How technology, behaviour, and tariffs reshape residential power demand: A comparative study of sub-hourly load curves for subpopulations in Great Britain and France

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ABSTRACT

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Accurate prospective analysis of power demand is critical for the energy transition. However, current residential models often rely on deterministic assumptions where building physics is the primary driver of power demand, often neglecting or underestimating other determinants. This paper aims to address this gap by exploring the different drivers of residential demand by analysing sub-hourly load curves for segments based on the building type and heating technologies. The study presents a unique comparative analysis utilising high-resolution smart meter data coupled with detailed contextual information from large household subpopulations in Great Britain and France. The results first suggest that distinct cultural habits and preferences shape the load curves in ways that differ between subpopulations. Second, heating systems and tariffs shape demand curves, with different technologies producing distinct load profiles and tariff incentives driving load shifting. Third, the analysis suggests that electrification represents a structural transformation of demand shape rather than a simple fuel substitution. This work highlights the power of cross-border comparisons in revealing the distinct cultural and technological drivers of energy consumption. These insights support a shift toward power demand models that integrate buildings, systems, appliances, tariffs, and behaviour as dynamic, interactive variables. For policymakers, stakeholders and grid operators, the findings underscore that a successful energy transition requires coordinating technology deployment, tariff designs, and public awareness to effectively manage the heterogeneity of future electrical loads.

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INTRODUCTION

The energy transition requires deep reductions in fossil fuel use while maintaining reliability in power systems. Unlike global trends, residential energy consumption in France and Great Britain has followed a decreasing trend over the past two decades, largely driven by energy efficiency improvements and building regulations (ADEME 2025; DESNZ 2024). However, the ongoing electrification of end-uses, like adoption of heat pumps and electric vehicles, is shifting a larger share of this demand toward electricity. Consequently, while total energy use is stabilising or declining, peak electrical loads are expected to rise and become increasingly sensitive to outdoor temperatures and occupant behaviour, placing new constraints on local power grids. In Europe, households account for roughly one quarter of final energy consumption, and about two-thirds of this energy is used for space heating ("Energy Consumption in Households" 2025). In the United Kingdom, the residential sector is the second largest energy consumer (Preet et al. 2025), underlining the central role of residential loads in winter and in decarbonisation strategies. To evaluate the demand-side transition scenarios, researchers rely on residential energy demand models. These models mainly rely on physics-based approaches where the building envelope characteristics and weather conditions (typically outdoor temperature) are considered the main determinants of the energy demand. While this tradition has resulted in insightful results into the thermal performance and retrofit potential, it often represents other factors like appliance use, occupant behaviour and tariff designs through simplified or static assumptions, despite evidence that these elements shape the daily power demand. For example, according to the energy balance report compiled by the French Statistical Service for Data and Environmental Studies (SDES 2023), in 2021, French statistics show that around 28% of household electricity is used for space heating and 15% for domestic hot water. The remainder is largely linked to other end-uses such as appliances, lighting and cooking, which are only weakly temperature dependent but sensitive to behaviour and equipment choices. As a result, behavioural, tariff and cultural drivers of residential demand tend to be underestimated in prospective analyses. Cross-country differences highlight some gaps: in France, 40% of residential total final consumption is provided by electricity (vs 27% from natural gas) (IEA 2023a), whereas in the UK 62% of residential consumption is provided by natural gas compared to 27% by electricity (IEA 2023b). This indicates that in both countries, the dominant share of space heating is provided by the respective primary energy source. The 2023 activity report by the CRE 2024 indicates that in France, a high number of households rely on time-of-use tariffs, whereas Great Britain has mostly flat electricity tariffs, with only around 9% of households currently on a time of use tariff (GOV.UK 2025). Yet many modelling studies work with homogenous households (O'Brien and Tahmasebi 2023), which means all households exhibit the same response to temperature changes and the same response to price changes. This raises the question of how much of the observed variation in sub-hourly power demand arises from physical factors such as building type and heating technology, and how much is driven by tariffs, appliance ownership and daily habits. The present study aims to address this gap by conducting a comparative analysis of sub-hourly residential energy use in Great Britain (SERL) (Elam et al. 2024b) and France (Panel Particuliers). Using high-resolution smart-meter datasets for subpopulations, it examines how key contextual factors such as building type, space-heating technology, tariff structure, and outdoor temperature shape household load profiles and temperature sensitivity. This cross-country approach offers novel insights but also highlights the challenges of aligning contextual and behavioural data between national datasets, given the relative scarcity of such context-rich smart-meter records.

LITERATURE REVIEW

Several studies have analysed what drives residential energy use, focusing on how economic, physical, and social factors influence consumption. Tsemekidi Tzeiranaki et al. (2019) studied energy use between 2000 and 2016 across the European Union and found that economic growth, cold weather, and larger dwellings increased residential energy demand. They also pointed out that cultural and behavioural factors strongly affect energy use, but these are difficult to measure because data are limited or not comparable between countries. At the household level, Brounen et al. (2012) used data from more than 300,000 Dutch homes to study both gas and electricity consumption. Their results showed that gas use depends mostly on the

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building's physical characteristics, such as its age and type, while electricity use is more related to household features like size and income. They stressed that most policies focus on technical building factors and tend to ignore how household behaviour and demographics also shape energy demand. Lévy and Belaïd (2018) analysed French housing survey data and showed that energy use changes with the life cycle of households, such as when families move or grow. They found that both housing type and social characteristics play key roles in how much energy is consumed. Borozan (2018) used data from 64 European regions to study economic, social, and climate factors affecting household energy use. The results show that income, unemployment, and education are significantly associated with energy consumption, suggesting that policies need to adapt to regional contexts. For the UK, Huebner et al. (2015) analysed data from 924 English households and found that building characteristics, such as dwelling size and type, explained the largest share of variability in domestic energy consumption (around 39%), with socio-demographics, heating behaviours, and attitudes contributing less after correcting for multicollinearity. Millar et al. (2025) state that heat-related energy constitutes the highest share of consumption in UK dwellings. However, energy demand still varies significantly between similar home types, underscoring the need for more nuanced assessment methods that reflect diverse occupant behaviours and usage patterns. A summary of these studies, including their methodologies and the key drivers of residential energy use they identified, is provided in Table 1.

