jet INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2025, VOL. 71, NO. 2, PP. 519-526
Manuscript received December 31,2024; revised May, 2025. doi: 10.24425/ijet.2025.153600

Verification and optimization of electrical energy consumption in university buildings

Paweł Poczekajło, Robert Suszyński, and Andrzej Antosz

***Abstract*—The article discusses the issue of measuring electrical energy consumption. Measurements and analyses of power consumption by selected receivers and electrical circuits are described. The measurements were carried out in selected university campus buildings. The authors included statistical data, also broken down by working period and time of day. Averaged charts are presented on a daily and weekly basis. Knowing the receivers on individual circuits (and their applications), attempts were made to analyze consumption and the possibilities of reducing electricity consumption. The paper also includes analyses related to further work and the possibilities of using the data collected from the energy consumption measurement in other applications and research.**

***Keywords*—energy consumption; measurement system; energy measurement; public building; energy consumption reduction; energy consumption optimization**

I. INTRODUCTION

Global "eco" trends focus on many aspects of environmental protection, with one of the most significant being the minimization of electrical energy consumption [1]-[5]. Despite years of efforts to increase the share of so-called green sources of electrical energy, in many regions of Europe, electricity is still largely generated by conventional coal power plants [6]-[8]. This is particularly noticeable in Central Europe, including Poland [9]-[11]. The current geopolitical, energy, and financial situation in Europe also necessitates the introduction of generally understood savings in the consumption of electricity. Electricity consumers can be informally divided into:

- residential consumers (households),
- commercial consumers (companies and businesses),
- industrial consumers (large industrial plants),
- state consumers (public institutions).

In many respects, it is beneficial for all public institutions, as public utility units, to particularly limit their consumption of electricity. The key benefits include:

- reduced financial costs (less budget burden),
- improved public image,
- setting a so-called good example,
- protection of the natural environment,
- real awareness and demonstration of benefits among the employees of the unit.

Public units are often very extensive, which translates into the use of many different electrical energy receivers and, consequently, significant energy consumption.

The article presents the results of measuring electricity consumption at the University of Technology, which is located in central Europe. This unit is a state higher education institution funded by public funds. Detailed measurements and analyses concern selected receivers (circuits). In subsequent sections, the used measurement system is described (Section 2), the results of measuring selected supply lines are presented (Section 3), and they are discussed and possibilities for reducing energy consumption are indicated, and potential savings are estimated (Section 4). Section 5 also proposes further research and other possibilities for using energy consumption measurements of selected devices. Section 6 is a summary.

II. ENERGY MEASUREMENT AND MEASUREMENT SYSTEM

The article concerns the general measurement of energy consumption by common commercial receivers. Therefore, the measurement will pertain to power supply lines of periodically variable electric current with parameters according to the PN-EN 60038 standard (IEC 60038) [12], [13]:

- frequency: 50Hz (+0.2Hz, -0.5Hz, i.e., 49.5Hz to 50.2Hz),
- effective voltage: 230V (±10%, i.e., 207V to 253V).

In the case of mains power supply, the power measurement can relate to active power, reactive power and apparent power [14] respectively:

$$P=UI\cos(\varphi)[\mathrm{W}], \quad (1)$$

$$Q=UI\sin(\varphi)=XI^2[\mathrm{Var}], \quad (2)$$

$$S=UI[\mathrm{VA}], \quad (3)$$

where: U – effective voltage value, I – effective current value, φ – phase shift, X – reactance, $\cos(\varphi) = P/S$ – power factor, $\sin(\varphi) = Q/S$ – reactive power factor, W – watt, the unit of active power, Var – var, the unit of reactive power (Volt Ampere Reactive), VA – volt-ampere, the unit of apparent power.

Active power can be defined as the power that is drawn by a connected receiver and converted into, for example, work or heat. Reactive power defines the amount of electrical energy pulsation due to capacitive and inductive elements present in receivers. Apparent power can be defined as the square root of the sum of the squares of active and reactive power.

In the presented analysis, the focus is on the measurement of active power, which is typically provided to the average

First Author and Second Author and Third Author are with Koszalin University of Technology, Faculty of Electronics and Computer Science, Koszalin, Poland. (e-mail: pawel.poczekajlo@tu.koszalin.pl).

