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The Impact of Cutting the Peak Power of Individual Customers on the Total Peak Power of the Customer Group

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Abstract—As power-based distribution tariffs become common, residential customers are incentivized to reduce individual peak demand. However, the system-level benefit of uncoordinated peak shaving remains uncertain. This paper quantifies how individual peak reductions translate to aggregated grid-level demand. Using hourly smart meter data from Finnish detached houses, individual apartments, and building-level common loads, modified consumption profiles were simulated by clipping individual demands to 70%, 80%, and 90% of their annual and monthly peaks. Monte Carlo simulations were then applied to evaluate the coincident peak demand of randomized groups ranging from 1 to 100 customers. Results demonstrate that while individual clipping reduces aggregated demand for small groups, this benefit diminishes rapidly as group size increases due to the natural diversity in consumption timing. These findings provide critical insights for distribution system operators designing cost-reflective tariffs and managing future grid capacity.

Index Terms— Demand response, peak shaving, power-based tariffs, smart meter data.

I. INTRODUCTION

Accurately estimating and managing peak electrical demand is increasingly critical in modern electricity distribution systems. In Finland, residential customers traditionally utilize high-power appliances such as electric saunas and space heaters. Furthermore, the rapid growth of electric vehicle (EV) charging, rooftop photovoltaic (PV) systems, battery energy storage systems, and heat pumps has introduced both flexible load potential and new complexities by fundamentally changing the relationship between annual energy consumption and peak demand [1]. Concurrently, approximately 30% of Finnish retail customers utilize dynamic spot-priced electricity contracts [2]. Without incentives for local peak shaving, price-optimized demand response can synchronize load spikes during low-price hours; studies indicate this uncoordinated phenomenon can overload local distribution transformers by up to 100% [3].

Distribution system operators (DSOs) face increasing pressure to optimize network capacity, as grid infrastructure must be sized to accommodate coincident peak loads driven by ongoing electrification. Historically, distribution tariffs for small customers relied on fixed monthly fees and volumetric energy charges, which do not fully reflect the cost drivers associated with peak demand capacity. Consequently, fixed fees have risen proportionally, leaving customer with limited opportunities to influence their distribution costs [4]. To address this, and facilitated by advanced smart metering, an increasing number of DSOs have introduced power-based tariffs for residential customers.

To rectify the currently fragmented tariff landscape, an amendment to the Finnish Electricity Market Act (effective July 2025) authorized the Energy Authority to mandate a harmonized national tariff structure [5]. Entering into force on January 1, 2029, this regulation establishes a unified power tariff framework for small customers (main fuse up to 3x63 A) [6]. Drawing on prior research regarding cost-reflectiveness and steering effects [7], the mandated tariff will base the power fee on the highest 60-minute average power demand measured during the billing month, applying to demand exceeding 8 kW.

As power-based tariffs become more common, customers are incentivized to shave their individual peak demands. However, from a DSO perspective, the value of individual demand shaping depends on its impact on aggregated load profiles at the distribution transformer level. Because network investments rely on the diversified, coincident demand of dozens or hundreds of customers, it remains an open question whether uncoordinated, individual peak clipping yields proportional, meaningful reductions in system-level peaks, or if the inherent diversity of consumption behaviors neutralizes the benefits of such customer-level actions. Supponen et al. investigated this relationship through simulations, analyzing the interactive effects of dynamic spot prices and power-based tariffs using 2015 smart meter consumption data [8]. Their findings indicated that while power tariffs could effectively mitigate spot-price-driven demand spikes at the distribution level, the aggregated system-

level impact of power-tariff-based control remained relatively modest compared to the original consumption baseline—even though individual customers reduced their peak demands by an average of 31.5%.

This paper continues to fill this gap by quantifying how individual peak reduction strategies translate to aggregated peak demand across varying customer group sizes. Using empirical smart meter data from three distinct customer categories—multi-dwelling apartments, common-area consumption in apartment buildings, and detached houses—this study simulates modified consumption profiles. Each customer’s hourly load is subjected to threshold clipping, limiting peak demand to 70%, 80%, and 90% of their respective annual or monthly individual peaks. A Monte Carlo simulation is then applied to evaluate the impact of these strategies on the coincident peak demand of randomized customer groups ranging from 1 to 100 customers. Furthermore, the study analyzes the frequency of clipping events (clipped hours) to assess the practical implications for end-users. The findings provide critical insights into how individual peak shaving scales within distribution networks, clarifying the relationship between customer-level incentives and grid-level outcomes.

