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USING THE UNIVERSITY ENERGY EFFICIENCY KNOWLEDGE HUB FOR ENERGY CERTIFICATION AND ENERGY AUDITS OF HIGHER EDUCATION INSTITUTIONS

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BACKGROUND AND OBJECTIVES. The general problem of the research is to define the essence of university energy efficiency as a special type of management of higher educational institution activity, increase of its energy autonomy level, scientific research on economical use of energy resources. University energy efficiency management is a special type of management, which is based on finding new opportunities to save energy resources based on innovations, ability to attract resources from a variety of sources.

METHODS. Logic, system and statistical analysis, and multiple regression methods were used to conduct energy monitoring of HUB use of energy efficiency knowledge. The method of cluster analysis was used for energy audit and energy certification of university buildings. The average value, value of mode and median, indicators of variation (variation range, average linear deviation and variation coefficient) of daily electricity consumption of building No.4 of Kyiv National University of Technologies and Design were calculated, statistical analysis of obtained data was made.

FINDINGS. Existing automatic energy accounting systems in university buildings were reviewed, a comparative table was compiled and the systems were ranked according to the sum of the scores obtained. The comparative analysis is carried out according to a set of criteria, including the unique features that distinguish these systems from each other. Based on the ranking results, the best model is selected and its advantages and disadvantages are identified. A simplified list of requirements and necessary functionality for the use of energy efficiency knowledge HUB for energy monitoring, energy audits and energy certification of university buildings has been developed.

CONCLUSION. The obtained asymmetry coefficient made it possible to conclude that there is a right-hand asymmetry in the amount of energy used in the university. The selected main factors influencing energy consumption allowed to monitor the energy efficiency of the university in 2020. The use of multiple regression equation allowed to take into account the main factors of energy consumption, the extent of their influence, to compare the obtained results with the actual consumption, to build energy profiles and to carry out energy certification of all buildings of Kyiv National University of Technologies and Design.

KEYWORDS: Energy efficiency knowledge HUB; university; energy monitoring; energy auditing; energy certification.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
17	6	3

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ВИКОРИСТАННЯ УНІВЕРСИТЕТСЬКОГО ХАБ ЗНАНЬ З ЕНЕРГОЕФЕКТИВНОСТІ ДЛЯ ПРОВЕДЕННЯ ЕНЕРГЕТИЧНОЇ СЕРТИФІКАЦІЇ ТА ЕНЕРГЕТИЧНОГО АУДИТУ ВИЩИХ НАВЧАЛЬНИХ ЗАКЛАДІВ

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ПОСТАНОВКА ПРОБЛЕМИ ТА ЗАВДАННЯ. Загальною проблемою дослідження є визначення сутності енергоефективності університету як особливого типу управління діяльністю вищого навчального закладу, підвищення рівня його енергоавтономії, наукових досліджень щодо економного використання енергоресурсів. Управління енергоефективністю університету є особливим типом управління, в основі якого – пошук нових можливостей економії енергоресурсів на основі інновацій, вміння залучати ресурси з найрізноманітніших джерел.

МЕТОДИ. Для проведення енергетичного моніторингу використання ХАБ знань з енергоефективності були використані методи логіки, системного і статистичного аналізу, множинної регресії. Для проведення енергоаудиту і енергосертіфікації будівель університету був використаний метод кластерного аналізу. Використано середнє значення, значення моди і медіани, показники варіації (розмах варіації, середнє лінійне відхилення і коефіцієнт варіації) добового електроспоживання будівлі корпусу №4 Київського національного університету технологій та дизайну, проведений статистичний аналіз отриманих даних.

РЕЗУЛЬТАТИ. Розглянуто існуючі системи автоматичного обліку використання енергії в університетських будівлях, складена порівняльна таблиця і вироблено ранжування систем за сумою отриманих балів. Порівняльний аналіз проведено по набору критеріїв, включаючи унікальні можливості, що відрізняють ці системи один від одного. За результатами ранжування обрана найкраща модель, виявлені її переваги і недоліки. Складено спрощений список вимог і необхідного функціоналу для використання ХАБ знань з енергоефективності для проведення енергетичного моніторингу, енергоаудиту і енергосертіфікації будівель університету.

