dependent end uses, the same normalised hourly data were aggregated by calendar month. For each apartment i, a 12-dimensional seasonal load-shape function was defined as

$$x_i^{\text{month}}(m) = \sum_{h \in m} \tilde{E}_{i,h}, m = 1, \dots, 12, \tag{3}$$

where the summation is taken over all hours belonging to month m. The resulting function represents the share of annual electricity consumption occurring in each month of the year.

By construction, this representation suppresses intra-day variation and highlights systematic seasonal demand patterns. In the Latvian context, such patterns are strongly associated with electricity-intensive appliances such as space and water heating, lighting, and other climate-sensitive loads. Differences in the seasonal load-shape functions are therefore interpreted as reflecting structural differences in appliance usage, rather than behavioural timing.

As with the diurnal analysis, group differences in seasonal load shapes were evaluated using one-way functional ANOVA on the apartment-level functions.

2.3. Functional ANOVA and Statistical Inference

Electricity demand profiles are inherently functional in nature: each apartment's consumption is not a single scalar observation, but a continuous trajectory over time with strong temporal dependence. Treating individual hours or months as independent observations, as in classical ANOVA, would therefore violate the independence assumption and lead to inflated significance due to pseudo-replication. Conversely, collapsing profiles to a small number of summary statistics (such as peak-to-average ratio or load factor) risks discarding structurally important information about timing and distribution of use.

Functional analysis of variance (functional ANOVA) provides a natural framework for comparing electricity load shapes while respecting their temporal structure. In this approach, each apartment-year is treated as a single observation in the form of a function defined over a common temporal domain. Group comparisons are then formulated in terms of equality of mean functions rather than equality of scalar means.

Formally, let $x_i(t)$ denote the normalised electricity demand function of apartment i, observed over a domain $t \in \mathcal{T}$ (hour of day, or month of year). Functional ANOVA tests the null hypothesis that the expected load-shape functions are identical across consumption groups:

$$\cdots = \mathbb{E}\left[x_i(t) \mid g = G\right], \forall t \in \mathcal{T}.$$

$$= \cdots = \mathbb{E}\left[x_i(t) \mid g = G\right], \forall t \in \mathcal{T}. \tag{4}$$

Unlike repeated-measures ANOVA, which models time as an additional factor and requires explicit specification of within-subject covariance structures, functional ANOVA treats the entire curve as the unit of analysis. This avoids the need to impose restrictive assumptions about correlation between adjacent hours or months, which are difficult to justify empirically for residential electricity demand.

Global testing and permutation-based inference

Functional ANOVA yields a pointwise F-statistic describing between-group and within-group variability at each point in the temporal domain. However, inference is not conducted at individual time points, as this would reintroduce multiple-testing and dependence issues. Instead, a *global* test statistic is constructed by aggregating the pointwise F-statistic over the domain, for example by integration or averaging.

Because residential electricity demand data are typically non-Gaussian and exhibit strong temporal autocorrelation, analytical F-distributions are not relied upon. Instead, statistical significance is assessed using permutation-based inference. Group labels are permuted at the apartment level, preserving the full functional structure of each load profile, and the global test statistic is recomputed for each permutation. The resulting empirical distribution provides a robust, distribution-free estimate of the p-value.

This permutation strategy ensures that any detected differences between consumption groups reflect systematic differences in load-shape structure rather than artefacts of serial correlation or unequal variance across time.

3. Results

3.1. Descriptive Statistics

Table 1 summarises the descriptive statistics of hourly electricity consumption across the four annual consumption groups and for the full sample.

The full dataset comprises approximately 3.1 million hourly observations derived from 198 apartments. As expected, mean hourly electricity consumption increases monotonically across annual consumption groups, ranging from 0.09 kWh h^{-1} in the lowest consumption group (0–999 kWh yr^{-1}) to 0.44 kWh h^{-1} in the highest group (≥3000 kWh yr^{-1}). A similar pattern is observed for the median hourly demand, which rises from 0.06 kWh h^{-1} in the lowest group to 0.32 kWh h^{-1} in the highest group. These differences reflect substantial variation in absolute electricity use intensity across apartments.