II. DATA DESCRIPTION

This study utilizes hourly electricity consumption data from three distinct customer groups in the Pirkanmaa region of Finland: detached houses, multi-apartment buildings’ common-area electricity (hereafter referred to as common consumption), and individual apartments.

The detached house dataset comprises hourly electricity consumption data from 20 single-family homes for the calendar year 2023. These homes represent a randomized sample of typical Finnish detached houses with varying building technologies, appliance configurations, and occupant behaviors. The buildings vary in age, heating methods, and total electrical load profiles, with the majority being equipped with rooftop PV systems. All homes are individually metered and billed based on their respective electricity use.

The second dataset includes 182 smart-metered electricity connection points measuring common consumption in multi-apartment buildings, collected over the calendar year 2021. These buildings, constructed between the 1960s and 2020s, are representative of typical Finnish apartment complexes. While most rely on district heating, several are equipped with ground-source heat pumps. The scope of electricity use within this group varies widely: some buildings exhibit minimal common-area consumption, whereas others demonstrate significant loads driven by shared electric saunas, mechanical ventilation systems, heat pumps, and outdoor car pre-heating systems. This building-level data reflects the combined load of all shared services, strictly excluding individual apartment loads.

The third dataset comprises hourly electricity consumption data from 8,560 individual apartments for the year 2021. These apartments span a wide range of types and sizes, ranging from studios to four-room units, both with and without private electric saunas. The apartments are located in multi-apartment buildings constructed between the 1960s and 2020s. To ensure data integrity, only apartments with valid, active hourly

consumption records for the entire calendar year were included in the final analysis; apartments registering zero consumption across the entire year were excluded. These units are individually metered, with residents independently responsible for their electricity costs.

III. METHODS

A. Clipping Scenarios

The primary aim of this study was to examine how customer-specific peak demand limitations—based on either annual or monthly peak values—affect the aggregated peak demand of customer groups of varying sizes. The analysis was conducted separately for each of the three customer categories: detached houses, common consumption, and individual apartments.

For each metering point, the following reference values were determined from hourly data:

1. The annual peak demand, defined as the maximum hourly average power over the calendar year.
2. The monthly peak demand, defined as the maximum hourly average power, identified separately for each calendar month.

Based on the annual and monthly peak demand values defined above, six modified consumption profiles were generated for each customer by applying fixed clipping thresholds:

1. Annual 90%, 80%, and 70% thresholds: Any hourly consumption exceeding 90%, 80%, or 70% of the customer’s annual peak demand was clipped to the respective threshold.
2. Monthly 90%, 80%, and 70% thresholds: For each calendar month, any hourly consumption exceeding 90%, 80%, or 70% of customers monthly peak demand was clipped to the respective threshold.

These scenarios generated new time-series datasets wherein only the peak hours were modified according to the selected clipping logic. This allowed for a highly controlled comparison against the original (unclipped) consumption data.

B. Monte Carlo Simulation

To evaluate the impact of individual clipping on group-level coincident demand, a Monte Carlo simulation was implemented. In each simulation round, customer groups of varying sizes were randomly sampled 500 times. The group sizes were defined as follows:

1. For common consumption and individual apartments, group sizes ranged from 1 to 100 customers.
2. For detached houses, governed by the smaller physical dataset, group sizes ranged from 1 to 20 customers.

In each sample, the hourly consumption values of all selected customers were summed to compute the total hourly load of the group. The annual peak demand of this aggregated load was then identified. To enable direct comparison across varying group sizes, the group peak demand was normalized by

dividing it by the number of customers in the group, yielding a "peak demand per customer" metric.

Crucially, the exact same sets of 500 customer combinations were evaluated across the original and all clipped datasets. This isolated the variables, ensuring that any observed changes in aggregated peak demand were solely attributable to the clipping strategies rather than variances in group composition. Within each simulated group, customers were randomly sampled without replacement, meaning each customer could appear only once per generated group.

The following key metrics were calculated and evaluated for the analysis:

1. The average, minimum and maximum number of hours clipped per customer under each of the six threshold scenarios.
2. The absolute peak demand per customer derived from the original, unclipped datasets.
3. The evolution of the annual maximum (worst-case) and average group peak demand per customer as a function of group size for each clipping scenario.
4. The relative percentage reduction in aggregated annual peak demand across different peak-shaving strategies, assessed by comparing the average peak demand per customer over all 500 Monte Carlo iterations between the original and clipped datasets.

IV. RESULTS

A. Number of Clipped Hours

As a first step in the analysis, the frequency of hourly consumption clipping under each of the six threshold scenarios was quantified. For every customer, the number of hours in which the original consumption exceeded the defined threshold was counted. These values were then examined by customer category—detached houses, common consumption, and individual apartments—to provide a comparative overview of clipping intensity across different customer types and usage patterns.