© The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0, https://creativecommons.org/licenses/by/4.0/), which permits use, distribution, and reproduction in any medium, provided that the Article is properly cited.

consumer as the amount of energy consumed by a given device. It should be noted that in cases where the receiver is a resistor and does not contain reactance, the phase shift $\varphi=0$ and thus $\cos(\varphi)=1$. At the same time, the active power Eq. (1) takes the form:

$$P=UI=RI^2=U^2R, \quad (4)$$

where: R – resistance of the receiver.
The basic unit of energy (work), according to the SI system, is the joule (J), which can be represented as [15]:

$$1[J]=1[Ws], \quad (5)$$

where: W – watt, s – second.
Eq. (5) describes the amount of energy used in one second by a device with a power of 1 watt [15]. For practical reasons, in the production and consumption of electrical energy, we usually use multiplied units, like:

$$1[kWh]= 3.61\times10^6[Ws]. \quad (6)$$

A. Measurement device and system

Since the aspect of electrical energy consumption and optimization of associated costs has been undertaken for several years, many solutions are available on the market to perform the necessary measurements. Recent years have also seen the development of remote operation, wireless communication, and cloud (server) services, so many systems offer easy acquisition and access to data from any location using, for example, a computer or mobile phone. The following requirements were preliminarily defined:

– data storage in the cloud and local database (depending on configuration),
– measurement of at least 3 channels (phases) on one device,
– wireless data transmission via WiFi,
– non-invasive measurement,
– possibility of installation in a standard distribution cabinet on a DIN35 rail,
– integrated power supply for the digital part.

After analyzing the current offerings of suppliers of electrical energy measurement systems, the decision was made to use the Zamel MEW-01 device [15]. The module is typically connected to the 3 phases of the power supply line (L1, L2, L3) and the neutral wire (N), while the measuring probes are attached to the same phases but specifically on the power supply lines of indicated circuits or devices. Zamel company provides the SUPLA software for operating the measurement modules. The basic functionalities of the software include:

– counting the total consumed/returned active electrical energy,
– a wizard to facilitate initial device configuration,
– combined measurement as well as independent measurement on three phases,
– displaying parameters for individual phases (voltage, intensity of active/reactive/apparent power, frequency, power factor (PF) of the phase angle of consumed and returned energy),
– generating charts (energy consumption over time, comparisons of specific time periods, rankings, consumption by phases, balances),
– recording measurement results in a database (MQTT communication),
– data saving to *.csv files.

In the SUPLA mobile application, it is possible to measure the current load on a given line in units [kW]. However, this measurement is not recorded, so its analysis over a longer period is not possible. The device records consumption in [kWh] for individual phases and collectively for all three. Subsequent records (measurements) are registered at equal intervals every 10 minutes along with the measurement number, specific date, and time. From a single measurement, the cumulative energy consumed by connected receivers since the first activation of the measuring device can be read. The device functions like a classic energy consumption meter. The counted amount of energy is stored in non-volatile memory, so power disconnection does not reset its readings. After appropriate calculations, the average power consumed by the receivers in a specified time interval (typically 10 minutes) can be obtained from subsequent recorded measurements.

III. Electricity Consumption and Power Measurement

For safety reasons and the presence of sensitive information, only selected measurement data are presented in the article, without providing detailed information on the locations of buildings, receiving devices, and measurement points. The University of Technology, like any typical scientific and educational unit, consists of a complex of buildings with various purposes (education, scientific research, administration, technical maintenance, server rooms, etc.). The variety of receivers is also very large, e.g., computers and computer equipment, workstations, technical and laboratory equipment, small and large power tools, external and internal lighting, social facilities, etc. The fact of having many different receivers complicates energy consumption analyses, but ultimately may offer greater possibilities in determining potential energy consumption limitations.

Five devices were available, allowing simultaneous measurement on a maximum of 15 single-phase lines (3 phases on each MEW-01 module). However, due to the specifics of the selected electrical distribution boards, it was not always possible to connect all three phases. In such cases, the measurement was performed on two or one phase. The measurement modules were connected as close as possible to the target receiving devices (or groups of receiving devices) in dedicated distribution cabinets.

After preliminary analyses concerning energy receivers, the following measurement points (circuits) were identified:

– P1 - elevator 1,
– P2 - elevator 2,
– P3 - server room (including cooling system),
– P4 - IT team room,
– P5 - campus printer (multifunctional device),
– P6 - group of computer laboratories (2 laboratory rooms and a laboratory service room),
– P7 - recording studio group and 2 computer laboratories,
– P8 - general group (rooms - sockets, lighting),
– P9 - general group (rooms - sockets, lighting),
– P10 - general corridor group (sockets, lighting).

A. Measurement methodology

Due to the number and diversity of receivers, the measuring devices were switched between different measurement points (a single measurement cycle lasted from 11 to 12 weeks). Measurements for individual phases are recorded at 10-minute intervals, but sometimes there were longer time intervals, e.g., during communication problems with the cloud database. Despite the potential absence of an entry in the database, the measurement of energy consumption (in [kWh]) was correctly performed. The device counted the consumed energy and, after establishing a connection to the network (database), recorded the current reading with the current timestamp. This made it possible to correctly calculate the average consumption and average power of the activated receivers. At the same time, measuring the consumed energy in [kWh] can be less intuitive than the direct amount of power consumed at a given moment in [kW]. For this reason, the average power consumption in a given time interval was calculated from the measurement data:

$$P_i = \frac{E_i - E_{i-1}[kWh]}{\frac{t_i - t_{i-1}}{60}[h]} \tag{7}$$

where: E_i – reading number i from the energy consumption meter, E_{i-1} – reading number i–1 from the energy consumption meter, t_i – timestamp for measurement number i, t_{i-1} – timestamp for measurement number i–1, t_i-t_{i-1} – time difference between measurements number i and i–1 expressed in minutes (usually 10 min). For each measurement point, about 11-12 thousand records were collected; presenting such a large number of results is practically impossible. In the case of electricity consumption, the typical cycle is repeated in daily and weekly periods. Therefore, from the collected data, the average consumption for a one-day and one-week time interval was determined. Due to the typical operation of the university on weekdays, the average results for the daily cycle were determined only from Monday to Friday.