ВИСНОВКИ. Отриманий коефіцієнт асиметрії дозволив зробити висновок про наявність правобічної асиметрії кількості використовуваної енергії в університеті. Визначені основні фактори, що впливають на електроспоживання, що дозволило зробити моніторинг енергоефективності університету в 2020 році. Використання рівняння множинної регресії визначило основні фактори енергоспоживання, ступінь їх впливу, порівняння отриманих результатів з фактичним споживанням, побудувати енергопрофілі і здійснити енергосертіфікацію всіх будівель Київського національного університету технологій та дизайну.

КЛЮЧОВІ СЛОВА: ХАБ знань з енергоефективності; університет; моніторинг енергоспоживання; енергоаудит; енергосертіфікація.

INTRODUCTION.

One of the most important main priorities of modernisation and technological development of the country's economy is to increase its energy efficiency. The current situation of inefficient and irrational use of resources in the system of higher education requires the development of an integrative approach to energy saving and energy efficiency management of higher education institutions (hereinafter HEI), the main components of which are energy management, energy audit, energy certification and monitoring based on reasonable use of international standards ISO 9000; ISO 50000 (Shaposhnikova *et al.*, 2016; Vieira et al., 2020). This reduces or eliminates the barriers to the implementation of energy efficiency measures, such as a lack of awareness of the savings potential (García *et al.*, 2020); insufficient or fragmented information on energy efficiency and the absence of a common system of energy efficiency indicators (Nayak *et al.*, 2021); and a lack of attention to the energy efficiency of the HEI's systems and processes (Nicola *et al.*, 2020).

Modern university buildings use a large number of resources, such as heat, cold and hot water, and electricity, which is the main energy consumed and is used for lighting, office equipment, ventilation and air conditioning systems (Werth *et al.*, 2021). The embedded electricity metering systems of these buildings have a rather simple structural organisation, with analogue and digital meters of different manufacturers installed on aggregated consumer groups (Di Stefano, 2000). This metering system does not allow a qualitative analysis of energy consumption, nor does it allow for measures to reduce it (Xing *et al.*, 2019). In order to improve the energy efficiency of university buildings, it is necessary to implement an automatic energy metering system (Abu-Rayash *et al.*, 2020; Wang *et al.*, 2021), capable of working with a large number of metering equipment manufacturers, with manual data entry and export capabilities from related systems (Liu *et al.*, 2019). The implementation of such a system will allow for more internal billing and qualitative consumption analysis, which facilitates rapid decision-making to optimise energy use. With more data and its analysis results, the university can more accurately predict energy consumption (Zhong *et al.*, 2020).

The aim of the study is to propose the use of a university energy efficiency knowledge hub for energy certification and energy audits of higher education institutions. The study was conducted in 2020 based on data from the Kyiv National University of Technologies and Design.

MATHERIALS AND METHODS.

Data description.

Most existing automatic energy accounting systems use software products (Table 1). They are compared based on expert evaluations. After summing up the scores obtained from the experts, we will rank the systems and choose the most suitable one for the implementation of energy monitoring of university buildings.

Table 1

Comparative analysis of automatic energy accounting systems in universities

Parameters	Name									
	Energy software	EASDKiU	RDM	Energy control	I-ems	Simatic	1C Cascade	Energy metering	Marcel	Energy
Software type	1	1	1	1	2	0	0	1	1	1
Need for third party software	2	2	2	2	1	1	0	2	2	1
Supported manufacturers	2	1	0	2	2	2	2	2	1	1
Communication standards	2	2	2	1	1	1	1	1	2	0
Energy Resources to be Accounted for	2	0	0	2	2	2	1	0	0	0
Parameters to be monitored	2	2	2	0	0	2	2	0	0	0
Manual input	0	0	0	0	0	2	2	1	0	0
Multi-tariff metering	0	2	0	0	2	0	0	2	0	0
Forecast	0	0	0	0	0	1	1	1	0	0
Displaying data in reports	2	2	2	2	2	1	2	2	2	1
Diagnosis of metering devices	2	1	2	1	0	2	0	0	0	1
Remote control	2	2	2	2	0	2	0	0	0	0
Recording of personnel actions	2	1	1	1	1	0	1	0	0	0
Automatic calculation	1	2	2	1	2	0	1	0	2	0
Document management system	1	0	0	0	1	0	2	1	0	0
Automatic distribution	0	2	1	0	1	0	1	0	1	0
Code openness	0	0	0	2	0	0	0	1	0	1
Amount of points	21	20	17	17	17	16	16	14	11	6