Table I presents the minimum, average, and maximum number of clipped hours per customer under each scenario. The number of clipped hours varied significantly across customer types and threshold strategies. When using annual peak demand as the reference point, the number of affected hours remained relatively low for both detached houses and apartments. However, when clipping was based on monthly peak demand, the frequency of clipping increased substantially due to the more localized, lower peak reference values.

The variation between the minimum and maximum number of clipped hours is substantial. In some apartments, the individual monthly or annual peak is a single extreme event, meaning that strict clipping limits no other hours during that period. Conversely, highly stable consumption profiles—typical of common-area loads—can experience thousands of clipped hours under more intensive thresholds, such as the 70% cap. In the most extreme cases, the number of clipped hours can exceed 8,700, representing nearly the entire 8,760 hours of a calendar

year. For these stable profiles, the 70% clipping logic functions more as a total capacity constraint than a peak-shaving measure.

TABLE I. NUMBER OF CLIPPED HOURS PER CUSTOMER

Customer Group	Metric	Clipped Hours					
		Monthly Threshold			Annual Threshold		
		70%	80%	90%	70%	80%	90%
Apartments	Ave.	154	102	68	26	12	5
Apartments	Max.	6245	4439	2950	5099	2084	780
Apartments	Min.	1	1	1	1	1	1
Common Consumption	Ave.	869	383	150	337	111	19
Common Consumption	Max.	8730	7635	3374	8559	5902	1018
Common Consumption	Min.	71	49	25	1	1	1
Detached Houses	Ave.	234	108	41	58	19	5
Detached Houses	Max.	590	277	79	206	83	16
Detached Houses	Min.	43	33	19	6	3	1

B. Effect on Aggregated Peak Demand

The core objective of this study was to evaluate how individual peak demand clipping influences aggregated peak demand across randomly formed customer groups of various sizes. Fig. 1 presents the absolute peak demand results, arranged horizontally across three panels: detached houses (left), common consumption (center), and individual apartments (right). The horizontal axis shows the size of each customer group. The vertical axis represents the peak demand per customer, calculated by dividing the group's aggregated annual peak demand by the number of customers in the group. This normalization allows for a fair comparison across group sizes and clearly illustrates how peak demand behavior evolves with aggregation.

In Fig. 1, triangle markers correspond to the highest identified peak across the 500 Monte Carlo samples for a given group size, while square markers represent the average peak demand across all samples using the original, unclipped data. The subsequent dashed lines without markers represent the maximum and average values under the 70% clipping scenarios for both the annual and monthly threshold levels. This visual structure allows for a clear comparison of how individual clipping affects the overall system-level peak in the most intensive peak-shaving scenarios, as well as how the choice between annual and monthly thresholds alters these outcomes. As expected, clipping reduces both the maximum and average peak values; however, the magnitude of this reduction diminishes rapidly as group size increases.

To further explore the impact of clipping strategies, Fig. 2 presents the relative percentage difference in aggregated peak demand between the clipped and original data across varying group sizes. This figure is arranged horizontally across three panels: detached houses (left), common consumption (center), and individual apartments (right). The vertical axis shows the relative reduction in peak demand compared to the unclipped baseline. Each point corresponds to the average peak demand across 500 Monte Carlo samples for that specific group size and clipping scenario.

