Energy Proceedings
Vol 39, 2024

ISSN 2004-2965

Does Peak Load Occur at the Same Time as High Electricity Prices? A Case Study of Sports Facilities

Mohammed Guezgouz[1*], Fredrik Wallin[1], Meysam Majidi Nezhad[1]

1 Mälardalen University, Future Energy Center, BOX883, Västerås, Sweden

(*Corresponding Author: mohammed.guezgouz@mdu.se)

ABSTRACT

In this study, a simple framework was developed that can help identify and quantify peak load at sports facilities called Rocklunda Fastigheter AB. By analysing the electricity demand profiles and electricity prices from the Nord pool market, we characterize the equipment contributing most to a particular peak load. In addition, we quantified peak loads that occur during high electricity prices. This framework is beneficial in choosing an appropriate demand-side management strategy for reducing peak loads and electricity costs for both academic and public end-users. Finally, a load-shifting strategy based on Mixed Integer Linear Programming (MILP) was developed to minimize the total annual electricity cost. This approach suggests shifting the electricity demand to the early morning hours while reducing it in the evening when the electricity prices are higher. Finally, a cost-benefit analysis revealed the potential for savings of up to 9.5% when implementing a flexibility factor of 30%.

Keywords: load shifting, electricity market, cost-saving, commercial buildings.

NONMENCLATURE

Abbreviations	
CHP	Combined heat and power
Elspot	Nord Pool market electricity price
MILP	Mixed Integer Linear Programming
LS	Load Shifting
Pl	Electricity demand
P_{ln}	New flexible electricity demand
UK	United Kingdom
SPs	Sports Facilities
Symbols	
f	Flexibility rate
α	Threshold

1. INTRODUCTION

The world has been experiencing record-high temperatures because of global warming [1]. The rise in temperature, forest fires, and extreme weather events are straightforward consequences of climate change [2]. Many regulations and rules have been established to slow down global warming [3]. While these measures target broader climate mitigation, it is crucial to address localized energy consumption, particularly in commercial buildings where electricity demand is significant, such as indoor sports facilities (SFs) [4].

One of the most challenging issues facing the power system is the capacity required to fulfil peak electricity demand [5]. The continuous increase in load raises concerns for electricity utilities to balance production and demand [6]. Possible flexible solutions include diesel generators or gas turbines. However, they are environmentally harmful and require considerable costs

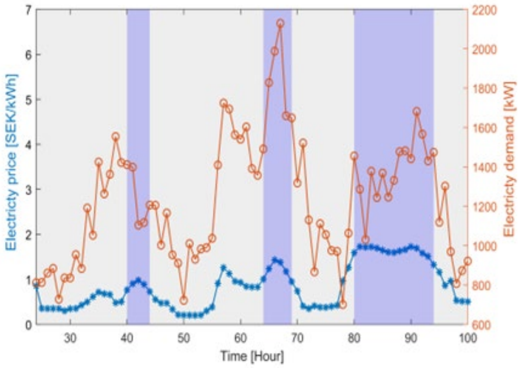

Fig. 1. Hourly electricity demand in ice rink arena and electricity price.

This is a paper for 15th International Conference on Applied Energy (ICAE2023), Dec. 3-7, 2023, Doha, Qatar.

in terms of maintenance and operation. Moreover, the peak load occurs only for a few hours during the day, so the power system should maintain additional generation capacity that is occasionally used [7]. On the consumer side, there are also several issues, such as soaring energy prices during peak hours, resulting in expensive electricity bills [6]. Understanding and evaluating this peak energy demand is essential to cope with these problems. Reducing peak load not only benefits public end-users but also grid operators and decreases the carbon emission footprint.