Source: based on (Gryshchenko *et al*., 2017; Kaplun *et al*., 2016).

The scores in Table 1 are as follows: 2 points if the function is fully implemented, 1 point if only part of the function is implemented, and 0 points if the function is not implemented at all or only a small part of it is implemented. When scoring the software type, 2 points were given to modular and modular software, as these types are the most advanced at the moment due to the fact that they allow gradual integration, selecting a set of necessary functions for each specific university building and extending the functionality as needed (Zhong *et al*., 2020). One point was given to stand-alone software that does not require basic software to be installed. Zero points were given to integrated systems requiring third-party software for installation and operation. A comparison of automatic accounting systems using the 'ranking' method revealed that the most functional system currently on the market is Energo software, but even though it has great functionality, it is not able to fully meet the needs of individual higher education institutions (Liu *et al.*, 2019). For example, the system does not allow for manual data entry, which rules out gradual integration. The system is not able to organise tariff calculation, which does not allow reducing the cost of electricity consumption without changing the amount of electricity consumption. Also, the system does not have any electricity forecasting functionality and is not capable of automatic notification of stakeholders. To address this issue, the system should be modular, which would not only make it more affordable and allow for gradual implementation, but also allow universities to tailor the necessary functionality to specific needs (Kaplun *et al.*, 2016). It would be most convenient to divide the functionality into categories, such as predictive module, accounting module, remote management module, document management module, quality control module. As a result, the modular system should be able to form a unified information space (Ganushchak-Efimenko *et al.*, 2018). In addition, the maximum expansion of devices available for reading and control is required, as well as the implementation of device-specific manual data entry functionality, which will allow enterprises to make gradual integration of automatic energy metering systems (Shcherbak *et al.*, 2019). The system should be easily scalable and capable of receiving data both via wired and wireless technologies without losing the quality of the data received. The system should be able to acquire data, automatically analyse it and produce forecasts, as well as optimise energy consumption, especially in the context of the Covid-19 pandemic (Shcherbak *et al.*, 2021). It is necessary to have a module for quality control of consumed resources, as well as to notify about abnormal situations both the operator and a certain circle of persons of the enterprise not only by e-mail, but also by SMS or autoinformer (Shcherbak *et al.*, 2021). This will increase the reliability and responsiveness of the system. At the same time, there should be functionality in the area of document management and employee monitoring (Shcherbak *et al.*, 2019). Currently, the market does not have a system that meets these requirements. This study proposes the use of a university energy efficiency knowledge HUB as a centralised point of personal energy metering for energy certification and energy audits of higher education institutions.

Method description.

As a result of daily monitoring we have consumption data for a day, collected at 30-minute intervals. The data obtained are shown in figure 1.

Find the indicators of the centre of distribution, such as the simple mean, mode and median. First, we find the simple average by summing the values and dividing by their number (eq. 1):