For each measured circuit, the following were determined:

- M - the average for the full measurement cycle,
- $M_{7\text{-}16}$ - the average for the full measurement cycle on weekdays from 7 am to 4 pm,
- $M_{16\text{-}7}$ - the average for the full measurement cycle on weekdays from 4 pm to 7 am,
- $M_{7\text{-}21}$ - the average for the full measurement cycle on weekdays from 7 am to 9 pm,
- $M_{21\text{-}7}$ - the average for the full measurement cycle on weekdays from 9 pm to 7 am,
- M_W - the average for the full measurement cycle on weekends,
- M_i - the average for the i-th week of measurement.

The results were collected and presented in Table 1. M_i was calculated only for the next 10 weeks (i=1,…,10), as for selected points, the first and last week of the measurement were not always complete.

B. Measurement results

Below are the measurement results for the indicated points of electric energy consumption on the Campus. Due to the amount of data, the results are presented on appropriate charts (Figs. 1 and 2).

IV. Analysis of Results and Possibilities for Reducing Energy Consumption

The conducted measurements and obtained results are preliminary studies, so their analysis was carried out manually (without the use of dedicated software or computer algorithms). Individual conclusions are often also the result of analyzing the operating methods of selected receivers to determine the possibilities of limiting energy consumption.

TABLE I
DETERMINED AVERAGE AND CUMULATIVE VALUES FOR MEASUREMENT POINTS (CIRCUITS)

Average power consumed [kW]		Measurement point P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
from the entire measurement period	M	0,167	0,227	10,137	0,571	0,044	0,096	0,376	0,57	0,228	0,310
	$M_{7\text{-}16}$	0,388	0,605	10,126	1,016	0,098	0,137	0,626	1,207	0,558	0,332
	$M_{16\text{-}7}$	0,092	0,099	10,146	0,406	0,024	0,073	0,295	0,325	0,108	0,305
	$M_{7\text{-}21}$	0,296	0,449	10,142	0,797	0,072	0,124	0,558	1,043	0,468	0,333
	$M_{21\text{-}7}$	0,073	0,063	10,131	0,407	0,024	0,059	0,224	0,113	0,010	0,291
	M_W	0,078	0,072	10,133	0,412	0,024	0,094	0,266	0,356	0,104	0,298
i-th week	M_1	0,184	0,252	10,382	0,570	0,043	0,128	0,566	0,766	0,360	0,174
	M_2	0,177	0,246	9,774	0,661	0,046	0,140	0,484	0,919	0,370	0,273
	M_3	0,184	0,253	10,401	0,660	0,045	0,153	0,399	0,694	0,317	0,306
	M_4	0,178	0,249	9,635	0,614	0,043	0,102	0,521	0,585	0,231	0,315
	M_5	0,189	0,262	10,547	0,573	0,042	0,125	0,386	0,689	0,251	0,336
	M_6	0,158	0,210	9,525	0,572	0,038	0,030	0,205	0,267	0,078	0,326
	M_7	0,128	0,161	10,500	0,493	0,049	0,028	0,162	0,197	0,030	0,323
	M_8	0,140	0,178	9,592	0,491	0,043	0,028	0,182	0,221	0,049	0,321
	M_9	0,178	0,243	10,329	0,539	0,054	0,133	0,456	0,769	0,348	0,361
	M_{10}	0,162	0,219	10,000	0,569	0,036	0,087	0,360	0,554	0,248	0,350
Summary energy [kWh]		344,7	467,1	20784,4	1206,4	81,6	194,8	740,6	1158,6	445,2	612,9

