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Proposal for a methodology to optimise electricity consumption on construction sites

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Abstract

The article deals with the sustainability of on-site resources with an emphasis on optimising electricity consumption. The research methodology is based on the investigation of electricity consumption on construction sites and the identification of prospective options to optimise consumption. From the investigation of construction sites, it was found that temporary buildings have the largest share in the total consumption. Significant energy savings could be achieved through the installation of renewable energy sources and heating management. The aim of the proposed methodology is to achieve not only immediate energy savings but also long-term sustainable operation on the site. Several factors have been considered in the development of this methodology, including the characteristics of work activities, electrical equipment, seasonal fluctuations and production.

Keywords: electric energy, electric construction vehicles, construction site, renewable energy

1. Introduction

Nowadays, when the construction industry is undergoing dynamic developments and increasing its demands on energy resources, it is essential to pay special attention to the efficient use of electricity on construction sites. The analysis of on-site energy consumption and the reserves for their reduction is at the heart of scientific approaches and principles for the development of efficiency improvement measures for energy conservation in the construction industry (Korol, 2018). With this in mind, this paper deals with the design of a comprehensive methodology for optimising electricity consumption with an emphasis on sustainability and energy efficiency at construction sites.

Given the size and importance of the construction industry to the world economy and its negative impact on the environment (Murray & Cotgrave, 2007), it is necessary to optimise all aspects of the construction industry. Energy consumption in the construction phase has become a key component of global energy consumption (Zhong etal., 2019). Effective management of electricity consumption on construction sites brings several benefits to construction companies. First, it can lead to significant cost savings through reduced energy expenditure. The Construction Industry Institute highlights that energy management methods can help construction companies achieve savings of up to 30 % in energy costs (Tucker, 2007).

To optimise energy consumption during construction, various factors such as energy infrastructure, resource and carbon management policies, energy pricing, environmental regulations, technological advances and energy consumption itself must be taken into account (Zhang, Liu, Zhang, & Lin, 2021). In particular, the importance of investigating the energy consumed in the construction process has been emphasized, but is often neglected in traditional research (Zhu, Zhang, Li, Feng, & Li, 2019). By understanding the evolution of electricity consumption on site, renewable energy sources, for example, can be implemented.

With the increase in the use of electric construction vehicles (Kong, Wang, Kong, Cong, & Feng, 2021) and the increase in overall energy consumption on construction sites, this trend is expected to continue to increase. The methodology seeks to take into account not only the current state but also the future needs of the industry, with an emphasis on optimising consumption in an environment where different work activities alternate and where there are seasonal fluctuations in energy needs.

In this paper, a thorough analysis of the current electricity consumption on selected buildings is carried out, specific areas with high savings potential are identified, and a methodology is developed based on this analysis. The methodology is not just a static solution, but adapts to technological developments and the rapidly changing needs of the construction industry. It does not only consider short-term energy savings, but also long-term sustainability in terms of electricity consumption on construction sites.

The overall aim of the paper is not only to present the importance of high consumption values on construction sites, but also to present concrete steps and innovative solutions that can lead to an efficient use of electricity within the construction process. The paper thus contributes to the debate on the sustainable future of the construction industry and its adaptation to current trends in energy efficiency. The management of site facilities by civil engineers helps to make construction sites more efficient, optimised and competitive (Gransberg, Popescu, & Ryan, 2006).

2. Methodology

Three different construction sites were selected as part of the investigation of electricity consumption during the construction phase. The selected sites met three parameters as a minimum of 10 temporary structures, the main structure has a reinforced concrete support system and at least one tower crane is used.

To achieve the objective, a combined approach using both metering, consumption analysis and qualitative energy management modelling methods was adopted. Existing statistics and site-specific measurements were used to obtain relevant data on actual energy demand. Leading experts in the field of energy and technology on construction sites were consulted in order to explore prospective savings opportunities and the trend of deploying electrification of construction machinery. A systematic approach was followed, identifying key areas of high energy consumption, analysing seasonal changes in demand and evaluating existing technological innovations. This information was used to develop a methodology that takes into account the specific characteristics of work activities on construction sites and responds to the dynamics of technological developments in the field of electrical construction machinery. The overall aim was to develop a flexible methodology that not only reflects the current state of the art but also covers future needs and innovations in the sector.