Dispersion of hourly consumption also increases with annual demand. The standard deviation rises from 0.12 kWh h^{-1} in the lowest group to 0.42 kWh h^{-1} in the highest group, indicating greater variability in hourly electricity use among high-consumption apartments. Upper-quartile values show a similar progression, with the 75th percentile increasing from 0.12 kWh h^{-1} to 0.55 kWh h^{-1} across the same groups. This suggests that higher annual consumption is associated not only with higher typical hourly demand, but also with a broader distribution of hourly usage levels.

Minimum hourly consumption is zero across all groups, reflecting periods of negligible or no recorded electricity use, which are common in residential smart-meter datasets. Maximum hourly values vary considerably, with the highest observed hourly load reaching approximately 11 kWh h^{-1}. Such extreme values are rare and likely correspond to short-duration

Table 1

Descriptive fleet statistics

Annual consumption group	0-999	1000-1999	2000-2999	3000+	Total
Number of flats in the sample	54	96	34	14	198
Number of hourly observations	856905	1505340	532434	214451	3109130
mean	0.09	0.17	0.28	0.44	0.19
Standard Deviation	0.12	0.21	0.3	0.42	0.25
Minimum	0	0	0	0	0
25% (1st Quartile)	0.03	0.06	0.1	0.17	0.06
50% (2nd Quartile)	0.06	0.11	0.18	0.32	0.11
75% (3rd Quartile)	0.12	0.21	0.35	0.55	0.22
Maximum	4.68	10.99	4.88	7.21	10.99

coincident appliance usage rather than sustained demand, and they are not representative of typical household behaviour.

Importantly, while the descriptive statistics clearly demonstrate strong differences in magnitude of hourly electricity consumption across annual consumption groups, they do not provide information on the temporal allocation of electricity use. Differences in mean, variance, and upper quantiles could arise either from higher usage intensity at the same times of day and year, or from systematically different daily or seasonal usage patterns. Distinguishing between these possibilities requires explicit analysis of load shapes.

For this reason, the descriptive analysis serves primarily to characterise the scale and dispersion of hourly electricity demand across the sample, while the subsequent functional analysis focuses on whether these magnitude differences translate into statistically significant differences in diurnal and seasonal load-shape structure after normalisation by annual consumption.

3.2. The Energy Use Patterns

Diurnal behavioural load-shape differences

Weekday profiles shown in Figure 2 exhibit pronounced morning and evening peaks associated with work-related activity patterns, while weekend profiles display elevated daytime consumption, reflecting increased household occupancy.

Figure 3 presents the mean normalised diurnal electricity demand profiles for apartments grouped by annual electricity consumption. All groups exhibit a pronounced evening peak and reduced night-time consumption, consistent with established residential electricity-use patterns.

Functional analysis of variance was used to test whether the diurnal load-shape functions differ systematically between consumption groups after normalisation by annual demand. The permutation-based global test based on the integrated functional F-statistic does not reject the null hypothesis of equal mean functions across groups (p = 0.24). This indicates that, once scale effects are removed, apartments with different annual electricity consumption allocate their electricity use similarly across the 24-hour day.

Although localised differences in the pointwise F-statistic are observed during the early evening hours, these differences are not sufficiently strong or persistent across the daily cycle to yield a statistically significant global effect. The results therefore suggest that higher annual electricity consumption is not associated with systematically different daily usage timing but rather reflects increased intensity of use within broadly similar behavioural schedules.

Seasonal redistribution of demand

Figure 4 presents the mean normalised monthly electricity consumption profiles for apartments grouped by annual electricity demand. All consumption groups exhibit a broadly similar seasonal structure, with increased electricity shares in autumn and winter months and lower shares during spring and early summer.