Table 1 Summary of studies on the drivers of residential energy and electricity consumption.

REFERENCE	GEOGRAPHY AND POPULATION	METHOD	KEY DRIVERS
(Tsemekidi Tzeiranaki et al. 2019)	EU (28 countries), Eurostat data	Linear regression	Economic growth, climate, dwelling size, behaviour
(Brounen et al. 2012)	Netherlands, 300,000 households	Statistical analysis	For gas: building's physical characteristics For electricity: household characteristics like size and income
(Lévy and Belaïd 2018)	France, ≈30,000 households	Logistic regression	Life cycle of households, housing type and demographic characteristics
(Borozan 2018)	Europe (64 regions)	Regression analysis	Income, unemployment, and education
(Huebner et al. 2015)	UK, 924 households	Lasso regression	Building characteristics, socio-demographic and behaviour
(Millar et al. 2025)	UK, 7 homes	Empirical monitoring and quantitative analysis	Building type, heating technology, occupant behaviour

A smaller number of studies have examined daily load profiles, often using smart-meter data from limited samples with scarce contextual information on households. For example, the UK's Energy Follow-Up Survey (EFUS 2017) performed a detailed analysis on electricity consumption data to evaluate trends in lighting, appliance ownership/use, and emerging smart technologies from 436 households, revealing how household characteristics drive daily consumption patterns that peak in mornings/evenings and vary seasonally Tynan (2021). Similarly, aggregated statistics from the Smart Energy Research Lab (SERL) provide insights into Great Britain domestic energy use but are presented without granular subpopulation breakdowns (Few et al. 2024).

Together, these studies reveal the complexity of household energy use but share a common limitation: they mainly examine total energy consumption rather than daily variations in power demand. Our study addresses this gap by combining smart meter data with contextual information to analyse sub-hourly load curves for both gas and electricity. While previous research often treats cross-country differences as a constraint, we view them as an opportunity. Comparing subpopulations from Great Britain and France provides valuable insights into how cultural (e.g., daily routines and usage habits), technological (e.g., heating systems and

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appliances), and tariff-related factors (e.g., pricing structures and incentives) influence power demand. Specifically, we explore how heating technologies, pricing structures, and user behaviours and habits shape daily load patterns. This comparative approach demonstrates how countries can learn from one another's experiences when developing energy policies. It also emphasizes that prospective modelling should account for multiple determinants, not just the physical characteristics of buildings. The following sections describe the datasets and analytical methods used to compare residential electricity demand patterns in France and Great Britain, present the main results on cultural, technological, and tariff-driven differences in load curves, and conclude with a discussion of their implications for modelling and policy.

DATA AND METHODS

DATASETS DESCRIPTION

This study utilises two smart meter datasets representing residential power demand for subpopulations in Great Britain and France. Both datasets provide sub-hourly resolution consumption data coupled with contextual data that enables comparative analysis of load profiles across the different subpopulations.

Great Britain: SERL Observatory

The SERL (Smart Energy Research Lab) Observatory is a comprehensive research dataset maintained by University College London that integrates smart meter data and linked contextual information for over 13,000 households across Great Britain. The dataset combines six core data streams: half-hourly electricity and gas smart meter readings, weather data, household survey responses, Energy Performance Certificates (EPC) data, tariff information, and geographic location data. The household sample is largely representative of Great Britain's regional distribution and Index of Multiple Deprivation (IMD)[1] quintiles, with minor geographic deviations (Wales and Yorkshire are slightly under- and over-represented, respectively) (Webborn et al. 2021). This level of representativeness supports the use of the sample for regional and deprivation-based comparisons, but it should not be interpreted as fully representative of all socio-economic or dwelling characteristics. The analysis utilises 2023 and 2024 data at 30-minute temporal resolution. The aggregated statistical dataset provides daily and half-hourly aggregated mean power demand by household segment and contextual variables (Elam et al. 2024a), and the energy data from SERL presented in this paper were either from the SERL statistical dataset or generated using the same aggregation methods. For this study, we analyse two datasets: (1) Gas smart meter data from 6,815 households, and (2) Electricity import (from the grid) smart meter data from 8,485 households. The data are publicly accessible through the UK Data Service (SN 8666) and documented in (Elam et al. 2024a, 2024b; Webborn et al. 2021). For consistency between the datasets used in this study, households equipped with rooftop photovoltaic (PV) systems were excluded from the SERL sample, as the French dataset does not include PV households. Therefore, solar generation does not affect the net demand patterns analysed in this study. This means that the SERL subpopulation analysed here is more restricted and should not be considered representative.

France: "Panel Particuliers"

The Panel Particuliers (PP) is a research panel of residential customers equipped with Linky smart meters, maintained by EDF Research & Development. The panel was established in 2018, with participating households representing market conditions accessible to all French energy providers. The panel comprises ~5,000 recruited households, with 1,336 households used in this analysis for 2024. The sample targets primary residences only in hexagonal France (excluding Corsica and overseas territories), includes customers on both regulated tariffs (TRV) and new market offers (NO). The Panel Particuliers is not representative of the French national population. Recruitment bias toward customers adopting new offers means the sample over-represents households with time-of-use (TOU) tariffs (95%) and electric heating (54%), compared to national prevalence rates (~40% with TOU tariffs (CRE 2025) and ~40% for electric heating (Ceren 2022)). The TOU tariffs provide 8 hours of off-peak rates, typically scheduled

1 Index of Multiple Deprivation (IMD), a composite indicator used in England to measure relative area-level deprivation across income, employment, health, education, crime, housing, and living environment.