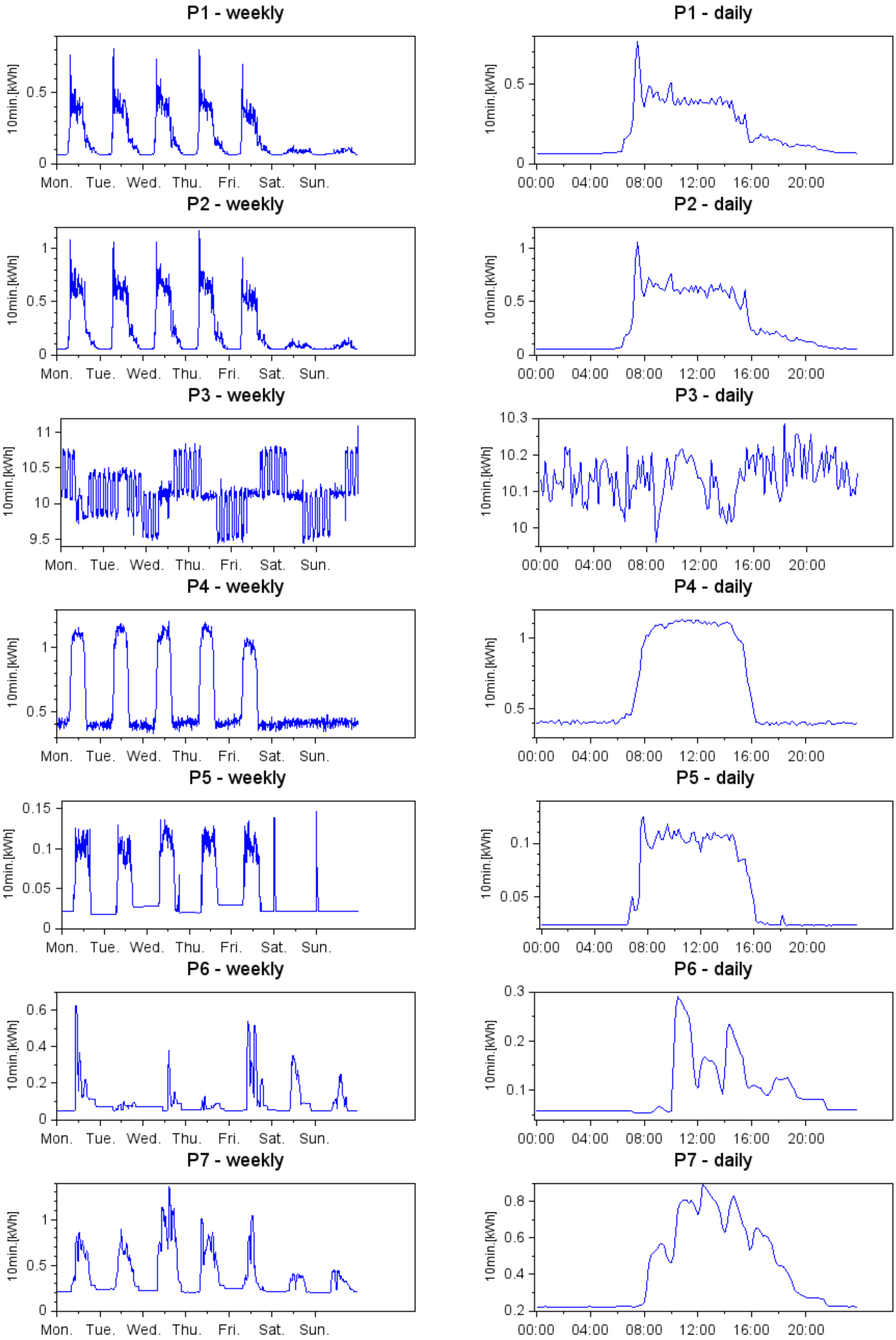

Fig. 1. Charts of average power consumption on circuit P1-P7 for the interval weekly and daily.