In this context, Karapidakis et al [8], analysed the energy usage of the Olympic Athletic Center in Athens. They suggested the concept of self-sufficiency to improve its efficiency. This involves using energy sources within the sports buildings to meet as much as possible of the energy demand. To reduce reliance on external sources, the study recommends installing photovoltaics (PV), a battery storage system, a combined heat and power (CHP) unit, and the existing generators at the facility. Powells et al [9], analysed 186 qualitative home tours in the United Kingdom (UK) to understand how flexibility is formed. Rather than attributing flexibility to individual behaviour and traits, which is common in industry and policy. They believe that social practices play a critical role in shaping electricity demand curves and should be the focus of future analysis. To illustrate this point, the authors explored how electricity usage can be adjusted to a time-of-use pricing system that aims to reduce evening consumption, and for what reasons. They argued that the regularity of social habits and how closely they adhere to traditional times and methods can limit or facilitate their ability to adapt to changes. Azaza et al. [10] developed an open-source platform for energy flow mapping to support decision-making and facilitate operational management in SFs. In another study [11], the authors employed Key Performance Indicators (KPIs) to assess energy usage and improve the overall efficiency of SFs. Given the above, there is a need to comprehensively understand and quantify energy consumption in SFs.

Electricity consumption, especially during periods of high peak prices, can result in significantly increased electricity cost. SFs are known for their substantial energy consumption due to unique operational requirements. Fig 1 illustrates the electricity demand profile of an ice rink arena alongside real-time electricity pricing data obtained from the Nord Pool market. Noticeable peak load instances often align with periods of elevated electricity costs, leading to expensive electricity bills. Therefore, this study focuses on quantifying peak loads that coincide with high electricity prices at Rocklunda SFs. The proposed framework aims to identify the equipment contributing the most to these peak loads. Additionally, we will develop a load-shifting strategy based on Mixed Integer Linear Programming (MILP) to minimize the total annual electricity cost. The cost savings resulting from this proposed strategy will also be evaluated based on various flexibility factors.

2. METHODS AND DATA

In SFs located in colder climates like Sweden, the necessity for electricity, heating and cooling is significant for several reasons [10]. Ensuring indoor comfort throughout the year is a top priority for athletes, spectators, and staff [11]. This is particularly essential during winter when heating becomes indispensable [10]. The Rocklunda area encompasses a large property owned by "Rocklunda Fastigheter AB" in Västerås, Sweden [11]. This location includes diverse sports and recreational facilities, with unique measurement features [10].

There are several smart meters in the facility for electricity consumption measurements. The hourly consumption data were obtained for the years 2020-2022. Moreover, this study aims at evaluating the peak electricity demand and its occurrence during expensive price hours. Therefore, electricity prices were obtained from the Nord Pool electricity wholesale market for the same years [12].

2.1 Peak load analysis

Various methodologies in academic literature have been used to determine and quantify peak load values in electricity demand analysis. The work by [13], utilized the quantile function with thresholds set at the 99th, 95th, and 90th percentiles to identify instances where

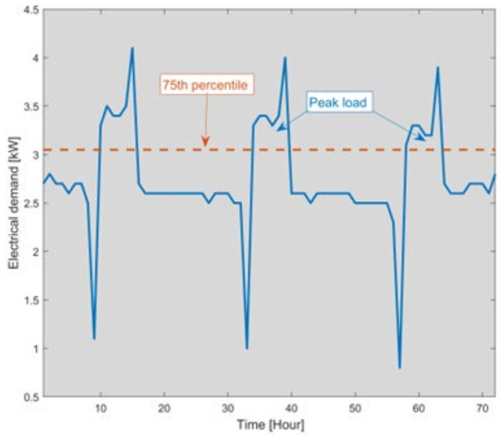

Fig. 2. Hourly electricity demand with a threshold of 75th percentile.

electricity demand exceeded these given thresholds. Conversely, the study [14] employed a Local Minima/Maxima analysis to determine peak load occurrences.

In addition, the authors of Ref [5], employed a distinct approach, by selecting a threshold of 0.9 MW set under the maximum daily demand value. This choice was established by examining the load curve data and considering the peak region's relationship with the mid-day load. Similarly, in the research [15], the peak threshold was defined based on the heating load exceeding the daily average heating power by 15%.

While existing methods often use daily average energy to set a peak threshold, it's important to note that this parameter can be optimized according to user preferences. This highlights the flexibility in peak load detection approaches, where strategically calibrating threshold values can align outcomes with the specific requirements of different scenarios.