The research methodology included the following steps:

- electricity consumption analysis,
- prospective savings opportunities,
- impact of electric construction vehicles,
- design methodology,
- assessment of innovative solutions.

1.1 Electricity consumption analysis

The research started with the processing of data from consumption measurements at selected construction sites for a time period of 150 days, from 15th June 2023 to 11th November 2023. The aim of this phase was to obtain detailed and accurate information on the amount of energy consumed at the temporary facilities and to identify areas of high energy consumption. To achieve this, metering equipment was installed on site to meet the basic criteria of recording and evaluating electricity consumption at hourly intervals and storing the data on remote storage. The same type of metering equipment was used for each site, which was factory calibrated with 99 % accuracy.

Table 1: Overview of electricity consumption

Time period	Site A	Site B	Site C
	quantity of workers		
	22 - 24	30 - 32	23 - 25
	quantity of temporary objects		
	10	12	13
Electricity consumption per 150 days [kWh]	6,765.38	8,627.59	8,022.19

Tab. 1 provides comparative data on manpower and electricity consumption at different construction sites over the time period. The electricity consumption is expressed in kilowatt hours (kWh) and includes the total amount of electricity consumed at the temporary construction sites at each site during the 150-day period of interest.

Tab. 1 provided an accurate picture of the actual energy profile of the temporary buildings on site, which formed the basis for the next steps in the research methodology. The average consumption per day ranged from 45.10 kWh/day for site A, 57.51 kWh/day for site B, and 53.48 kWh/day for site C.

Figure 1: Averaged consumption patterns during the day

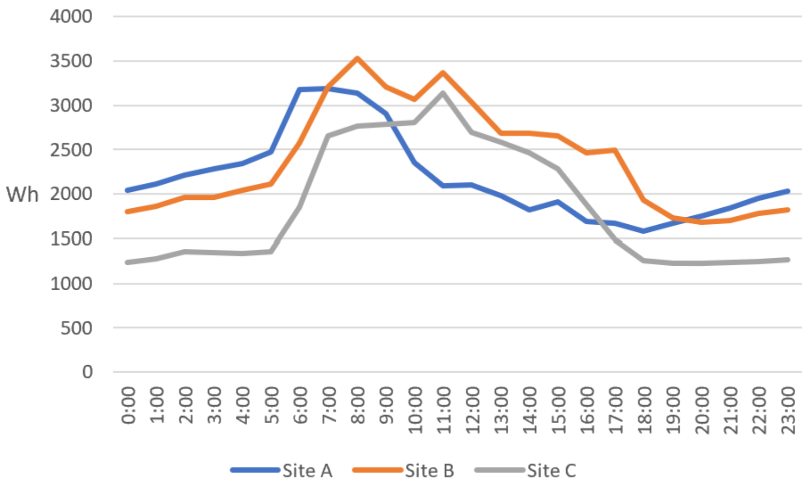

Fig. 1 describes the averaged electricity consumption patterns for temporary site buildings A, B, and C, clearly showing the difference in consumption on weekdays and weekends. The time period with the highest consumption is between 6 a.m. and 18:00 6 p.m.. Peak consumption is identified for site A at 7 a.m. during the working time pool, for site B at 8 a.m. during the working time pool, and for site C at 11 a.m. during the working time pool. These characteristics indicate that electricity consumption is closely linked to work activities and the daily cycle, with potential opportunities to optimise energy efficiency at specific time periods.

Another treatment is to investigate the impact of cold weather on electricity consumption. In particular, the focus was on the hours during the night when site personnel were not present in the temporary buildings. However, higher consumption was noted during colder weather days, primarily due to the heating of the temporary buildings. For comparison, the consumption during the cold nights from 1st October to 11th November 2023 was averaged for a total of 42 nights. During this period, the region was experiencing a cooling trend. The warm nights were averaged from 15th June to 30th September 2023.