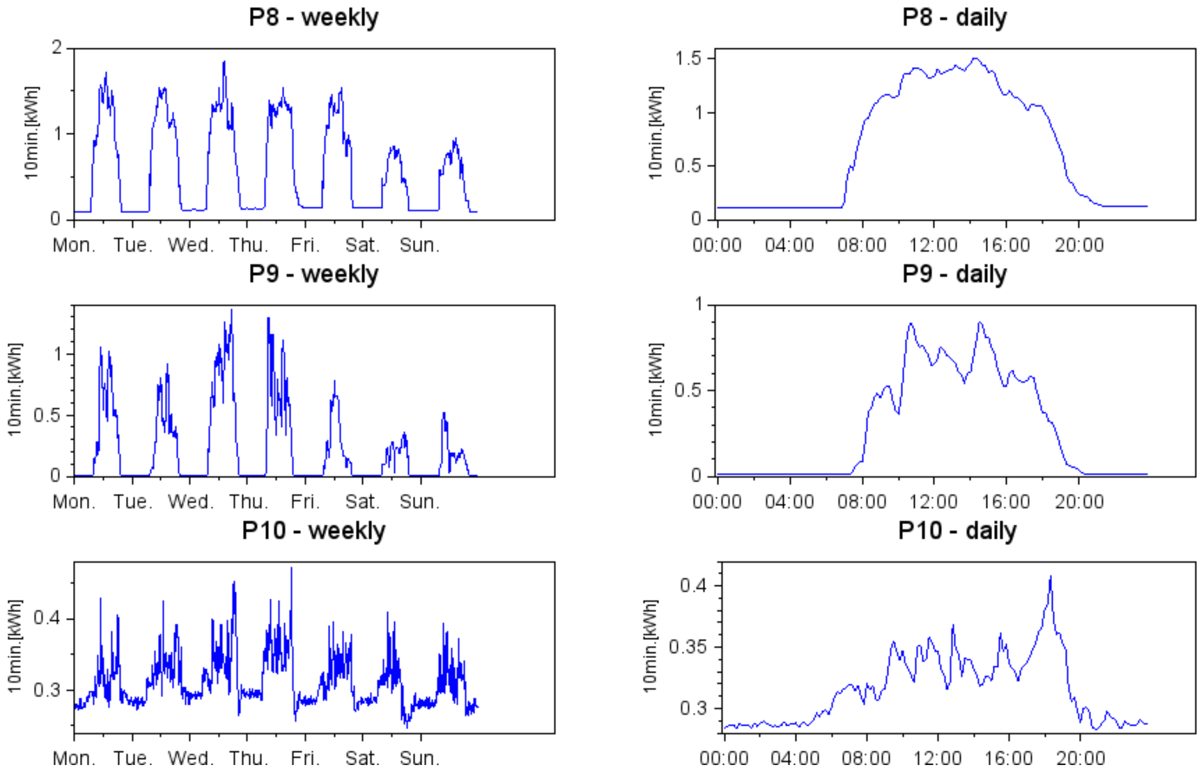

Fig. 2. Charts of average power consumption on circuit P8-P10 for the interval weekly and daily.

A. P1 / P2 (elevator 1 / 2)

The analysis of energy consumption by elevators showed their highest usage in the morning hours (7:00 - 8:00 AM). Further power consumption is quite even until about 4:00 PM. This clearly indicates the highest use of elevators during the start and during the work hours of the University's administration (typical working hours for administration are 7:30 AM - 3:30 PM). Since educational activities take place from 8:00 AM - 9:00 PM, their realization has less impact on the use of elevators. The scientific-research part of the University's activities may be carried out from 7:30 AM - 9:00 PM. This suggests that this aspect of the University's activities also has a minimal impact on the use of elevators. The charts clearly show that on weekdays (Mon.-Fri.) after 4:00 PM, the elevators are practically unused. This pattern is quite significant considering that the University is typically a scientific and educational unit. For the elevators themselves, the currently consumed power was analyzed in more detail. It turned out that for P2, with a single person load (about 90kg), the indicated power during ascent (up) was about 3000W, and during descent (down) about 300W. Such a large discrepancy suggested a malfunction in the elevator mechanism. However, after consulting with the service, the results turned out to be correct, and the discrepancy results from the selection of the counterweight, which is set for half of the allowable load (i.e., about 350kg). Consequently, it was verified how many people usually use the elevator in a single trip. Most often, it is one or two people (up to 80% of trips). This situation suggests that appropriate adjustment of the counterweight will allow for lowering the power consumption by the elevators. An even better solution would be a system for dynamic adjustment of the counterweight depending on the current load of the elevator. The power consumption values on the charts are much lower than the measured actual power consumption (mentioned 3000W) because the chart presents an average consumption over 10 minutes. Meanwhile, the elevator usually operates for a few to several seconds (highest power consumption) and then stands idle for several minutes (zero power consumption). From the point of view of savings, it is also worth noting that typically smaller elevators that consume less power (P1) are sufficient for trips. Comparing the power consumption by elevators P1 and P2, potential energy savings for this approach can be estimated:

$$E\downarrow = 467.1[kWh] - 344.7[kWh] = 122.4[kWh] \text{ (over 10 weeks)}$$

B. P3 (server room)

Server room facilities are currently one of the most important locations in administrative units. Network services necessary for the functioning of individual units are run on the appropriate server units. The services themselves must be operational 24/7 (e.g., www server or email), so that all employees and interested parties have access to the indicated resources. In the case of campus units (universities), additional systems related to student service, the educational process, and scientific/research systems and repositories are added. Also, the administrative part often requires continuous operation of selected services related to, for example, current employee service, accounting, or payments. Among the campus server services, data storage systems in the cloud and all services related to delivering dedicated systems and computing machines are also indispensable. From the point of view of energy consumption by server rooms, it is important that energy consumption is continuous and uninterrupted, barring critical failures. With increased demand for selected services, the use of hardware resources of server units also increases. This usually translates into higher energy consumption. From the charts, one can notice cyclic power spikes, which result from the operation of the cooling system (ventilation and air conditioning). This system operates stably, as evidenced by the consistency of work cycles. Since the individual averages (Table 1) are almost identical, it can be inferred that the servers are evenly loaded throughout the day. Considering the University's work cycle, energy consumption should be significantly lower at night and on weekends. The server systems are probably not properly optimized in terms of used hardware resources (released resources should translate into lower power consumption by hardware server units). Potential savings by introducing simple elements related to, for example, switching off unnecessary hardware units, can be estimated by the difference between the highest and lowest average power consumption for individual weeks:

$$E\downarrow = (10.547[kW] - 9.525[kW]) \cdot 24[h] \cdot 70days = 1716.96[kWh] \text{ (over 10 weeks)}$$