$$\bar{x} = \frac{\sum x_i}{n}. \quad (1)$$

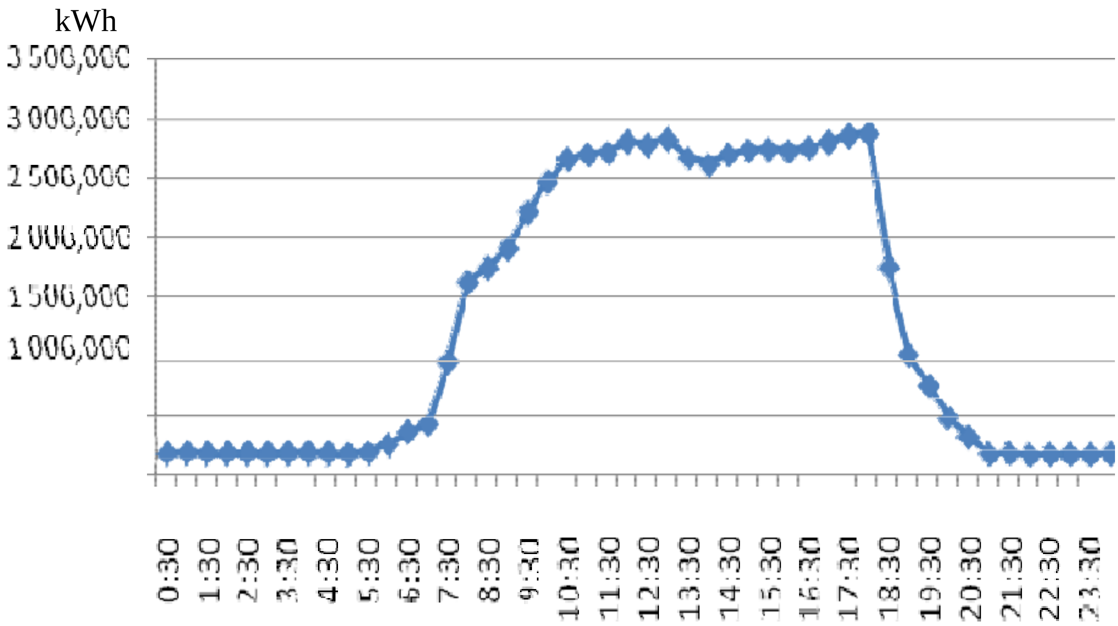


Figure 1. **Diagram of the daily electricity consumption of KNUTD Building 4**

Next, find the modulus of our series. The result is two values occurring with the same highest frequency. From the results, we can conclude that the series is multimodal and does not follow the law of the normal distribution. The median is a good proxy for asymmetric distribution, because even in the presence of outliers, the median is more robust to outliers. As the number of values in the series is even, it is necessary to take the two central values of the ranked series and find their mean.

It is also necessary to find measures of variation, such as variance, dispersion, and linear mean deviation. The range of variation is the difference between the maximum and minimum values of the series (Eq. 2):

$$R = x_{\max} - x_{\min}. \quad (2)$$

The linear mean deviation is calculated to account for the differences of all units in the population under study (Eq. 3):

$$d = \frac{\sum |x_{i} - \bar{x}|}{f}. \quad (3)$$

The variance is a measure of the deviation from the mean. The calculation will be done by the method of moments (Eq. 4):

$$D = \frac{\sum x_i^2}{n} - \bar{x}^2. \quad (4)$$

In this case, the standard deviation is determined by Eq. 5:

$$\sigma = \sqrt{D}. \quad (5)$$

The coefficient of variation is a measure of the relative dispersion of population values, showing what proportion of the mean value of that value constitutes its mean dispersion (Eq. 6):

$$\gamma = \frac{\sigma}{\bar{x}}. \quad (6)$$

The linear coefficient of variation, or relative linear deviation, characterises the proportion of the average value of a trait that is absolute deviations from the mean (Eq. 7):

$$K_d = \frac{d}{\bar{x}}. \quad (7)$$

The most accurate and common measure of asymmetry is the moment coefficient of asymmetry: As = M3/s3, where M3 is the third-order central moment, s is the standard deviation. The estimation of the significance of the asymmetry index is given by the mean square error of the asymmetry coefficient.

RESULTS AND DISCUSSION.

As a result of statistical analysis of the data, it was found that electricity consumption data in KNUTD buildings does not follow the law of normal distribution, hence there is no possibility to make a qualitative assessment and build an accurate prediction of electricity consumption (Kaplun *et al.*, 2016). For a more qualitative analysis, the main factors affecting electricity consumption were identified. KNUTD has unregulated central heating, individual air conditioning systems, and central and individual lighting (Kaplun *et al.*, 2016). Therefore, we selected the following main factors: average outdoor air temperature, average daylight hours, heating period, and average number of people working per day during the month (Gryshchenko *et al.*, 2017). The following data were obtained from the year-long monitoring, as presented in Table 2.