In this study, we introduce a novel metric to quantify peak load occurrences during periods of expensive electricity prices, referred to as Expensive Peak Load (EPL). EPL periods are defined as high-demand hours coinciding with high electricity prices from real-time pricing markets such as Nordpool, using a daily threshold. The EPL metric simplifies peak load analysis by normalizing it into a binary time series. Specifically, when both electricity price and electricity demand exceed a certain threshold, EPL is assigned a value of 1; otherwise, it is set to 0, as shown in Eq. (1).

$$\begin{gathered}\mathrm{EPL} = 1 \text{ if } \mathrm{P_l(t)} \geq \alpha_\mathrm{a} \,\&\, \mathrm{El_{spot}(t)} \geq \alpha_\mathrm{b} \\ \mathrm{EPL} = 0 \text{ otherwise}\end{gathered} \tag{1}$$

In the current study, the daily thresholds (αa end αb) are set to the 75th percentile (Q3) for load and electricity prices, as given in Fig 2. First, the peak load hours are identified, and the index is retained. These peak load hours indexes are used on the electricity price vector, and only the hours when the electricity price is above the selected threshold are considered. The total number of hours of EPL can provide insight into how frequently high consumption occurs in SFs during periods of high prices.

2.2 Load shifting strategy

In the context of optimizing energy consumption and cost savings, the current study introduces a load-shifting strategy (called also demand side management) aimed at assessing the flexibility advantages in conjunction with peak demand reduction [16]. We have developed a MILP model, which revolves around the reduction of annual electricity costs.

Within the MILP model framework, we account for a set of constraints that guide the load-shifting process. Notably, these constraints ensure that the total daily load remains constant while allowing the load to vary within a specified flexibility factor (LS_f) ranging from 5% to 30% as given the equation (2) below [16].

$$\begin{gathered}\mathrm{P_{ln}}\begin{cases}\mathrm{P_l(t)} = P_l(t) + LS_f^{\pm -}(t) & \textit{while } LS_f \neq 0 \\ \mathrm{P_l(t)} & \text{otherwise}\end{cases} \\ \sum_{t=1}^{24} \mathrm{LS_f^+} - \mathrm{LS_f^-} = 0 \text{ while } \mathrm{f} \in (5\% - 30\%)\end{gathered} \tag{2}$$

Where P_{ln} is the new flexible created load. Pl is the actual load profile while LS is the percentage of increased or decreased electrical load according to the flexibility factor (f).

3. *RESULTS AND DISCUSSION*

Central to this study is the question of whether these peak load occurrences coincide with periods of elevated electricity prices in Rocklunda SFs. To address this, Fig 3 presents peak load results that coincide with high electricity price hours on a daily scale, employing the same 75th percentile threshold. It is noteworthy that this threshold can be adaptable to user preferences. Fig 3 summarizes the peak load hours percentage occurring within high electricity price intervals. Examining the fluctuation for the irrigation system (HEL6554) reveals that 41.5 % of peak load instances aligned with expensive price periods in 2021.

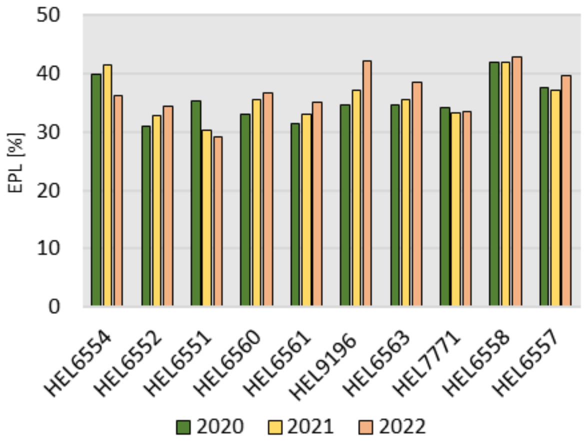

Fig. 3. Proportion of peak load occurring during high electricity prices – analyzing the percentage of peak hours coinciding with elevated electricity costs.

This percentage is reduced to 36% in 2022. Conversely, for Floorball Arena (HEL9196), despite the relative consistency in peak hour frequency, an apparent increase in consumption during high electricity price hours emerged (rising from 34% in 2020 to 42% in 2022).