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in the evening and overnight starting from 10 PM (6 hours at night), with 2 hours available at midday. Findings from this dataset are therefore more applicable to French households with electrical heating and having TOU tariffs. This analysis uses 2024 data collected at 30-minute intervals. The dataset includes power demand in Watts, with data on building type, heating systems, and tariff structure. Different homes can have distinct off-peak periods, which can vary considerably in timing.

Unlike SERL, the Panel Particuliers dataset does not include external temperature measurements. We therefore integrated municipal weather station data by: (1) matching each household to its municipality, (2) identifying the nearest weather station for that municipality using French geographical and meteorological databases, (3) resampling raw temperature measurements to 30-minute resolution using linear interpolation to match the load curve temporal granularity, and (4) merging temperature and consumption data by matching household municipality and timestamp. This data fusion approach introduces potential measurement uncertainty from spatial mismatches between municipalities and stations, which we acknowledge in our discussion of limitations. A comparable source of uncertainty also exists in the SERL dataset, where temperatures are modelled on a 30 km × 30 km grid from nearby weather station data rather than being measured at each dwelling.

Table 2 summarizes the key characteristics of both datasets. The two datasets differ substantially in population size, temporal coverage, heating technology prevalence, and tariff structures; differences that are important for interpreting comparative results and understanding the contexts in which load curves are shaped.

Table 2 Summary of the key characteristics of both subpopulations.

CHARACTERISTICS	SERL	PANEL PARTICULIERS
Sample size used in the study	6,815 gas and 8,485 electric smart meters	1,336 electric smart meters
Temporal coverage	2023 & 2024	2024
Time resolution	30 minutes	30 minutes
Dominant heating technology	Gas	Electric
Tariff structure	Mostly flat-rate tariffs	~95% time-of-use pricing
Key limitations	Pre-aggregated data for this study; limits analysis of diversity	Not nationally representative for this study

ANALYTICAL METHOD

Households were segmented according to their type (detached and semi-detached residences as single dwelling unit vs flats and apartments as multi-dwelling unit) and heating energy source (electric space heating vs gas boilers or other). Electric heating includes direct electric heaters, electric radiators as well as, in some GB cases, electric storage heaters and a small number of heat pumps. Within the Panel Particuliers non-electric heating subpopulation, a further distinction was made between households with and without electric domestic hot water (DHW).

The data used in this study are individual 30-minute consumption readings aggregated into mean daily profiles over a year (48 timesteps per 24-hour period) for the full population of interest and for each segment. The French data (Panel Particuliers) are recorded in Central European Time (CET, UTC+1), while the SERL data are recorded in Western European Time (WET, UTC+0).

To enable fair comparison between building types and countries with different housing stocks, we normalize energy demand by floor area (W/m²). This allows direct comparison based on the same functional unit.

To compare the segments, the following key quantities of interest were analysed:

- Normalised hourly load curves: The shape of the mean normalised load curves per segment are analysed to identify the key differences across the studied subpopulations.

- Thermal gradient: To analyse the temperature gradient, a linear regression quantifies how electricity demand responds to external temperatures between −5°C and 15.5°C, which is commonly used in similar studies (Hanmer et al. 2026). Within this range, temperature is the dominant driver of power demand for temperature-sensitive households. When the energy use analysed represents the main heating fuel, or the total energy use in the home, then the gradient provides information about the thermal efficiency of the building (Hanmer et al. 2026). The slopes of this linear regression are calculated and compared for selected segments.

RESULTS

NON-SPACE HEATING ELECTRICITY DEMAND

This subsection compares households with non-electric space heating to isolate differences linked to non-heating uses such as DHW, cooking, lighting, and appliances. The analysis focuses on SERL electricity demand for households with gas heating in Great Britain and Panel Particuliers households with non-electric space heating in France, including a subset without electric domestic hot water.

Figure 1 presents normalised daily load curves for these three subpopulations. In the morning, the British curve shows a steeper increase in demand, suggesting shorter, more intensive use of appliances, whereas the French curves rise more gradually, indicating a smoother start to daily activities. Around midday, both countries show an increase in electricity demand. The British curve displays a small bump around 13:00, while the French curves exhibit a more pronounced bump between 10:00 and 12:00. This difference is likely due to more frequent lunches at home in France, as well as the operation of appliances such as electric water heaters, washing machines, and dishwashers during off-peak tariff periods. All three curves exhibit a pronounced evening peak around 18:00–19:00 local time, with the British peak slightly higher, which may reflect more coincident appliance use during the evening, or differences in appliance efficiency, although this requires further investigation. The British peak also appears to be slightly time-shifted relative to the French curves, which could reflect cultural differences in typical daily activity schedules. At night, the British curve reaches the lowest demand level, which could be caused by characteristics of appliances, less appliances on standby, different appliances ownership. While the French curve for households with electric domestic hot water shows the highest night-time intensity, driven by off-peak operation of water heaters. The green curve without electric domestic hot water lies between these two, confirming the contribution of electric hot water to the French night-time base load.