Functional analysis of variance was applied to test whether seasonal load-shape functions differ systematically across annual consumption groups after normalisation by annual demand. The permutation-based global test based on the integrated functional F-statistic does not reject the null hypothesis of equal mean functions (p = 0.30). This indicates that apartments with higher annual electricity consumption do not allocate a significantly larger share of their electricity use to specific seasons of the year compared with lower-consumption apartments.

Although localised differences in the pointwise functional F-statistic are observed in individual

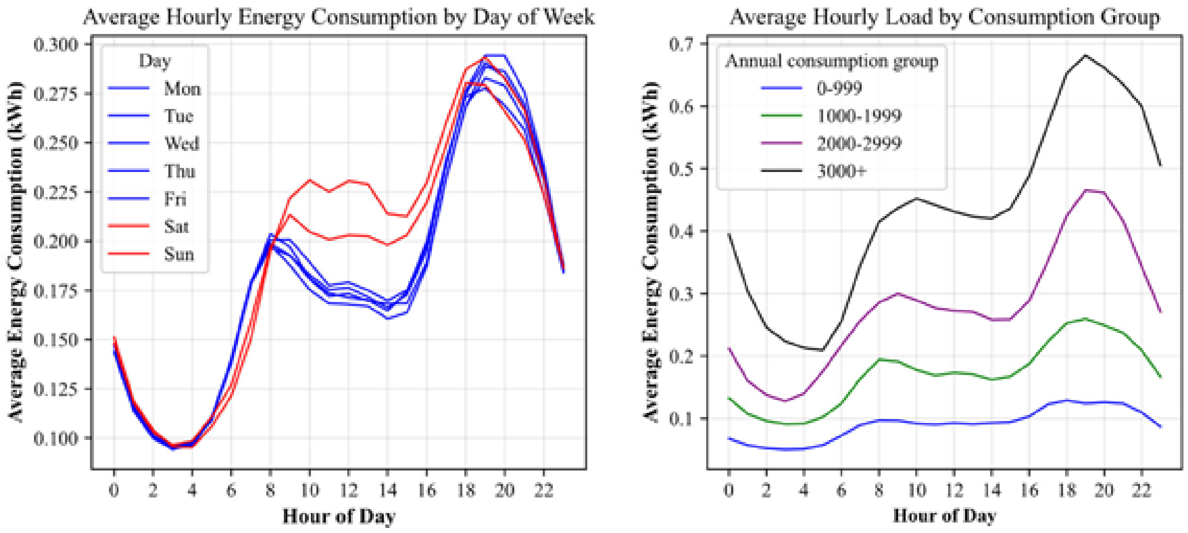

Figure 2. Household Hourly Electricity Consumption Distribution Depending on Day of Week (a) and by Annual Consumption Group (b)