Table 2: Comparison of averaged night-time consumption

	Site A			Site B			Site C		
	cold nights	warm nights	difference	cold nights	warm nights	difference	cold nights	warm nights	difference
20:00	2.76	0.64	2.12	3.67	0.90	2.77	4.93	0.59	4.34
21:00	2.78	0.64	2.14	3.80	0.88	2.91	5.13	0.63	4.50
22:00	2.81	0.65	2.16	3.97	0.92	3.06	5.33	0.70	4.64
23:00	2.85	0.66	2.19	4.09	0.93	3.17	5.54	0.74	4.80
0:00	2.84	0.65	2.19	4.06	0.95	3.11	5.39	0.80	4.59
1:00	2.87	0.68	2.20	4.22	0.98	3.24	5.42	0.89	4.53
2:00	3.00	0.75	2.25	4.44	1.02	3.41	5.49	1.00	4.49
3:00	2.96	0.74	2.22	4.37	1.05	3.32	5.55	1.08	4.47
4:00	2.95	0.74	2.21	4.49	1.11	3.38	5.50	1.18	4.32
5:00	3.02	0.74	2.28	4.65	1.14	3.51	5.57	1.33	4.23
	Sum of the difference (kWh)		21.96			31.88			44.92

Tab. 2 provides detailed data on electricity consumption in the time interval from 8 p.m. to 5 a.m. during cold and warm nights. The sum of the difference indicates the total differences in consumption between cold and warm nights over the entire time interval. Tab. 2 summarises these values for each site and provides an in-depth look at the dynamics of electricity consumption during the night hours, and clearly shows how this consumption varies.

Figure 2: Consumption comparison view

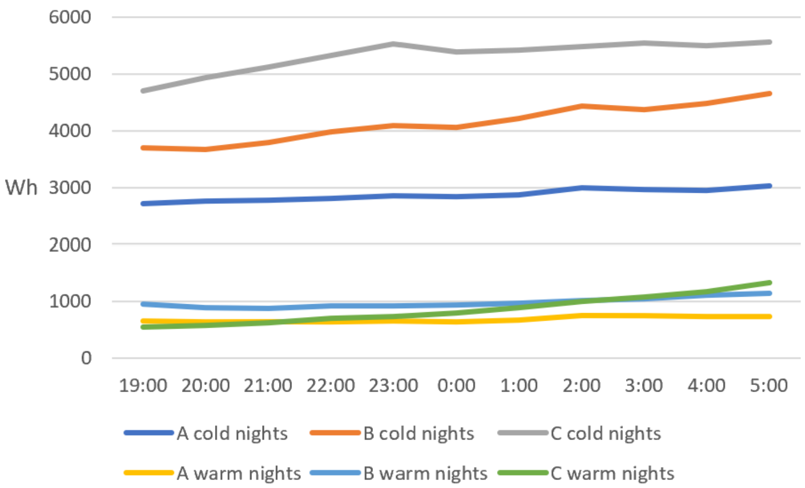

Fig. 2 provides a graphical representation of what the consumption was during the night for that interval and also shows that the waveform was linear, indicating that the operation of the appliances was steady. The observation showed that the difference in consumption between warm and cold nights was heating.

1.2 Prospective savings opportunities

Prospective electricity-saving opportunities are a key aspect of the drive for more efficient and sustainable use of resources on construction sites. The analysis has identified a number of key areas where significant savings can be made while contributing to environmental and economic improvements.

One of the main prospective savings opportunities is the optimisation of electricity consumption at times of high energy demand by using alternative energy sources. The efficiency of consuming the electricity generated from the panels lies in the immediate utilisation (Branker, Pathak, & Pearce, 2011). The data has shown that there are specific time periods when electricity consumption is significantly higher in temporary buildings on construction sites.

It is proposed to implement 5 kWp photovoltaic panels that could be installed on the roof of the construction containers to generate electricity on site. The basic parameters of the PV plant are crystalline silicon panel technology, system losses of 14 %, inclination angle of 35°. The geographical location of the investigated sites is characterized by an annual irradiance in the plane of 1,515.51 kWh/m^2 and an inter-annual variability of 46.58 kWh (Database used PVGIS-SARAH2, 2023).