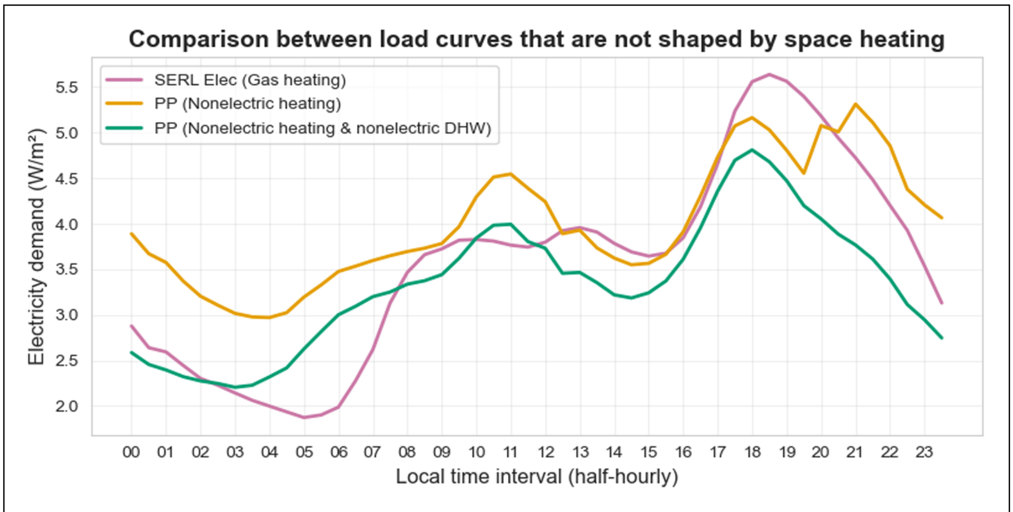

Figure 1 Normalised daily non-heating residential load curves (SERL: 6,779 households; PP: 723 and 435 households).

Overall, these results show that even when electric space heating is excluded, daily profiles differ significantly between the two countries due to variations in appliance ownership and characteristics, tariff incentives, cultural habits, and occupant behaviour.

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WITH SPACE HEATING

Equipped with electric space heating

This subsection focuses on households with electric space heating to examine how different electric heating technologies shape daily demand profiles in Great Britain and France. The curves reflect total household electricity consumption, including appliances, electric space heating, and domestic hot water. The analysis compares electric demand for SERL households with electric heating in Great Britain and Panel Particuliers households with electric heating in France. SERL households with electric heating include a mix of storage heaters, electric radiators and a smaller share of heat pumps (Elam et al. 2024a). For the French subpopulation, information on the specific types of electric heating systems is not available for this study. The analysis compares aggregated electric demand for these SERL and Panel Particuliers subpopulations.

Figure 2 presents normalised daily load curves. Both profiles show clear heating-driven features, but they differ markedly in the timing and intensity of peaks, reflecting contrasting technologies and tariff structures.

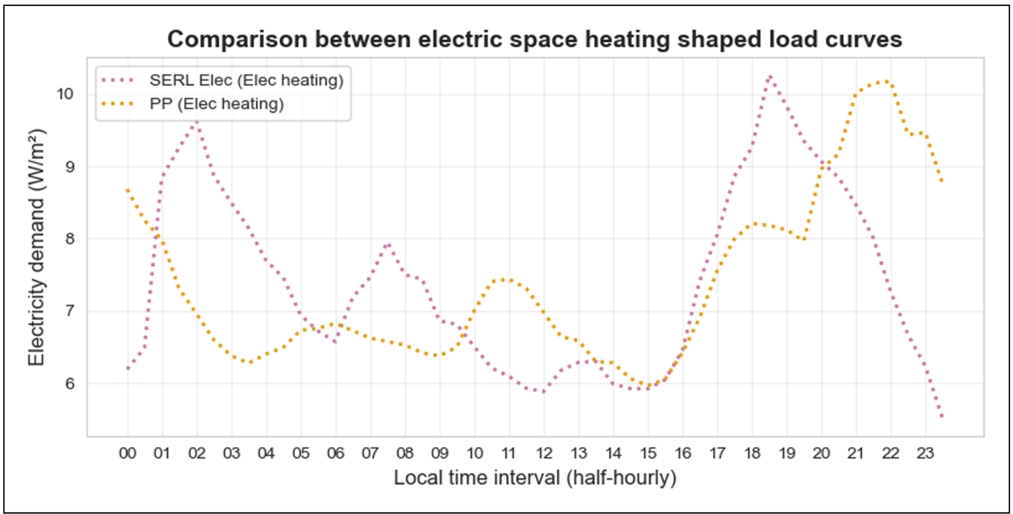

Figure 2 Normalised daily equipped with electric-heating residential load curves (SERL: 460; PP: 613 households).

The SERL curve displays a pronounced peak around 01:00–02:00, which reveals that storage heaters are charging during off-peak tariff periods. The Panel Particuliers curve starts at a high level at midnight, due to domestic hot water activation aligned with off-peak hours late at night but then declines more gradually over the first hours of the day, indicating more continuous operation of direct electric heating rather than a charging event. During the late morning and early afternoon (approximately 09:00–16:00), British demand falls to its lowest values, while French demand remains slightly higher and has a local maxima around 11:00, due to electric domestic hot water heating promoted by off-peak tariffs, as well as the presence of occupants at that time of day, whose activities including the use of appliances contribute to the observed increase in power demand. From late afternoon onwards, both curves rise sharply as occupants return home and increase heating and appliance use. The British curve peaks more sharply around 18:00–19:00, whereas the French curve climbs more gradually to a sustained late-evening plateau around 21:00–22:00, likely reflecting a combination of domestic hot water use and other evening household activities. Notably, the peak amplitude is almost identical in both cases.

Overall, these results show that British electric space heating produces intense peaks linked to storage-heater operation at late night, while French electric space heating generates a higher and more sustained base load with smoother peaks, reflecting differences in heating technology, tariff incentives, and occupant behaviour, although the relative contribution of each factor remains unclear.