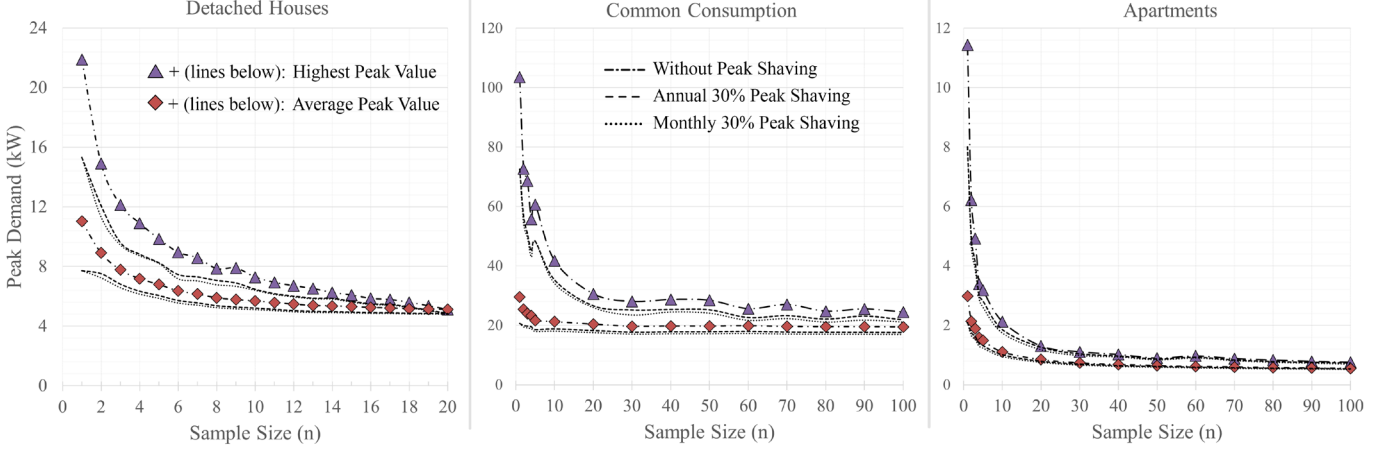


Figure 1. Annual peak demand with different peak shaving methods

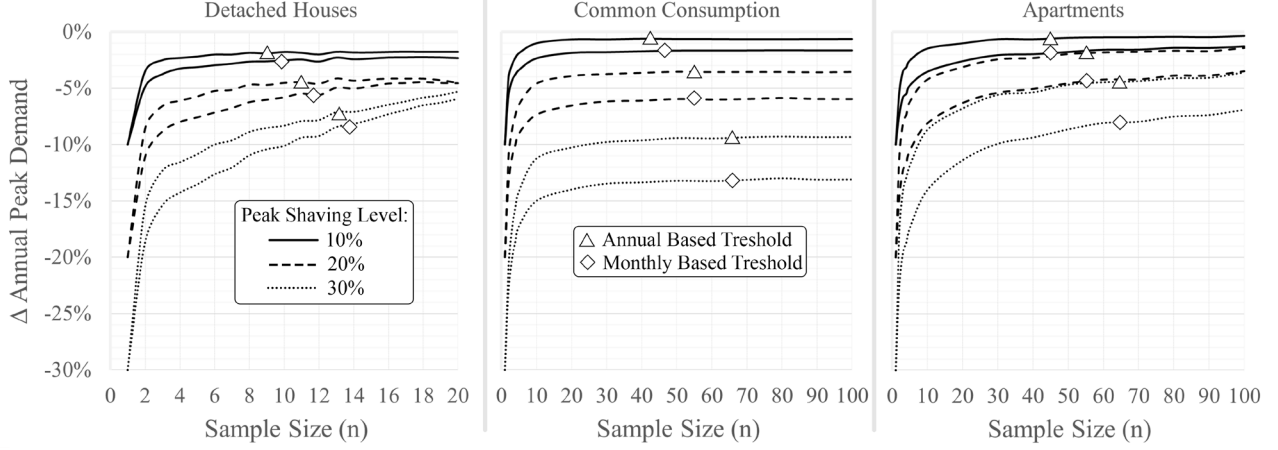


Figure 2. Relative change in annual peak demand with different peak shaving methods

Lines with square markers correspond to the monthly peak threshold scenarios (more frequent clipping), while lines with triangle markers represent the annual peak threshold scenarios (less frequent clipping). Within each category, the respective lines represent the 90%, 80%, and 70% clipping thresholds.

The results reveal that clipping based on monthly peak thresholds yields greater reductions in aggregated peak demand than yearly thresholds, which is consistent with the higher number of clipped hours observed in those scenarios. However, the effectiveness of individual clipping diminishes rapidly as the number of aggregated customers increases. This attenuation is primarily due to the natural coincidence factor and the variation in the timing of individual peak demands.

For detached houses, the relative reduction in peak demand falls to less than half of the individual customer reduction across all scenarios when just three customers are aggregated. In the case of common consumption, the relative reductions drop quickly for groups of up to 10 to 20 customers, after which they begin to stabilize. For example, under the most aggressive scenario—a 30% monthly peak-shaving reduction—the aggregated impact levels off at approximately 13%. For individual apartments, the trend is similar. The relative reduction reaches 5% or less after aggregating approximately 40 customers under

all clipping strategies, with the exception of the 30% monthly clipping scenario.

V. DISCUSSION

The results demonstrate that the impact of individual peak shaving on the aggregated peak demand of customer groups is inherently limited due to the natural variation in the timing of individual consumption peaks. These findings align with the prior Finnish study by Supponen et al. [8], as well as international research investigating the correlation between demand charges and system-level peaks. Passey et al. identified a low correlation (0.56) in Sydney between individual peak charges and network peak responsibility [9], while El Gohary et al. in Central Sweden found that high diversity factors make individual demand charges unsuitable for delaying infrastructure investments, arguing they do not provide the correct price signals to improve distribution network conditions [10]. Lebel et al. further argue in a US report that such charges are generally inefficient for system-level capacity recovery, reinforcing the attenuation effects observed in this study [11].