Electricity generation was adequately adapted to the specifics of consumption for each construction site separately. Hourly consumption during the day and generation options for the highest resource efficiency were taken into account. This approach is also referred to as 'differentiated generation', where generation is subject to actual consumption.

Table 1: Comparison of electricity production and consumption

Months	Site A		Site B		Site C	
	production (kWh)	consumption (kWh)	production (kWh)	consumption (kWh)	production (kWh)	consumption (kWh)
June	296.03	465.52	332.08	569.45	255.65	446.19
July	587.90	880.58	541.76	959.57	360.72	768.54
August	521.41	876.99	619.26	1,240.01	346.05	771.34
September	435.56	801.15	456.79	1,122.80	362.27	886.61
October	278.25	2,454.53	278.25	2,828.02	278.25	3,221.46
November	50.36	1,286.61	50.36	1,907.34	50.36	1,928.05
Sum	2,169.52	6,765.38	2,278.50	8,627.19	1,653.30	8,022.19
Percentage saving		32 %		26 %		21 %

Tab. 3 gives us the production and consumption values for each month. The modelling software programme *SOLAR PRO* was used to simulate the production, in which the possible quantities of optimal electricity production with respect to the consumption of a specific construction site were evaluated. The programme processed the consumption during the eventual production and evaluated the possible electricity savings in a given month. A 5 kWp plant would produce more in the summer months, but no storage in batteries or release of electricity to the grid was considered for the specific consumption at the temporary sites. For the temporary buildings on Site A, there would be an eventual electricity saving of 32 %.

Another energy-saving measure could be to turn off the heating. Electric heaters were used to modify the indoor environment in all temporary buildings. Fig. 2 demonstrated the operation of these devices, which caused an increase in consumption. This effect could be described as a waste of energy, as no one was on the sites at the time. The staff heated the area during the night as well as during the day.

The modelling logic for consumption optimisation consisted in controlling the operation of the heaters, which used electricity as a source. The time when it is not necessary to heat the premises was determined and the real consumption for this time was calculated. The eventual consumption savings did not include the operation of devices such as cameras, security systems, lighting. The difference is based on Tab. 2.

Table 2: Heating energy savings

Months	Site A		Site B		Site C	
	reduction of heating at night	consumption	reduction of heating at night	consumption	reduction of heating at night	consumption
June	-	465.52	-	569.45	-	446.19
July	-	880.58	-	959.57	-	768.54
August	-	876.99	-	1,240.01	-	771.34
September	-	801.15	-	1,122.80	-	886.61
October	680.70	2,454.53	988.31	2,828.02	1,392.43	3,221.46
November	241.54	1,286.61	350.69	1,907.34	494.09	1,928.05
Sum	922.24	6,765.38	1,339.01	8,627.19	1,886.52	8,022.19
Percentage saving		14 %		16 %		24 %

Tab. 4 provides a comprehensive view of the heating savings at the selected sites during the two cold months. Each construction site has its own nighttime energy savings value based on Tab. 2, which serves as a reference point for evaluating heating reduction measures. The sum of the energy savings summarises the total heating reduction during the reporting period for each site. The heating setup should be adjusted for the arrival and departure of site personnel. From the investigation, it was found that the earliest arrival to the construction sites was at 6:30 a.m. and the latest departure was at 7 p.m.. In order to maintain thermal comfort, the heating in the temporary buildings would be automatically started from 6 a.m.. The percentage values then express the ratio between the heating savings at night and the total electricity consumption, thus clearly illustrating the savings dynamics over the two months.

The application of both energy-saving solutions would achieve significant reductions in electricity consumption for individual temporary facilities, which would ultimately have a positive impact on site operations. Savings are modelled at 46 % for the temporary buildings on site A, 42 % for the construction offices on site B, and 45 % for the construction containers on site C.

1.3 Impact of electric of construction vehicles

A mini excavator and telescopic handler were deployed at each site during the study period. These machines performed construction work and had a diesel engine. The charging of these vehicles would need to be considered if electric-powered variants of the machinery were to replace them at the sites. The charging of construction vehicles has a significant impact on power consumption (Dai, Zhao, Zhang, Yu, Fan, & Liu, 2020) and thus the overall energy consumption on the construction site. Although electrification may increase the power drawn, it may ultimately contribute to more efficient consumption of other resources (Rezaeimozafar, Eskandari, Amini, Moradi, & Siano, 2020).