Electric versus gas space heating

This subsection compares how gas and electric space heating reshape daily gas and electricity demand profiles in Great Britain and France. The analysis considers three segments: gas-heated

SERL households in Great Britain, electrically-heated SERL households, and electrically-heated Panel Particuliers households in France.

Figure 3 shows that gas-heated British households have the highest and most variable profile, with two pronounced peaks around 07:00–08:00 and 17:00–19:00, reaching more than 20 W/m² of gas consumption in the morning and evening. Between these peaks, demand drops substantially, especially overnight and in the early afternoon, reflecting intermittent boiler operation with high-power firing during reheating periods and low consumption when thermostats are satisfied, or set-back temperatures are used. In contrast, the electrically-heated subpopulation has a much flatter curve. Their curve rises gently in the late morning, shows a moderate early-afternoon dip, and then increases again in the evening, but without the sharp spikes observed for gas consumption in gas-heated subpopulation.

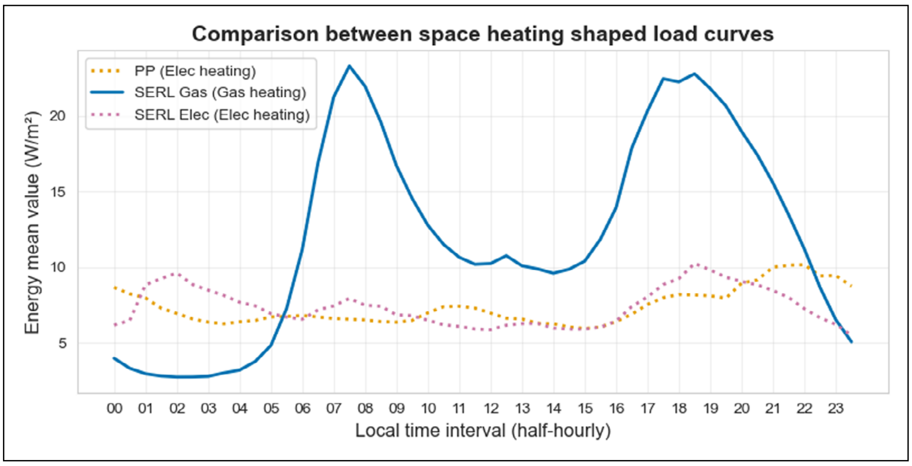

Figure 3 Normalised daily residential load curves for different space heating source (SERL gas: 6,092; SERL electric: 460; PP: 613 households).

Overall, these results indicate that gas boilers create short, high-intensity demand peaks superimposed on a relatively low base load, while electric space heating in both countries generates much flatter profiles with smaller peak-to-trough differences. These differences likely reflect interactions between occupant practices and context (e.g. tariff structures, prices, and heating control options like heating the living room more than the bedroom or reducing heating when the home is unoccupied), but these mechanisms are not directly tested in this study and remain an interesting topic for future research.

TYPE OF BUILDING

Figure 4 compares normalised daily curves for multi-dwelling unit (MDU) and single dwelling unit (SDU) for three groups: SERL gas-meter households, SERL electricity-import smart meter households, and Panel Particuliers electric smart meter data. All values are expressed in W/m² to remove the effect of larger dwelling size in SDU.

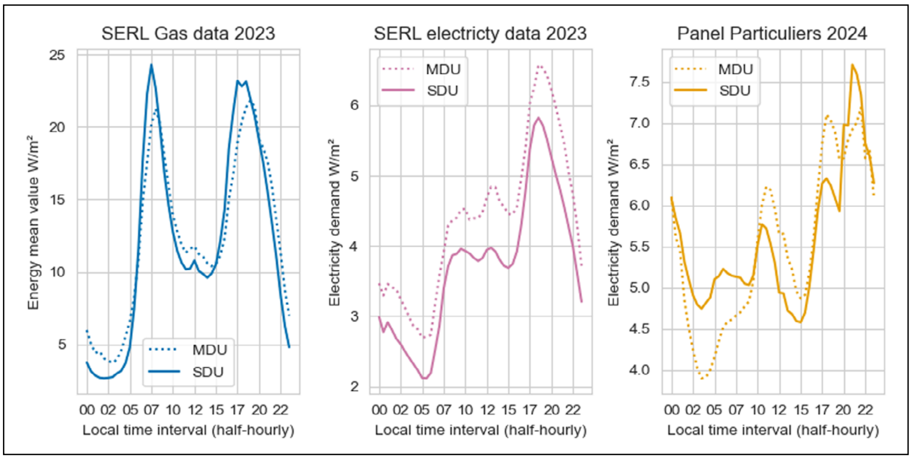

Figure 4 Normalised daily residential load curves for different building type (SERL vs PP).

For SERL gas-meter households, MDU and SDU follow similar shapes with two strong peaks in the morning and evening, but SDU show higher morning and evening peaks. This suggests that the higher peaks observed in SDU may reflect a combination of greater heat losses associated

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with larger exposed envelope surfaces and a higher likelihood of larger households, which increase domestic hot water (DHW) and appliance demand. However, the relative contribution of these factors to peak demand cannot be determined from the available data. Differences in heating management, such as SDU might be heating a larger proportion of rooms or using higher set points, could also play a role, or the MDU rely more on building thermal inertia or accept larger temperature setbacks during these periods, but this would need to be confirmed using dedicated survey data. MDU show higher power demand at night and around noon, which may be linked to the presence of the occupants at home, and their work status.

For SERL electricity-import smart meter households, MDU show higher normalised demand than SDU for most of the day, especially in the morning and evening. This pattern may reflect households spending more time at home, occupying a larger share of rooms, or relying more on electric appliances for cooking and hot water. It also suggests that appliance ownership and use are concentrated in smaller floor areas in MDU, increasing W/m².