To assess the impact of each factor on energy consumption, we construct a multiple regression equation for the 4 factors. The linear multiple regression equation is as follows (Eq. 8):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m + \varepsilon, \quad (8)$$

where β_0 – free term; β_n – values of the coefficients of influence of each specific factor on the final result; X_n – quantitative value of the factor.

The result is a regression equation:

$$Y = -1341024{,}7002 + 110{,}5904X_1 + 3638{,}9134X_2 - \\ - 2518{,}0966X_3 - 7304{,}7214X_4.$$

Table 2

Data from the monitoring of KNUTD Building No.4 in 2020

Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Electricity consumption, kWh	186808	160339	141634	97250	56985	35941	22192	43904	58684	122035	173193	211063
Heating period, days	31	29	31	28	0	0	0	0	5	31	30	31
Personnel, pers.	425,1	427,5	426,8	427,2	427	425	422	424	418,3	421,2	423,5	427
Average air temperature, ℃	–12,9	–6,8	–2,2	6,2	16,09	26	28,3	26,5	17,4	1,2	–1,15	–6,71
Average duration of daylight hours, h	7,16	9,2	11,4	14,2	16,4	18,3	17,4	15,2	12,52	10,21	8	6,36

To assess the quality of the resulting equation, calculate for each month and calculate the variance as a percentage. The results of the calculation are presented in the Table 3.

Table 3

Results of calculations of energy consumption in building No.4 of KNUTD in 2020

Month	Actual electricity consumption, kWh	Estimated electricity consumption, kWh	Deviation, kWh	Rejection, %
January	186808	189573,69	2729,69	1,46
February	160339	167838,34	7499,24	4,67
March	141634	137347,22	4286,77	3,02
April	97250	97200,84	49,15	0,05
May	56985	59958,95	2973,95	5,21
June	35941	33519,82	2421,17	6,73
July	22192	22582,19	390,19	1,76
August	43904	39211,83	4682,16	7,79
September	58684	61524,31	2840,31	4,84
October	122035	123554,43	1519,44	1,24
November	173193	167975,65	5217,35	3,01
December	211063	201766,60	9296,39	4,40

The actual and estimated energy consumption data are also presented as a graph in Figure 2.