Table 3: Maximum reserved capacity of construction sites

	Site A	Site B	Site C	Charging
Maximum reserved capacity [A]	80	100	100	32

Tab. 5 provides an overview of the maximum reserved electrical capacity at each site in amperes (A). This capacity is a critical indicator that characterises the ability of the grid to provide electrical power to the site, with the last column, *Charging*, indicating the required capacity that is reserved specifically for charging. The numerical values in amperes (A) represent the maximum amount of electricity that can be reserved for charging electric vehicles on a given construction site (Un-Noor, Padmanaban, Mihet-Popa, Mollah, & Hossain, 2017).

For the possibility of charging electric vehicles, it would be necessary to increase the reserved capacity of the tapping point for the site power supply by 32 A and to make modifications to the on-site electrical network to ensure functionality and safety.

1.4 Design methodology

Designing a methodology to optimise electricity consumption is a complex process that requires a systematic approach and analysis of relevant factors related to energy efficiency. The methodology is designed to maximise energy savings, minimise the environmental footprint, and ensure efficient operation of the construction process.

During the construction phase, it is critical to ensure efficient use of electricity and maximise energy efficiency. The following are the main steps have been established by the research:

- power supply design,
- monitoring of consumption,
- consumption analysis,
- identification of solutions for optimisation,
- implementation of solutions,
- ongoing monitoring,
- evaluation of innovative solutions,
- improvements and redeployment.

The importance of measuring the effectiveness of innovative solutions is stressed, which is in line with the need for continuous monitoring (Wolczek, 2019) and evaluation during the construction phase. The aim is to ensure that the implemented solutions are effective in optimising electricity consumption. Re-use of successful solutions can lead to cost savings and streamlined implementation processes (Ljovkina, Dusseault, Zaharova, & Klochkov, 2019).

The methodology highlights the value of evaluating and integrating innovative solutions, such as renewable energy technologies, to further optimise electricity consumption in building processes. In addition, the principle of reusing solutions is essential to promote sustainability and efficiency in construction operations.

1.5 Assessment of innovative solutions

The assessment of innovative solutions in the context of the investigation in this paper focuses on three areas: the installation of renewable energy sources, driving and electrification of construction vehicles. Technological efficiency focuses on the ability to translate reductions in resource consumption through innovation, assessing their practical feasibility within construction processes and their impact on existing working practices. At the same time, it is important to analyse how innovative solutions affect productivity, quality of work and the financial costs associated with them.

The installation of photovoltaic panels on the roof of construction containers needs to be appropriately adapted to the site conditions and the technical conditions of the electricity grid operator. The decision not to store excess energy in batteries and not to send excess electricity to the grid is about minimizing input costs (Asgharzadeh, Marion, Deline, Hansen, Stein, & Toor, 2018). The size of the source was set at 5 kWp so that the maximum energy could be used to power the site. The size of the source will ideally fit on an area of 60 m2, which represents 5 standard containers side by side. The initial cost can be around €7,500.00, based on indicative prices for 1 kWp in the range of €1,350.00 to €1,550.00 (Mayfield, 2019). The economic aspect can change the repeatability or rental of the equipment. An important factor is the location, since the latter is linked to the location of the containers, the shading of these areas needs to be limited.

Automating the central switching off of the electric heating would bring energy savings in a way that minimises disruption to the thermal comfort of the indoor environment. Temporary buildings on site are not subject to stringent energy requirements (Ascione, De Masi, Festa, Gigante, Ruggiero, & Vanoli, 2022) which would create pressure to ensure heat leakage, so other solutions need to be approached. This would avoid heating during the night and the heating would be switched on centrally before the arrival of the construction workers. Adjusting the settings seasonally leads to significant energy savings and financial benefits.