For Panel Particuliers, MDU and SDU curves intersect several times across the day. MDU tend to have slightly higher intensity during midday and evening, whereas SDU dominate during early morning and late at night. This alternating pattern points to the influence of French tariff design: off-peak tariffs encourage households to shift appliance use (e.g. washing machines, dishwashers, electric hot water) to midday and late-evening (off-peak periods). However, the studied subpopulations may have different off-peak time slots, potentially introducing sample bias, therefore, making it challenging to interpret the results.

Overall, the three panels highlight that, once floor area is controlled for, differences between building types are likely influenced by heat loss from envelope surfaces, heating management, presence at home, and appliance use rather than by the physical size of the dwellings, underlining the need to represent these dimensions in demand modelling. Nonetheless, socio-demographic characteristics such as household size, life stage and employment status are likely to play an important role, but were not explicitly examined in this study and should be investigated in future work.

TEMPERATURE GRADIENT ANALYSIS

To complement the load-curve analysis, a temperature gradient analysis was performed to quantify how sensitive normalised electricity demand is to changes in outdoor temperature for different heating configurations for different segments of both subpopulations. By fitting linear relationships between mean daily power demand (W/m²) and mean daily external temperature, this approach provides a simple metric in (W/m²)/°C that can be directly compared across datasets. Understanding these gradients is important for assessing how strongly residential energy use is driven by outside temperature, which in turn informs system planning, demand forecasting, and the implications of shifting from gas to electric heating in each context.

Temperature gradient for non-electric heating

Figure 5 compares how normalised electricity demand varies with mean daily outdoor temperature for households without electric space heating in Great Britain and France. Graph (a) shows SERL 2023 electricity demand for households with non-electric (mainly gas) heating, while graph (b) shows Panel Particuliers 2024 households with non-electric space heating and non-electric domestic hot water.

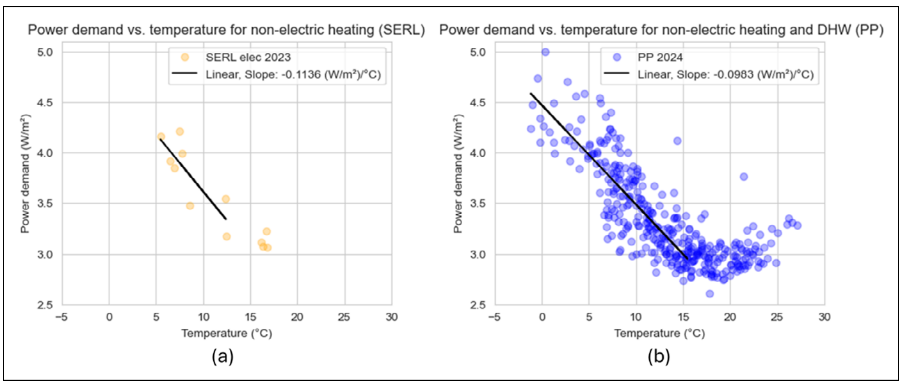

Figure 5 Temperature gradient analysis of non-electrically heated homes **(a)** SERL vs **(b)** Panel Particuliers, (W/m²)/°C.

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In both graphs, power demand in W/m² decreases as temperature rises, indicating that even in the absence of electric space heating and electric DHW, residential electricity use remains correlated to temperature, likely driven indirectly by water-heating appliances such as washing machines, dishwashers, and electric kettles and seasonal sensitivities primarily driven by lighting (due to shorter days in winter). The fitted linear gradients are similar, with slopes of about -0.11 (W/m²)/°C for SERL and -0.09 (W/m²)/°C for Panel Particuliers. The British dataset contains one aggregated point per month, while the French dataset provides daily values, which explains the compact orange cluster in panel (a) and the dense blue cloud in panel (b).

Despite the similar slopes, absolute demand levels differ slightly, with British households tending to have somewhat higher intensities at colder temperatures. As temperatures approach 15–20°C, both datasets appear to converge toward a common baseline around 3 W/m². Although, for the SERL data this trend is less certain due to the limited number of points at higher temperature. The baseline likely corresponds to largely temperature-independent uses such as lighting (seasonal), and standby loads. Overall, the gradients show that non-electrically heated homes in both countries exhibit comparable moderate temperature sensitivity.

Temperature gradient for electric heating

Figure 6 compares how normalised electricity demand varies with mean daily outdoor temperature for electrically heated households in Great Britain and France. Panel (a) shows SERL 2023 electricity demand for households with electric space heating, while panel (b) shows Panel Particuliers 2024 households with electric space heating.

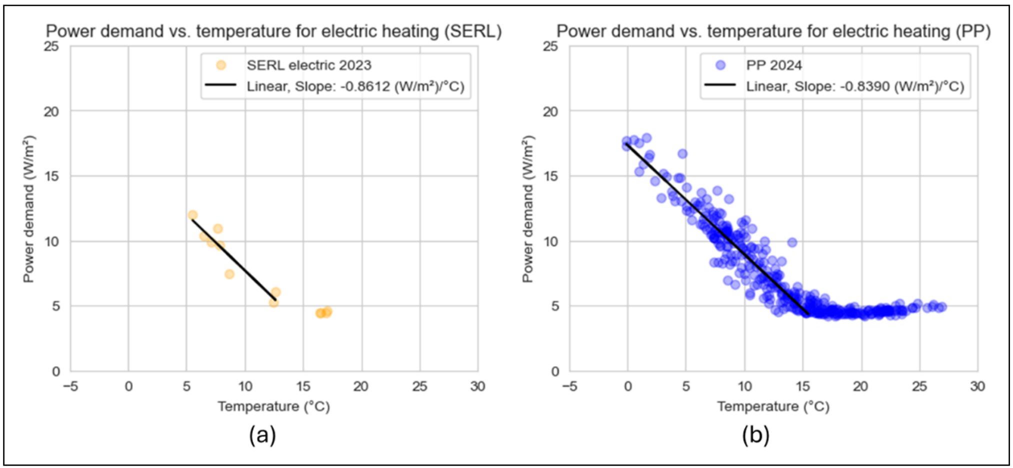

Figure 6 Temperature gradient analysis of electrically heated homes **(a)** SERL vs **(b)** Panel Particuliers, (W/m²)/°C.