This study focused on historical hourly consumption data from the years 2021 and 2023, reflecting typical residential behavior in the Pirkanmaa region at that time. Looking ahead, the situation may evolve as residential buildings adopt more

flexible and energy-intensive loads, such as EV charging systems, battery energy storage systems, modern heat pump technologies, and smart control systems for legacy electric heating. As these technologies become more common and are increasingly controlled based on market-based quarter-hourly spot prices, it is likely that consumption will become more synchronized—particularly during low-price moments. This behavioral shift could reduce the current diversity in peak demand timing and lead to more concentrated, coincident group-level peaks. In such a scenario, incentives for demand limitation (e.g., power-based distribution tariffs) may yield more significant aggregated network effects than those observed in this study.

A natural next step for future research would be to investigate the coincidence of peak demand events with low spot price hours in recent years. Traditionally, low electricity prices have indicated periods of low overall demand. However, with the growing share of variable renewable generation in the Nordic grid, it is increasingly possible for prices to drop significantly even during high-demand periods.

The latest regulatory updates in Finland have established a harmonized power tariff structure based on monthly peak demands [6]. During the preparatory working group phases, there was considerable debate regarding whether to base fees on annual or monthly peaks [7]. Ultimately, the monthly peak demand was selected to provide greater flexibility for customers, avoiding punitive fees across the entire year caused by a single, isolated demand spike. In this study, we evaluated the impact of both threshold types. The results indicate that while the difference between the two approaches diminishes in larger aggregated groups, monthly thresholds yield a demonstrably more effective aggregated impact, thereby supporting the regulatory decision. Conversely, the analysis also revealed that targeting monthly peak shaving requires a significantly higher frequency of clipping events. This makes it more challenging for customers to identify and consistently execute peak shaving potential every month. Consequently, further research is warranted to explore whether time-of-use or seasonal power tariffs—which would require less intensive peak shaving outside of high-load heating periods, for example—might offer a more optimal balance.

There are several limitations worth noting in this study. First, the analysis was geographically limited to the Pirkanmaa region of Finland; the results may not generalize across different network areas with alternative building stocks, climate conditions, or customer behaviors. Second, the study evaluated customer groups strictly by type (detached houses, individual apartments, or common area consumption) without combining them into mixed portfolios. In real-world settings, distribution transformers serve a combination of these load types, which could alter the dynamics of aggregation. Furthermore, the clipping strategy used in this analysis statically limited the power during peak hours without rescheduling the excess consumption to other time periods. In real-world scenarios where consumption is shifted rather than curtailed (e.g., delayed EV charging or price-responsive space heating), the net benefit to the grid may be limited if secondary rebound peaks emerge elsewhere in the load curve and, in some cases, may even exceed the original peak.

Finally, although the primary objective of this study was to demonstrate how individual peak demand reductions affect group-level peak behavior, the selected thresholds of 90%, 80%, and 70% do not represent specific technological implementations. In practice, some customers—such as EV owners or buildings equipped with energy management systems—may have significant flexibility and motivation to manage their loads. Conversely, others (e.g., tenants in small, district-heated apartments) may possess very limited technical ability or financial incentive to do so.

VI. CONCLUSION

This study examined how individual peak shaving strategies affect the aggregated peak demand of residential customers across varying group sizes and clipping thresholds. Using hourly consumption data from detached houses, individual apartments, and building-level common area loads, both annual and monthly peak-based clipping were applied at 90%, 80%, and 70% thresholds. Monte Carlo simulations were then conducted to evaluate the impacts across randomized groupings ranging from 1 to 100 customers.

A significant observation from the analysis is that clipping based on monthly peak thresholds consistently yielded greater reductions in the aggregated annual peak demand compared to clipping based on a single annual threshold. This suggests that more frequent, monthly-based demand management is more effective at capturing and mitigating the diverse peaks that contribute to the system-level maximum, regardless of the customer category.

Despite these diminishing returns at the system level, peak shaving remains a valuable tool—especially in future scenarios characterized by the increasing adoption of flexible, high-power loads. Technologies like EV charging and battery energy storage systems may cause future peak demands to align more closely due to price optimization. Under such conditions, power-based tariffs and active control strategies could achieve far more substantial system-level impacts. Future studies should consider dynamic load shifting instead of static clipping, explore aggregated behavior under real-time pricing models, and evaluate mixed customer portfolios to better capture real-world network conditions and the true potential of coordinated flexibility.

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