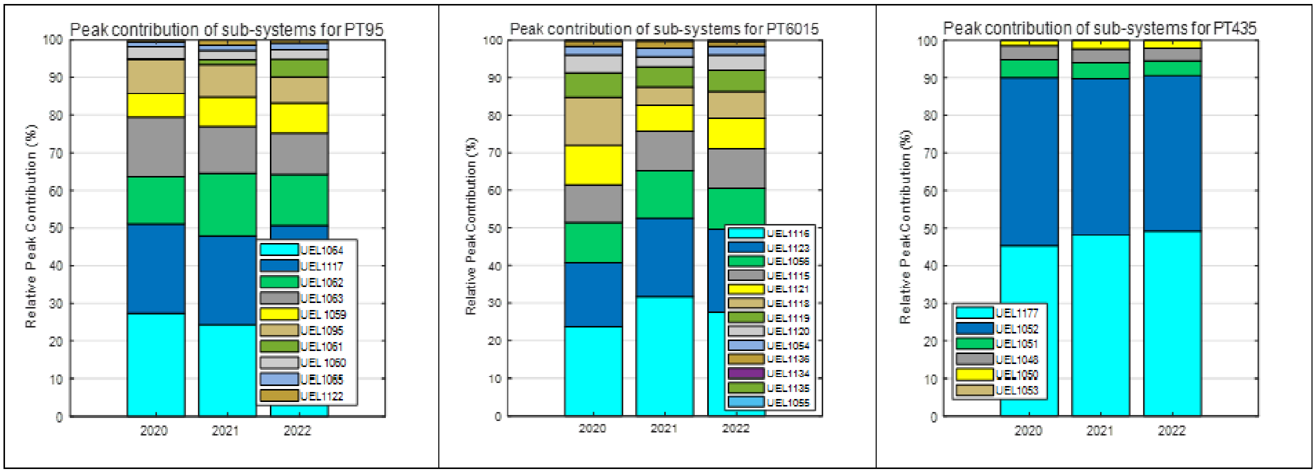

Fig. 4. Sub-systems contribution to the peak load during high electricity price hours.

Notably, a parallel trend is evident for the meter of PT435, wherein 42% of the total peak load instances coincide with costly electricity hours.

This metric of EPL serves as a pivotal indicator, shedding light on consumption patterns during intervals characterized by costly electricity, as explained by the predefined threshold. It is essential to highlight that this metric exhibits a significant sensitivity to the chosen threshold. The selectivity and quantification of peak demand instances in conjunction with high-priced electricity intervals employed can effectuate substantial alterations in the presented metric's outcomes.

For the evaluation of sub-systems' contribution to the peak load during high electricity price hours, we obtained the load profiles of sub-meters connected to the three high-voltage grid connection points. The results are illustrated in Fig 4.

In the context of PT95, the UEL 1064 sub-system, encompassing building functions, ventilation, and lighting, contributes approximately 24% to 27% of the total consumption. Notably, the UEL 1117 system associated with the ABB Nord building constitutes an additional 23% share.

Furthermore, the combined contributions of two cooling machines UEL 1062 and UEL 1063 amount to 26% to 28% during hours marked by high electricity prices. These components emerge as the most frequently utilized units during periods of elevated electricity demand, signifying that potential cost savings could be realized by optimizing their energy usage. For the PT6015, this grid connection point interconnects multiple sub-systems. Considering the sub-meter named UEL 1116, linked to the cooling machine 1, is the dominant contributor, accounting for an electricity consumption share ranging from 23% to 31% during high