In both graphs, power demand in W/m² decreases strongly as temperature rises, indicating high thermal sensitivity of electricity use when space heating is electric. The fitted linear gradients are steep and similar in magnitude, with slopes of about −0.86 (W/m²)/°C for the SERL subpopulation and −0.83 (W/m²)/°C for the Panel Particuliers subpopulation. Compared with the non-electric-heating segments, these gradients are almost an order of magnitude larger, confirming that space heating dominates the temperature dependence of electricity demand.

The SERL dataset again provides one aggregated point per month, producing a compact set of orange markers that follow the regression line closely, whereas the Panel Particuliers dataset includes daily values, resulting in a dense blue cloud with greater scatter around the fitted line. At low temperatures (below about 5°C), PP shows high intensities between roughly 12 and 18 W/m² meanwhile, SERL includes no observations below approximately 5°C, so we cannot assess demand at very low temperatures in that dataset. At milder temperatures around 15–20°C, demand converges toward 4–5 W/m², which can be interpreted as the non-heating baseline of other end-uses. Overall, these results show that electrically heated homes in Great Britain and France have similar temperature gradients in W/m² per °C, despite differences in technologies and tariffs, underscoring the strong and comparable impact of outdoor temperature on electric heating demand in both contexts.

Temperature gradient for type of energy

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Figure 7 compares how normalised energy demand varies with mean daily outdoor temperature for gas-metered and electricity-metered households, highlighting differences in overall thermal sensitivity between the two measurement bases. Graph (a) presents SERL 2023 gas-meter data for households with gas heating, while graph (b) shows Panel Particuliers 2024 electricity smart meter data for electrically-heated households.

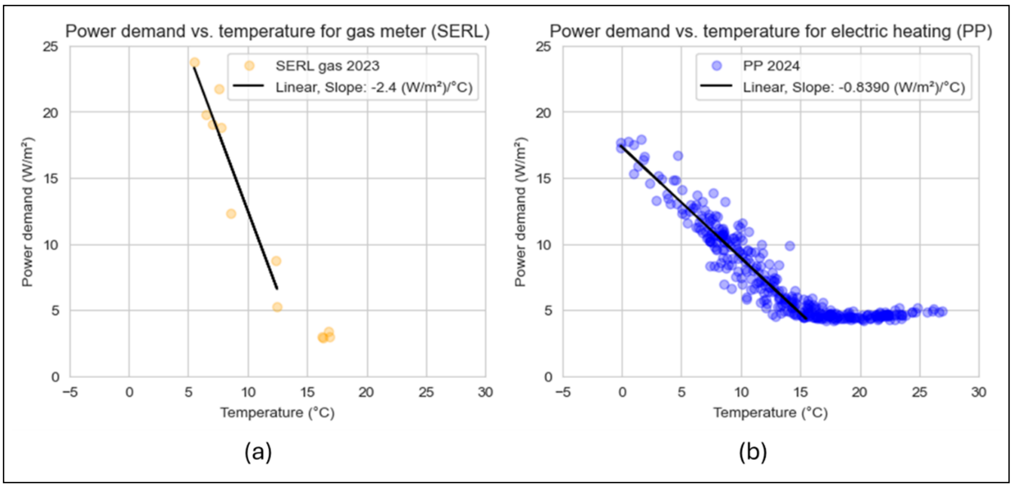

Figure 7 Temperature gradient analysis from **(a)** gas meter SERL vs **(b)** electric meter Panel Particuliers for electric heated, (W/m²)/°C.

In both graphs, demand in W/m² decreases as temperature rises, but the magnitude of this effect is different. For gas-heated households, the fitted linear gradient is steep, with a slope of –2.4 (W/m²)/°C, meaning that each 1°C increase in outdoor temperature reduces gas power demand by more than 2 W/m². For electrically heated households, the slope is much flatter, around –0.839 (W/m²)/°C, so the same 1°C change reduces electric demand by less than 0.9 W/m². This three to one ratio in absolute slopes shows that gas demand is more temperature-sensitive than electric demand for these subpopulations.

The difference is also visible in absolute levels. At low winter temperatures near 0–5°C, gas-meter demand seems to exceed 20 W/m², while electrically-heated households draw closer to 18–14 W/m². As temperatures approach 15–20°C, both curves converge towards lower values around 3–6 W/m², which can be interpreted as a non-heating baseline dominated by temperature-independent uses. Overall, the figure indicates that gas boiler operation produces very strong temperature-driven peaks in gas demand, whereas electric heating spreads its temperature response more moderately. This suggests that a transition from gas to electric heating could shift part of the thermal sensitivity from the gas network to the electricity system. However, the magnitude of this shift would depend on the type of electric heating adopted (whether its heat pumps or radiators or other) as well as differences in dwelling type and building efficiency.

This subsection highlights that energy demand for a population is not driven by a single factor but by the interaction of heating type, fuel type, and the share of non-heating end uses. For future electrification pathways, this means that replacing gas boilers with electric systems will not only shift energy from the gas network to the power system but will also change the temperature gradient, which is important for planning and flexibility measures.