C. P4 (IT team room)

The IT team is typically responsible for maintaining the efficiency of all IT services and telecommunications infrastructure at the University. Their typical working hours are the same as for the administration (i.e., 7:30 AM - 3:30 PM). The charts clearly show that most devices are only turned on during working hours. Turning off unnecessary devices after work is a good practice, allowing for real savings in electrical energy consumption. During the afternoon/night and on weekends, power consumption is at a level of <40% of the average consumption during typical working hours. Potential savings can be estimated similarly to P3, by the difference between the highest and lowest average power for selected weeks:

$$E\downarrow = (0.661[kW] - 0.491[kW]) \cdot 24[h] \cdot 70days = 285.6[kWh] \text{ (over 10 weeks)}$$

D. P5 (campus printer)

A standard multifunction printer is a device with relatively low power consumption. Given its typical use for university administration, its operating cycles coincide with working hours from 7:30 AM - 3:30 PM. Outside these hours, the average consumption is 24W. On weekends, one can notice cyclical power spikes (short-term), which were verified as the activation of the service mode to ensure the efficiency of the printer's components. However, standby consumption is quite high, depending on the enabled features and settings; the manufacturer declares consumption of even <5W for the energy-saving mode. Potential savings from implementing proper configuration for standby mode can amount to:

$$E\downarrow = (24[W] - 5[W]) \cdot 15[h] \cdot 70days = 19.95[kWh] \text{ (over 10 weeks)}$$

E. P6 (group of computer laboratories)

The use of teaching and laboratory rooms is in accordance with classes, which are usually conducted in 2-hour cycles (8-10, 10-12, 12-14, etc., possibly with 0.5h or 1h shifts). For practical reasons, most classes take place between 8:00 AM - 4:00 PM. This is also noticeable on the charts. Increased power consumption outside these hours (and in non-typical cycles - other than 2-hour classes), suggests that the equipment in the rooms is not turned off immediately after the end of classes, but at the end of the day. It is also significant that there is a low power consumption at night (an average of about 59W) when no classes are held. Pointing out potential savings is difficult here, as power consumption should be correlated with room occupancy (e.g., based on the class schedule). Such detailed analysis would require measurement of the load not on the main circuits supplying groups of rooms, but on individual lines in specific rooms.

F. P7 (studio and computer laboratories group)

Since the circuit is mixed (different usage of receivers in different time intervals), its analysis is somewhat complicated. There is a typical work cycle from 8:00 AM - 4:00 PM. Outside these hours, consumption is significantly less. The charts also show 2-hour educational cycles when there are spikes in power consumption. Outside typical working hours, power consumption is over 220W (practically every day of the week), which is a relatively high value. It is necessary to verify the operation of the receivers - it is possible that educational equipment remains on overnight or is in standby mode. In this case, it would be necessary to reconfigure the equipment to completely turn off after a specified period of inactivity and manual activation via a button on the housing. The need to keep studio computers running, which process recordings, could explain this, but in this case, the power consumption is practically constant, while the load on studio computers is rather uneven and non-cyclical. Similar to circuit P6, indicating potential savings here is difficult due to the diversity of devices and the purpose of the rooms. A more detailed analysis (on the power supply of specific rooms) is an essential element for further analyses.

TABLE II
COMPILED INFORMATION REGARDING ELECTRICITY CONSUMPTION AND POTENTIAL SAVINGS

	Measurement points										Total
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
Cumulative energy consumption over the entire measurement period [kWh]	344	467	20784	1206	81	194	740	1158	445	612	26036,3*
Percentage share in total consumption*	1,3%	1,7%	79,8%	4,6%	0,3%	0,7%	2,8%	4,4%	1,7%	2,35%	100,00%
Estimated savings in consumption [kWh]	-	122,4	1717,0	285,6	20,0	-	-	-	-	152,9	2297,8
Percentage ratio relative to total consumption*	-	0,47	6,59	1,10	0,08	-	-	-	-	0,59	8,83

G. P8 / P9 (general groups)

Charts for general room circuits (sockets and lighting) indicate a typical work cycle from 8:00 AM - 6:00 PM. During night hours, consumption is significantly lower, especially for P9, where the average power consumption is 10W. Circuit P8 for the same time interval averages 113W, suggesting the presence of a continuously turned-on electrical device. The average power consumption for circuits P8 and P9, for the time interval 7:00 AM - 4:00 PM, is 1027W and 558W, respectively. These values seem quite high, suggesting the presence of excess receivers during working hours. Further analysis revealed that power consumption for circuit P8 is partly due to an elevator located in the building. For circuit P9, overall power consumption is not large, and considering it covers sockets and lighting in several rooms, the energy usage seems justified. Potential savings may occur for circuit P8, but without detailed analysis, estimation is significantly difficult.