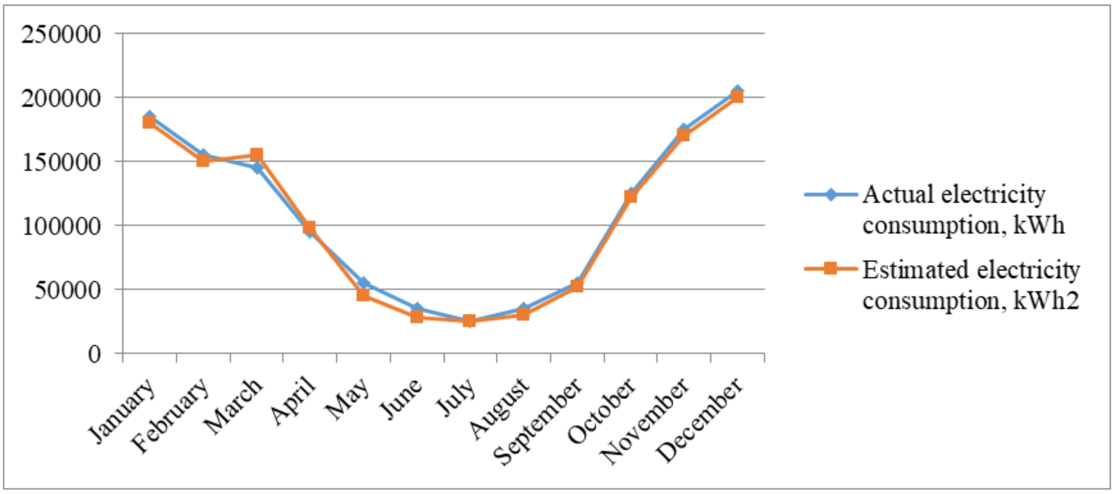
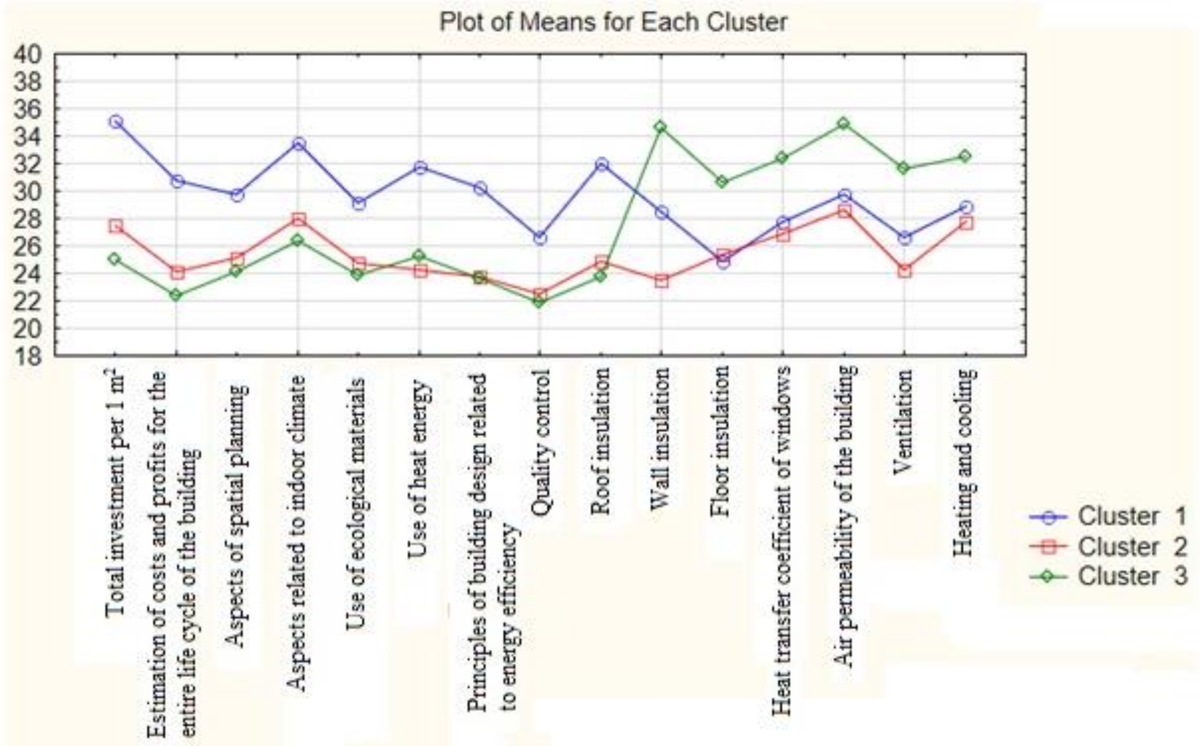


Figure 2. **Schedule of actual and estimated electricity consumption in building No.4 of KNUTD in 2020**

The evaluation shows that the deviation of the calculated electricity consumption from the actual electricity consumption in the peak values does not exceed 7.8%, and the average deviation is 3.68%, which is a good indicator of the accuracy of the model. Due to the high accuracy of the model, knowing the values of the coefficients, it is possible to construct a sufficiently accurate forecast of energy consumption.