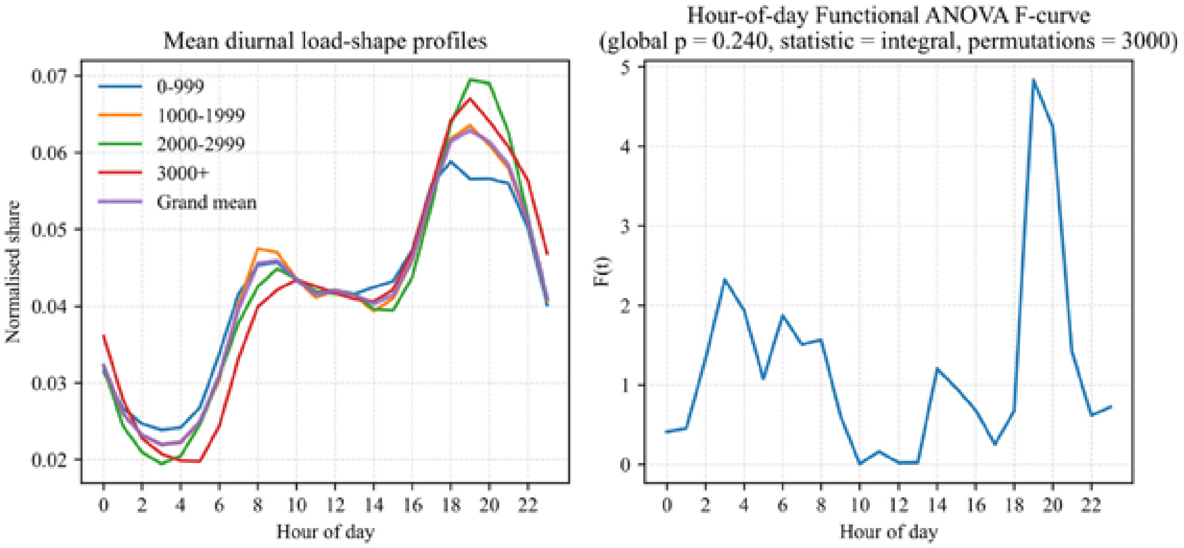

Figure 3. Statistical diurnal load shape (a) and functional ANOVA analysis (b) among household groups

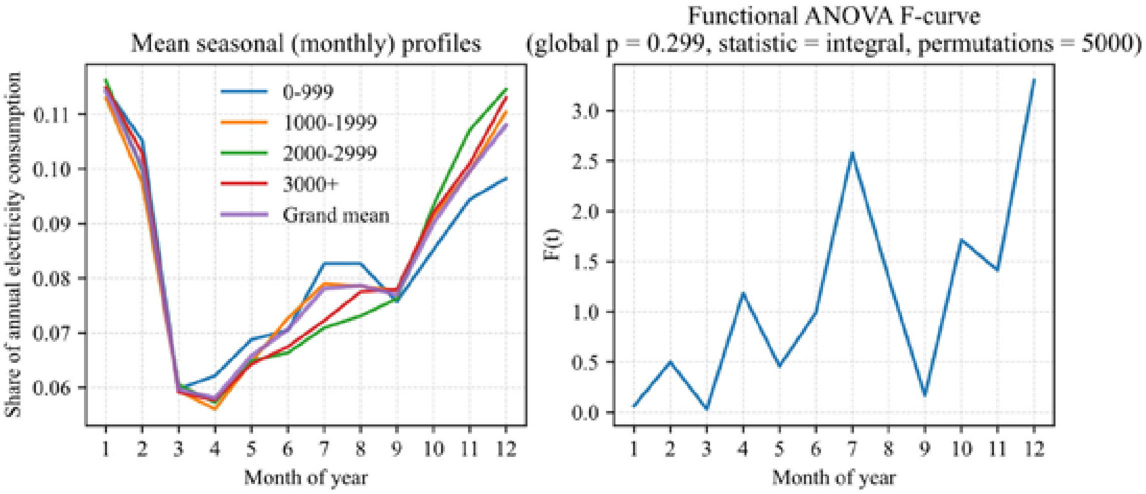

Figure 4. Normalised monthly profiles and function (a) and ANOVA analysis (b) among household groups

months, these differences are not sufficiently strong or persistent across the annual cycle to yield statistically significant global effects. The results therefore suggest that higher annual electricity consumption is not primarily associated with distinct seasonal usage patterns, such as increased winter-dominated electric heating, but rather reflects a broadly proportional increase in electricity use throughout the year.

The seasonal profile is derived from empirical residential electricity data by computing the average daily consumption for each day of the year and normalising this series by its annual mean.

To obtain a smooth and repeatable representation suitable for simulation, the normalised day-of-year profile is approximated using a third-order Fourier series, retaining the fundamental annual frequency and the first two higher harmonics. This specification captures the dominant seasonal structure of residential electricity demand, including the winter–summer contrast and intermediate shoulder-period behaviour, while filtering short-term fluctuations caused by holidays, weather anomalies, and sampling noise (Figure 5).