H. P10 (general corridor group)

Charts for corridors indicate heavier loading by devices from 7:00 AM - 9:00 PM, likely due to lighting activated during these hours. These indications suggest the possibility of limiting consumption between 9:00 AM - 2:00 PM, when daylight adequately illuminates the internal passageways. Most corridors and connectors have windows, so this solution is feasible. Additionally, the lights in these locations are manually switched on, so the receivers are on all the time. A much better solution could be the installation of a system with motion sensors or light sources with built-in sensors (bulb+sensor in one housing). Such a simple solution would allow for significant reduction in energy consumption during the indicated hours. However, consumption during night hours is very high for a corridor (communication path), averaging over 290W (when lighting is off). Further analysis revealed that the circuit also powers two vending machines (one with sweets, the other with hot drinks). Depending on the manufacturer and configuration, a vending machine in standby mode consumes an estimated 10W to 100W of continuous power. Clearly, connected devices are not configured to operate in energy-saving modes, especially since neither machine has a built-in refrigeration system. Since the machines are operational 24 hours a day, savings from their proper setting can be estimated based on night-time consumption ($M_{21\text{-}7}$), when only these power consumers are active. The upper limit of power consumption by such machines in standby mode was assumed for the estimation:

$$E\downarrow = (291[W] - 2\cdot100[W]) \cdot 24[h] \cdot 70\text{days} = 152.88[kWh]$$
(over 10 weeks)

In analyzing the final results (total [kWh] consumption) for individual circuits, it is also important to note the large disparity in consumption between the circuits. Most (apart from P5 – the printer) are multi-receiver circuits and larger circuits covering several rooms. Despite this, it's notable that P3 (server room) accounts for as much as 79.8% of the overall measured power consumption. In this context, seeking savings in other circuits may not yield such significant benefits. From the perspective of continuing research, attention should be paid to the metering of rooms equipped with devices with the highest power consumption, which are turned on for extended periods of time.

V. Opportunities for Additional Research and Development

Measurement and analysis of energy consumption by various receivers (or groups of receivers) can realistically contribute to locating devices that excessively consume electricity. Further steps and actions are mainly about limiting this consumption, which can translate into real financial savings. However, measuring current power consumption, especially in the context of individual receivers, can be used in many ways. Below are a few alternative issues concerning data analysis from energy consumption by receivers.

A. Detecting failures or damage in electrical devices

Measurement data of electricity consumption by individual receivers can contain significant information from the perspective of potential malfunction or failure occurrence. Typically, improper functioning of receivers translates into anomalies in the range of consumed electrical energy. In simple solutions, deviations from the norm can be verified (i.e., sudden spikes in electrical energy consumption or an increase relative to average consumption). In more complex solutions, profile data for the indicated device (information about the amount of energy consumed in a proper working cycle of the device) can be used. Current measurement data can then be compared with the device's profile to verify deviations. An advantage of this method is that having detailed information about the operating cycle, deviations for specific stages of operation can be identified, thereby pinpointing specific (potentially damaged) components. More complex systems (circuits) where groups of different devices are used can also be analyzed. In this case, profiling may be difficult, but analysis of average consumption will also be helpful.

By conducting detailed analyses, it is also possible to attempt to identify the consumption of various electrical and electromechanical components and parts before their definitive failure (which completely disqualifies further operation of the device). Such a system can be termed an early diagnostics system for electrical devices and electronic components (subcomponents). Many modern devices (with digital controllers) can analyze power (or current) consumption by selected system components and based on this perform preliminary diagnostics of failures. However, this usually increases the production cost of devices, especially if they are complex or industrial solutions. A system based on independent measurement of main power supply circuits can be a cheaper and more universal solution. An independent measurement system (e.g., the used Zamel MEW-01) can be easily installed in almost any place in the power supply system.

B. Optimization of server room operation (or functionally other systems)

Server rooms are usually very complex systems consisting of a group of different devices (server computers and peripherals, computational and database arrays, network equipment, power modules, cooling modules, air conditioning devices, monitoring systems, etc.). With so many different devices, analyzing and adjusting the operation of server rooms to needs and current capabilities is significantly difficult. Many devices (usually from different manufacturers) operating under various systems do not facilitate integration into operation under a single supervisory system. This can be related to industrial SCADA systems, where integration within subsystems and devices from one manufacturer is simple, but costs can then be very high. Meanwhile, with a budget selection of different system components, common problems with their integration are encountered.

The use of measurement modules or dedicated power distribution units (PDUs) [16], [17], to measure current electricity consumption in server rooms, can greatly facilitate controlling their operation. This is a relatively inexpensive element to implement compared to, for example, replacing server room equipment with those of the appropriate functionalities. Based on measurement data of energy consumption for individual devices, it is easy to optimize the operation of server rooms.

C. Controlling work cycles in relation to tariffs

Electricity consumption measurement can also be used to control the current activation of individual receivers and their work cycles. Correlating appropriate information and functionalities concerning specific electricity tariffs will allow for the operation of the most energy-intensive activities at times when costs are lowest. Since appropriate tariffs function cyclically at specified hours, it is possible to correlate only based on time programming. This approach works if the load (power consumption) is constant and independent of external factors. When power consumption varies depending on, for example, weather conditions, current system load, etc., it is easier to switch the system to operate during cheaper tariff hours based on current energy consumption.