Electrification of construction vehicles will reduce local emissions and noise (Zhao, & Heywood, 2017). However, research has pointed to the need to modify the construction site network and in particular to increase the spare capacity required for charging. The problem of planning and deployment of charging stations should therefore take into account, in particular, the limitations of the electricity network (Zhang, Chen, Cai, & Pan, 2019). There is a lack of comprehensive coverage of electric vehicle charging technology, standards and infrastructure requirements during the construction phase.

The assessment offers insights into technological efficiency that can influence productivity gains, financial profitability, environmental impact reduction and long-term prospects. This can add an important new dimension of sustainability to the construction site.

3. Results

In this study, we analysed the electricity consumption of selected construction machines using a combined approach, employing consumption measurement methods, consumption analysis, and qualitative modelling in the field of energy management. The data collected was used to identify key areas of high energy consumption and to develop a methodology to optimise consumption.

An analysis of electricity consumption at selected construction sites over a 150 day period showed differences in consumption among sites. Site A had an average consumption of 45.10 kWh/day, site B 57.51 kWh/day, and site C 53.48 kWh/day. Peak consumption was identified during working hours, indicating a close correlation between consumption and work activities.

Analysis of the impact of cold weather showed that cold nights caused higher consumption, mainly due to the heating of temporary buildings. The linear consumption pattern observed during the investigation created the potential for heating optimisation.

We identified promising savings opportunities in the implementation of photovoltaic panels on building containers, where savings of up to 32 % could be achieved. Other measures include more efficient heating management, which could lead to savings of between 14 % and 24 %.

The research also investigated possible increases in electricity consumption, and the deployed construction vehicles represent a use case for electrification. Increasing the capacity of the electrical grid to charge the vehicles would be necessary for the successful implementation of electrification.

The methodology for optimising electricity consumption involves a comprehensive approach, including consumption, identification of cost-saving solutions, their implementation, monitoring, and continuous optimisation. The evaluation of innovative solutions should focus on technological efficiency and their ability to reduce environmental impact.

4. Discussion

Investigations arising from studies of electricity consumption issues on construction sites and the implementation of the proposed methodology have identified a number of areas. The first area identified is the identification of areas of high energy consumption. The analysis of electricity at the selected construction sites showed clear seasonal fluctuations and consumption patterns during working and non-working hours. This information is key to developing an effective methodology that reflects the specifics of work activities and time periods. Further, areas for PV panel deployment and where there may be a substitution to electric were identified.

Further research could focus on the use of other selected renewable sources such as small wind turbines. Exploring the potential challenges associated with the integration of small wind turbines can increase energy efficiency. Turbines could also be deployed for nighttime production.

The results obtained from this study have broad implications for the construction industry and related areas of sustainability. An important aspect is the discovery of seasonal variations in energy consumption, which provides insight into the dynamics of working and non-working seasons. This information can serve as a basis for flexible planning and management of construction operations that optimise electricity consumption over time.

Research could begin on developing intelligent control systems that dynamically adjust energy consumption on site according to actual needs. This could include automated control of heating, cooling, and other energy-intensive systems in site operations.

5. Conclusion

The study provides important insights and suggestions in the field of optimising electricity consumption on construction sites. Based on a final analysis of consumption at selected construction sites, we identified key areas of high consumption and identified seasonal fluctuations and the pattern of consumption over the days.

One of the main findings is the need for targeted intervention in the heating of temporary buildings. The proposed measure of automatically switching off the heating during non-working hours proves to be an effective strategy to achieve significant energy savings. This measure not only contributes to an increase in consumption but also reflects the specificities of work activities and time periods.

The use of renewable energy sources, specifically photovoltaic panels, represents a promising approach to the dependence of construction sites on traditional forms of energy. The installation of these panels on the roofs of construction containers can significantly contribute to the sustainability and environmental impact of construction operations.

In the final assessment of the results and discussion of the research on sustainability in construction, key ideas emerge. The results obtained carry with them the need for further research in this area, while a number of questions and challenges still remain open. Another important aspect is the move towards closer collaboration between researchers and the construction industry, which can ensure faster implementation of innovations and their practical validation on real projects. The knowledge gained should also find its way into practice, providing recommendations for the construction community, regulators, and other actors in the sector. The overall benefit of the research for the construction sector lies not only in environmental savings but also in potential improvements in economic efficiency and social sustainability.

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