4. Discussion

This article constitutes the first analytical stage of a broader research programme aimed at assessing the technical viability of rooftop photovoltaic (PV) deployment on multi-apartment residential buildings in Riga, Latvia, with a particular focus on locally available energy and its potential contribution to urban energy resilience.

From this perspective, functional analysis of residential electricity demand is a necessary step to verify whether differences in annual electricity consumption across

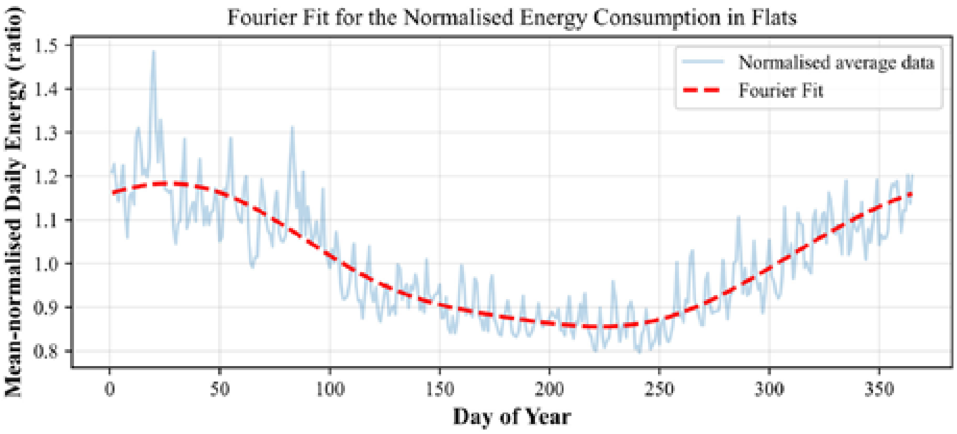

Figure 5. Fourier fit for annual normalised energy consumption in apartments

apartments translate into materially different temporal demand structures. If such differences were present, they would require distinct demand representations in later PV availability and energy flow simulations. Conversely, if load shapes are broadly invariant after normalisation, subsequent modelling can focus on energy magnitude and building-level aggregation rather than on behavioural segmentation.

Behavioural interpretation of diurnal load shapes

The absence of statistically significant differences in diurnal load shapes across consumption groups suggests that households with markedly different annual electricity demand nevertheless follow broadly similar daily routines. After normalisation, all groups exhibit the characteristic residential pattern of reduced night-time demand, a gradual morning increase, and a pronounced evening peak. Functional ANOVA confirms that any observed local differences, particularly during early evening hours, are not sufficiently strong or persistent across the daily cycle to constitute systematic behavioural divergence.

From a behavioural perspective, this finding implies that higher electricity consumption is not associated with extended occupancy periods, shifted activity schedules, or qualitatively different daily routines. Instead, households appear to use electricity at similar times of day, but at different absolute levels. This has important implications for demand-side management strategies in apartment settings, as it suggests that the potential for behavioural time-shifting scales with total consumption rather than varying structurally between low- and high-consumption households.

Seasonal structure and the electric heating assumption

The seasonal analysis addresses a hypothesis that is particularly relevant for PV and resilience studies: that higher electricity consumption reflects winter-dominated electric space heating, resulting in strong seasonal demand asymmetry. Such an assumption would have direct implications for PV contribution to resilience, as winter electricity demand coincides with lower solar availability.

The results do not support this assumption. Once electricity consumption is normalised by annual demand, the seasonal allocation of use is statistically indistinguishable across consumption groups.

All groups exhibit a broadly similar seasonal profile, with moderately higher electricity shares in autumn and winter months and lower shares in spring and early summer. However, the highest consumption group does not display a systematically stronger winter concentration than lower-consumption groups. The absence of statistically significant seasonal differentiation suggests that electric space heating is not a dominant driver of annual electricity demand differences within the analysed apartment stock.