VI. Conclusion and Further Work

The presented measurement results, and estimates show the possibilities of introducing potential savings in electricity consumption. Table 2 summarizes the data for the full measurement cycle (10 weeks). The total estimated savings for a 10-week period amount to 2297.8kWh (which represents 8.83% of the cumulative measured consumption). The largest share in potential savings comes from circuits P3 and P4 (6.59% and 1.10% of total measured consumption, respectively). Both circuits can be characterized as loads related to IT and network infrastructure. Measuring electricity consumption is currently extremely important and often even a requirement for public institutions. Usually, the main goal is to introduce appropriate financial savings. Often, actions related to reducing energy consumption have not only an economic but also a political or social dimension. Thus, the conducted measurements and analyses present valuable data and can improve the image and functioning of the University. The presented analyses and conclusions will be used to optimize energy consumption in selected electrical circuits. After carrying out the appropriate work, there are plans to perform measurements again to determine the extent of savings in electricity consumption. Measurement work will also be conducted on other receivers and circuits , also using modern processing techniques [18]. The obtained data and results will be presented and described in subsequent publications.

References

[1] S. Offermann, “Creating a Strategic Energy Reduction Plan”, River Publishers, 2014, ISBN: 9788770224482

[2] 2. S. Li, X. Gu, M. Cheng and X. Zhang, “Simulation Analysis of Energy Consumption for Intelligent Green Building”, International Conference on Robots & Intelligent System (ICRIS), Sanya, China, pp. 569-575, 2020. https://doi.org/10.1109/ICRIS52159.2020.00145

[3] C. Turner and M. Frankel, “Energy Performance of LEED for New Construction Buildings”, U.S. Green Building Council, New Buildings Institute, White Salmon, WA, 2008. https://newbuildings.org/wp-content/uploads/2015/11/Energy_Performance_of_LEED-NC_Buildings-Final_3-4-08b1.pdf

[4] Keon-ho, L., Young-hak, S., Hwan-yong, K. , Je-hyeon, L., “A Study of Optimal Energy Consumption Measures for Building Façades with a Parametric Combination of Blinds”, Lighting and HVAC Systems, Journal of Asian Architecture and Building Engineering, 15(2), 2016. https://doi.org/10.3130/jaabe.15.319

[5] R. Klyuev, I. Morgoev, A. Morgoeva, et.al., “Methods of Forecasting Electric Energy Consumption: A Literature Review”, MDPI Energies, 15, 2022. https://doi.org/10.3390/en15238919

[6] Online. Energy Production and Consumption. Access 02 Jan 2024. https://ourworldindata.org/energy-production-consumption

[7] P. Alves D., K. Kanellopoulos, et.al., “EU coal regions: opportunities and challenges ahead”, EUR 29292 EN, Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/064809

[8] Online. Shedding light on energy - 2023 edition - Interactive publications. Access 02 Jan 2024.
https://ec.europa.eu/eurostat/cache/infographs/energy_2021/bloc-2a.html

[9] Online. Primary energy consumption. Access 02 Jan 2024. https://ourworldindata.org/grapher/primary-energy-cons?tab=chart&country=~POL

[10] J. Kotelska, “Restructuring conditions for traditional industry enterprises in Poland”, Scientific Papers of Silesian University of Technology, pp. 93-108, 2019. http://dx.doi.org/10.29119/1641-3466.2019.134.8

[11] K. Bódis, I. Kougias, N. Taylor, et.al., “Solar Photovoltaic Electricity Generation: A Lifeline for the European Coal Regions in Transition”, Sustainability, 11, 2019. https://doi.org/10.3390/su11133703

[12] IEC standard voltages, IEC 60038:2009+AMD1:2021 CSV Consolidated version. Access 02 Jan 2024. https://webstore.iec.ch/publication/72877

[13] CENELEC standard voltages, BS EN 60038:2011. Access 02 Jan 2024. https://www.en-standard.eu/bs-en-60038-2011-cenelec-standard-voltages/

[14] The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition, in IEEE Std 100-2000, pp.1-1362, 11 Dec. 2000. http://dx.doi.org/10.1109/IEEESTD.2000.322230

[15] Online. Power monitor wi-fi 3F+N. Access 02 Jan 2024. https://zamel.com/pl/tmp/supla/monitor-energii-elektrycznej-wi-fi-3fn-typ-mew-01\

[16] M. Faisal, T. Walter, S. Montenegro, ”Power distribution unit (PDU) for a distributed computing network”, Proceedings of the XXth Conference of Open Innovations Association FRUCT, pp. 108-113, 2017. https://doi.org/10.23919/FRUCT.2017.8250171

[17] Online. PowerPDU 8QS. Access 02 Jan 2024. https://www.netio-products.com/en/device/powerpdu-8qs

[18] P. Poczekajło, R. Suszyński, “Modern computing methods for digital signal processing engineering systems”, Procedia Computer Science 192(11), pp. 3534-3541, 2021.
https://doi.org/10.1016/j.procs.2021.09.126