The energy profile of KNUTD buildings is defined as follows: the total investment is evaluated against the national average (100%); expenses and profits are evaluated against the invested funds or the obtained effects over the whole life cycle of the building. Energy consumption is assessed similarly. The best results correspond to passive house or zero energy consumption standards. The quality control assessment is based on a given degree of quality control during the construction of the house. A high rating can be obtained if a building inspection has been carried out or is planned, but the highest rating is given if, in addition to the building quality check, an energy certification by an independent company has also been carried out. The parameters of the building are characterised by numerical values. Thermal insulation of the roof, walls and floor is assessed by measuring the thickness of the thermal insulation material in centimetres. The thermal conductivity of windows is indicated by the heat transfer coefficient. The air permeability of the building is determined by the degree of compaction. To assess energy systems, the ventilation system and its energy efficiency, heating and cooling systems, and the use of renewable energy for heat and electricity are analysed. The results of the cluster analysis of the energy efficiency status of the 15 KNUTD buildings for the 16 assessed indicators are shown in Figure 3.



Source: calculated from expert assessments.

Figure 3. **Results of a cluster analysis of the energy efficiency status of KNUTD buildings (STATISTICA10 listing)**

The data in Fig. 3 confirms the fact that all KNTUD buildings can be divided into 3 classes (clusters) according to the level of energy consumption and energy efficiency achieved. The definition of the objects that fell to each of the obtained clusters is given in Fig. 4–6. The first cluster includes the buildings of the academic building №1 (B1) and the academic building №4 (B4) (Fig. 4). These objects are characterised by a rather high level of energy consumption.

Members of Cluster Number 1
and Distances from Respective
Cluster contains 2 cases

	Distance
Б1	11353,57
Б4	11353,57

Source: calculated from expert assessments.

Figure 4. **List of KNUTD buildings in cluster 1 (High level of energy consumption)**

The second cluster includes buildings of the academic building № 2 (B2), the academic building № 3 (B3), the academic building № 2 (B2), dormitory № 2 (B9), dormitory № 3 (B10), dormitory № 4 (B11), dormitory № 5 (B12), dormitory № 6 (B13), dormitory № 7 (B14), dormitory № 8 (B15) (Fig. 6). These facilities are characterized by an average level of energy consumption.

Members of Cluster Number 2 and Distances from Respective Cluster contains 9 cases	
	Distance
Б2	475,96
Б3	731,18
Б9	2234,42
Б10	2328,99
Б11	538,98
Б12	2307,67
Б13	2151,33
Б14	10295,95
Б15	1487,82

Source: calculated from expert assessments.

Figure 5. **List of KNUTD buildings in cluster 2 (Average energy consumption)**

In the third cluster were the buildings of Training Building 5 (B5), Training Building 8 (B6), Building 6 (B7) and Building 7 (B8) (Figure 7).

Members of Cluster Number 3 and Distances from Respective Cluster contains 4 cases	
	Distance
Б5	1036,916
Б6	444,261
Б7	231,782
Б8	378,972

Source: calculated from expert assessments.

Figure 6. **List of KNUTD buildings in cluster 3 (Below average energy consumption)**

These facilities are characterized by relatively low energy consumption, which is explained by high roof, wall and floor insulation, low thermal conductivity of windows and air permeability of the buildings. Thus, by using cluster analysis tools it was possible to unambiguously determine the level of energy consumption in the studied buildings and the achieved level of energy management.

CONCLUSION.

Electricity consumption is a specific function that does not follow the laws of normal distribution and has a significant asymmetry, which indicates that standard statistical methods cannot be used to estimate and predict electricity consumption. Electricity consumption depends on many factors, the influence of which can be taken into account by a multiple regression equation. Thanks to this equation, we can make forecasts with an accuracy of 3.68%. The modern market offers a significant number of automatic energy accounting systems. The existing systems have great functionality not only in the area of metering, but also in the area of quality assessment of the consumed resource, SCADAsystems, as well as in the area of electronic document management and forecasting. To date, although the market has promising accounting systems, it is not able to meet all the individual needs of higher education institutions. The use of an automated metering point of the university's Energy Efficiency Knowledge Hub has enabled the energy certification and energy audit of the Kyiv National University of Technologies and Design.

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ABBREVIATIONS:

%	Percentage
COVID-19	Corona Virus Disease 2019, corona virus infection 2019-nCoV
Eq.	Formula of calculation
Fig.	Figures
HEI	Higher education institution
HUB	Common connection point
KNUTD	Kyiv National University of Technologies and Design

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