This result is consistent with the institutional and technical context of Latvian multi-apartment housing, where district heating remains prevalent and direct electric heating is relatively uncommon in older and mid-aged buildings. It also underscores the risk of inferring appliance usage patterns from annual consumption levels alone, without explicit information on dwelling characteristics or heating technologies.

Structural drivers and baseline electricity use

Taken together, the diurnal and seasonal results point towards baseline and continuously operating loads as the primary contributors to higher annual electricity consumption. Differences in appliance ownership, dwelling size, plug-load density, and standby consumption are likely explanations for the observed variation in total electricity demand. Crucially, these factors increase electricity use relatively uniformly across time, rather than altering the temporal structure of consumption.

This interpretation aligns with the finding that normalised load shapes are highly similar across groups, and that differences in demand manifest predominantly as changes in magnitude rather than timing. From a modelling perspective, this suggests that representative load shapes can be meaningfully scaled across consumption levels within the apartment sector, simplifying energy system simulations without sacrificing empirical validity.

Implications for PV self-consumption and energy modelling

The finding that load shapes are broadly invariant across consumption groups has direct implications for modelling photovoltaic self-consumption, battery storage, and energy flow optimisation in apartment buildings. If temporal demand patterns are similar across households, then differences in self-consumption potential and storage utilisation are driven primarily by total demand rather than by behavioural or seasonal timing differences.

This supports the use of common, smoothed load-shape representations, such as Fourier-based seasonal profiles, in simulation studies, provided that scaling is handled appropriately. It also reduces the risk of overfitting group-specific demand profiles in contexts where empirical evidence does not support their existence.

Scope, limitations, and directions for further research

The conclusions of this study are specific to apartment electricity consumption within the analysed dataset and should be interpreted within this context. The analysis does not include explicit information on dwelling age, floor area, heating technology, or cooling equipment, nor does it distinguish newer apartment buildings that may rely on electric heating or air conditioning. It is therefore possible that more recent housing stock exhibits different seasonal dynamics, particularly in winter and summer months.

Investigating such effects would require additional metadata on building characteristics and household conditions, and constitutes a natural direction for future research. Importantly, the absence of evidence for electric heating effects in the present analysis does not imply that such effects do not exist in specific sub-segments of the housing stock, but rather that they cannot be inferred from aggregate apartment electricity consumption alone.

5. Conclusion

This article analysed high-resolution residential electricity consumption in multi-apartment buildings in Riga as the first stage of a broader assessment of rooftop photovoltaic (PV) deployment and local energy availability. Using hourly data from a representative sample of 198 apartments, the study examined whether differences in annual electricity consumption are associated with systematically different temporal demand patterns.

The results show that, although absolute electricity consumption varies substantially across annual consumption groups, the temporal structure of electricity use does not. After normalisation by annual demand, neither diurnal nor seasonal load-shape functions differ statistically across consumption bands. Functional analysis of variance confirms that higher electricity consumption in apartments is driven primarily by scale effects rather than by distinct daily routines or seasonally concentrated usage.

These findings indicate that commonly assumed explanations, such as winter-dominated electric space heating in high-consumption apartment households, are not supported by the data at statistically significant level for the analysed multi-apartment housing stock. Instead, higher demand appears to reflect broadly proportional increases in electricity use across time, consistent with differences in baseline and continuously operating loads.

From a practical perspective, the results support the use of representative diurnal and seasonal demand profiles that can be scaled by annual consumption or building size in subsequent PV and energy-flow modelling. This simplifies demand representation while preserving empirical validity, which is particularly relevant for resilience-oriented assessments of locally available energy in dense urban environments.

Future research will extend this analysis to building typologies and newer apartment stock, where electrified heating or cooling may introduce stronger temporal differentiation, and integrate demand results with PV generation and storage modelling at the building and city scale.

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Author's Contributions

A.R. conducted the main research and analysis. A.L. provided methodological guidance and critically reviewed the manuscript.

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