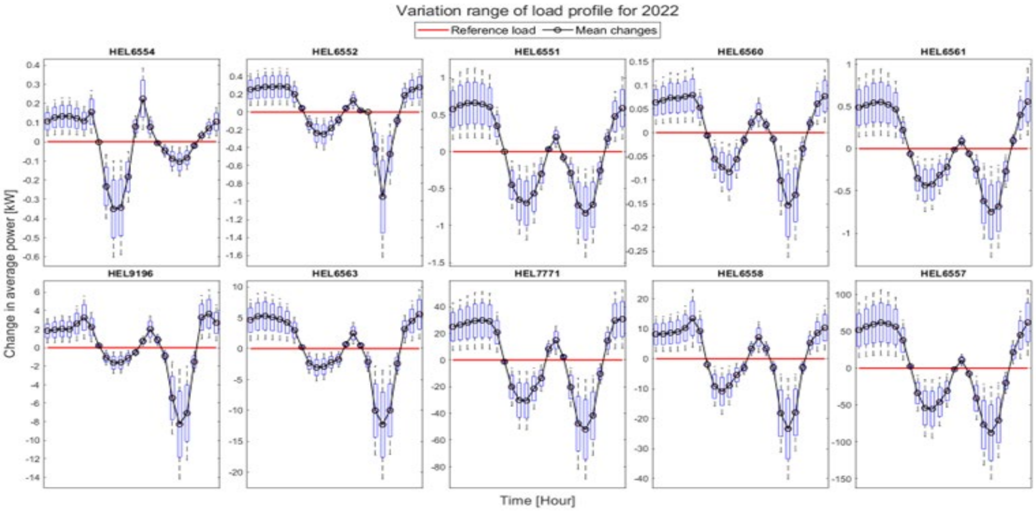

Fig. 5. Variation of deferable load in relation to reference load daily profile: impact of load shifting strategy on consumption reduction and increase hours (Solid red line – reference load).

electricity prices. This is closely followed by sub-system UEL 1123 (cooling machine 2), representing 17% to 23% of the load.

Conversely, the PT435 connects only six sub-systems. The submeters UEL 1177 (The gym) and UEL 1052 (The football stadium building) constitute around 90% of the load during peak hours characterized by expensive electricity. This breakdown of sub-system contributions unveils key potential cost-saving areas, emphasizing the significance of demand-side management strategies in aligning energy consumption with cost-effective practices.

The load-shifting strategy outcomes are depicted in Fig 5, showing the results for ten primary meters within Rocklunda SFs. The range of variations exhibited by the flexible daily load profiles is compared against the original load, represented by blue boxes and the red solid line, respectively. Observations reveal that the electricity demand experiences visible increments during the early morning and afternoon periods. Conversely, the load experiences reductions during elevated electricity prices, primarily in the morning and evening hours. This strategic modulation of the daily load profile results in notable cost savings, achieved without necessitating any modifications to the aggregate daily load.

In addition, the strategic augmentation, rather than being concentrated within one hour, extends over varying hours, specifically from 10 pm to 7 am, and 1 pm to 3 pm. To balance the increase in demand during the day, the load shifting strategy decreases the electricity demand during the morning and evening hours, as demonstrated by the blue boxes situated below the reference red line. This synchronized modulation occurs consistently across all studied load systems. In principle, these distinctive shifts are associated with electricity prices; the strategy aligns with increasing demand during hours characterized by lower costs, while conversely reducing load during peak-cost hours.

In assessing potential cost savings from varying levels of flexibility factor, we calculate annual cost reductions for each level. The estimated outcomes reveal potential savings ranging from 1.5% to 9.5% of the annual electricity cost. This corresponds to flexibility factors varying between 5% and 30%. It is imperative to emphasize that these savings were achieved without load reduction or setting new technology investments such as battery storage. Instead, the strategy shifted electricity demand by switching consumption from high-priced hours to more economical ones. This analysis highlights the efficacy of the demand-side management strategy in reducing peak load, particularly during expensive electricity prices.

4. CONCLUSIONS

In sports facilities located in a cold climate, electricity consumption during expensive hours can range from 30% to 40% of total peak hours. After analysing the sub-system consumption of ice rinks arenas, it was found that the biggest contributors to the peak load consumption in pricy hours are the cooling machines of ice rinks arenas. Although SFs have limited flexibility (for example scheduled games or training), varying flexibility factors from 5% to 30% in a theoretical load-shifting strategy, resulted in a cost saving of 1.5% to 9.5% for most of the studied buildings. It is worth noting that these findings are highly sensitive to the threshold used for the identification of peak loads and expensive electricity prices.

ACKNOWLEDGEMENT

The authors would like to thank the Knowledge Foundation (KK-Stiftelsen) for their funding support under the project Reduction and Reuse of Energy with Interconnected Distribution and Demand (R2D2). Our gratitude is also extended to Rocklunda Fastigheter AB for their cooperation and for providing the input data.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] M. Elnour et al., “Performance and energy optimization of building automation and management systems: Towards smart sustainable carbon-neutral sports facilities,” Renewable and Sustainable Energy Reviews, vol. 162. Elsevier Ltd, Jul. 01, 2022. doi: 10.1016/j.rser.2022.112401.