DISCUSSION

The results indicate that residential load profiles in Great Britain and France vary across subpopulations defined by space heating technologies, tariff structures, building types, and occupant behaviour. Even after normalization by floor area, clear differences emerge between the two countries and across segments, suggesting that beyond space heating and domestic hot water, non-heating uses, tariffs, and cultural factors are likely to contribute to the observed demand patterns. However, the absence of fine data like appliance-level measurements, limits us to qualitative interpretations and prevents definitive conclusions or quantification of each element's contribution to peak magnitude, shape or timing.

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The non-heating load curves revealed patterns influenced by daily habits, such as short and high-power appliance routines around breakfast and morning preparations for the British subpopulation and lunch at home or programming laundry loads overnight for the French subpopulation. They also suggest the impact of tariff incentives, with higher consumption during off-peak hours among the French subpopulations.

For electric heating segments, the contrast between storage heater dominated British profiles and French direct electric heating becomes clearer. British electrically-heated homes show pronounced peaks at night and in the early evening, corresponding to storage heater charging and evening boosts, whereas French profiles have more sustained demand spread across the day and night. This suggests that technology choice and tariff design do not just change the magnitude of demand but also reschedule it in time, with implications for peak management, though evaluating these effects quantitatively would require more granular data.

The temperature gradient analysis shows a difference in weather sensitivity across segments. Non-electrically heated homes in both countries have modest, similar gradients (≈ –0.1 W/m²/°C), meaning appliances use is only weakly temperature-dependent, whereas electrically-heated homes have much steeper gradients (≈ –0.83 W/m²/°C) and gas-heated SERL households the steepest of all (≈ –2.4 W/m²/°C), suggesting that heating contributes substantially to the observed temperature-related variability. For electrification strategies, shifting from gas boilers to electric heating could transfer temperature sensitive demand from the gas grid to the electricity grid. This suggests that well designed electrification particularly through efficient technologies such as heat pumps can moderate, though not eliminate, winter peaks. Nevertheless, these effects depend on heating technology, building characteristics, and occupancy patterns, and must therefore be carefully considered in capacity planning, flexibility provision, and tariff design.

From a system perspective, the observed differences in temperature sensitivity suggest that electrification of heating could shift a substantial share of weather-dependent demand from gas to electricity networks. However, this does not necessarily imply increased system stress in all contexts. The impact on peak demand depends on several interacting factors, including the type of electric heating technology (e.g. direct electric vs heat pumps), building thermal performance, and the extent to which tariffs or control strategies shift or smooth demand. While the present analysis does not directly assess system adequacy or peak capacity constraints, the results highlight conditions under which electrification could either increase or reduce peak loads.

Several limitations must be considered when interpreting these findings. The Panel Particuliers sample is not representative of the French residential population and over-represents electrically heated and peak/off-peak tariff households, while SERL is broadly representative of Great Britain but for this study provided statistics only in aggregated form. Differences in years, climate conditions, and building vintages between the two countries may also influence the results, despite the use of normalization and temperature-gradient methods. The Panel Particuliers had a data fusion to get the outside temperatures which can create some uncertainties. Despite the analytical potential of smart-meter datasets, their integration across national contexts remains constrained by variations in metadata quality and the availability of complementary survey information. Nevertheless, the consistency of key patterns such as the dominance of heating in temperature sensitivity, the influence of tariffs on night and midday peaks, and the importance of building type and occupancy management suggests that the qualitative insights are robust and transferable to wider policy and modelling discussions in both countries.

Finally, the datasets do not contain data for PV generation at household level, even though both can have a very significant impact on electricity demand. Moreover, we do not explicitly distinguish between different electric heating technologies in this study, in particular electric heat pumps, whose specific contribution to load profiles would be a valuable focus for future work.

Future research should extend this work by integrating socio-demographic information and building performance data more explicitly, exploring how income, tenure, and renovation level modulate heating practices and temperature sensitivity. Looking into appliance characteristics and ownership could also explain more of the shape of the load curves. Future efforts to integrate context-rich smart-meter datasets across countries will be essential to deepen understanding of how local conditions shape residential electricity demand. Finally, analysing individual or small sample data would help better evaluate the diversity, variability and similarities across the different subpopulations.

Overall, the work demonstrates that understanding residential load curves for electrification planning requires a complementary consideration of technology, tariffs, building stock, HVAC systems and behaviour rather than a solely physical aspect of buildings.

CONCLUSION

This work provides a detailed comparison of normalised residential load curves and temperature sensitivities for subpopulation in Great Britain and France, distinguishing non-heating uses, electric and non-electric space heating, and different building types. By combining high-resolution smart-meter data with contextual data that enables the segmentation by heating technology, dwelling type, and outdoor temperature, the analysis shows that the observed load curves differ across subpopulations, and these differences may reflect variations in space-heating technology, appliance characteristics, occupant behaviour and tariff design.

A key contribution is the use of a cross-border perspective to separate technological from behavioural effects: homes with similar technologies (e.g., electric heating) display comparable temperature gradients in both countries, while differences in tariffs design and daily routines explain shifts in peak timing, night-time baseloads, and midday bumps. This demonstrates the value of coordinated analyses across countries when assessing electrification pathways and demand-side flexibility options.

For policymakers and grid operators, these findings suggest that electrification should not be approached as only a fuel substitution, but rather as a transition shaped by interactions between technology, tariffs, building characteristics, and user behaviour. Therefore, it necessitates a strategy that integrates adaptable tariff structures, effective communication with households, and further research into behavioural responses. Such measures could help to provide conditions in which individuals adapt their energy-use habits to new technologies in ways that align with the stability of the energy system, while simultaneously ensuring comfort and meeting daily needs.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **Display session poster.** Poster relating to this article. DOI: https://doi.org/10.66506/essp.1-217-26.s1

COMPETING INTERESTS

The authors have no competing interests to declare.

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