[2] N. J. Abram et al., “Connections of climate change and variability to large and extreme forest fires in southeast Australia,” Communications Earth and Environment, vol. 2. Nature Publishing Group, 2021. doi: 10.1038/s43247-020-00065-8.

[3] X. Zheng, D. Streimikiene, T. Balezentis, A. Mardani, F. Cavallaro, and H. Liao, “A review of greenhouse gas emission profiles, dynamics, and climate change mitigation efforts across the key climate change players,” Journal of Cleaner Production, vol. 234,pp. 1113–1133, Oct. 10, 2019. doi: 10.1016/j.jclepro.2019.06.140.

[4] M. Santamouris, “Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change,” Energy and Buildings, vol. 207. Elsevier Ltd, Jan. 15, 2020. doi: 10.1016/j.enbuild.2019.109482.

[5] S. Chapaloglou et al., “Smart energy management algorithm for load smoothing and peak shaving based on load forecasting of an island’s power system,” Appl Energy, vol. 238, pp. 627–642, Mar. 2019, doi: 10.1016/j.apenergy.2019.01.102.

[6] G. Gholamibozanjani and M. Farid, “Peak load shifting using a price-based control in PCM-enhanced buildings,” Solar Energy, vol. 211, 2020, doi: 10.1016/j.solener.2020.09.016.

[7] Y. Yang, R. Li, and T. Huang, “Smart meter data analysis of a building cluster for heating load profile quantification and peak load shifting,” Energies (Basel), vol. 13, no. 17, 2020, doi: 10.3390/en13174343.

[8] E. Karapidakis, S. Apostolakis, and N. Vidakis, “An approach of energy self-sufficiency at sports facilities,” in Journal of Physics: Conference Series, Institute of Physics, 2022. doi: 10.1088/1742-6596/2339/1/012022.

[9] G. Powells, H. Bulkeley, S. Bell, and E. Judson, “Peak electricity demand and the flexibility of everyday life,” Geoforum, vol. 55, pp. 43–52, 2014, doi: 10.1016/j.geoforum.2014.04.014.

[10] M. Azaza, A. Eskilsson, and F. Wallin, “An open-source visualization platform for energy flows mapping and enhanced decision making,” in Energy Procedia, Elsevier Ltd, 2019, pp. 3208–3214. doi: 10.1016/j.egypro.2019.01.1006.

[11] M. Azaza, A. Eskilsson, and F. Wallin, “Energy flow mapping and key performance indicators for energy efficiency support: A case study a sports facility,” in Energy Procedia, Elsevier Ltd, 2019, pp. 4350–4356. doi: 10.1016/j.egypro.2019.01.785.

[12] “Nord Pool” Accessed: Jul. 11, 2023. [Online]. Available: https://www.nordpoolgroup.com/

[13] K. Gajowniczek and T. Zabkowski, “Two-stage electricity demand modeling using machine learning algorithms,” Energies (Basel), vol. 10, no. 10, 2017, doi: 10.3390/en10101547.

[14] N. Erdogan, F. Erden, and M. Kisacikoglu, “A fast and efficient coordinated vehicle-to-grid discharging control scheme for peak shaving in power distribution system,” Journal of Modern Power Systems and Clean Energy, vol. 6, no. 3, pp. 555–566, May 2018, doi: 10.1007/s40565-017-0375-z.

[15] Y. Yang, R. Li, and T. Huang, “Smart meter data analysis of a building cluster for heating load profile quantification and peak load shifting,” Energies (Basel), vol. 13, no. 17, 2020, doi: 10.3390/en13174343.

[16] M. S. Javed, J. Jurasz, M. McPherson, Y. Dai, and T. Ma, “Quantitative evaluation of renewable-energy-based remote microgrids: curtailment, load shifting, and reliability,” Renewable and Sustainable Energy Reviews, vol. 164, Aug. 2022, doi: 10.1016/j.rser.2022.112516.