Global J. Environ. Sci. Manage. 5(4): 501-514, Autumn 2019

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Application of international energy efficiency standards for energy auditing in a University buildings

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ARTICLE INFO

Article History:
Received 01 April 2019
Revised 22 August 2019
Accepted 14 September 2019

Keywords:
Energy Auditing
Energy Efficiency
Energy Management
Energy Building
University Facilities

ABSTRACT

This study seeks to provide insights on understanding the contemporary problems of energy efficiency in Ukrainian universities by developing a comprehensive energy efficiency management framework that encompasses its participating subjects, objects and key drivers along with suggesting its implementation mechanism and tools. Emphasis should be given that the current situation of inefficient and irrational consumption of energy resources within the system of higher education in Ukraine challenges the development of an integrative approach to energy saving and energy efficiency management. It is argued that the key elements of this integrative approach to energy management are energy auditing, energy certification and energy monitoring based on the consistent use of ISO 9000 international standards. Over the last 10 years energy consumption in Ukrainian higher education institutions against the world best practice exceed by 30-40%. This triggers a critical need to building an integrative approach to energy saving and energy efficiency management. The findings revealed that disincentives reduce the degree of energy efficiency by 25%. Constructing energy profiles by a hierarchical clustering method demonstrated that 68% of the campus buildings belong to a 5th class out of 7, i. e. being highly energy intensive. Following the DGNB (German Sustainable Building Council) approach to evaluate energy efficiency has enabled to eliminate 17% of the G category classrooms (extra energy intensive) from the University heating facilities. The clustering method to assess 15 University buildings by 16 performance indicators identified 5 clusters in terms of energy consumption and energy efficiency.

DOI: 10.22034/gjesm.2019.04.09

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
49	7	1

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Note: Discussion period for this manuscript open until January 1, 2020 on GJESM website at the “Show Article.

INTRODUCTION

The potential of energy saving in Ukraine is enormous: the effect from reducing energy consumption brings results that are comparable in scale to the production or imports of natural energy sources and makes it possible to cut energy consumption within the country almost in half. Moreover, the investment required to implement energy efficiency measures might be three times less than the alternative capital inputs to increase the same amount of energy production. It is important that energy efficiency is realized in all areas of its application - in energy production sector, for transportation purposes, energy consumption, etc. Each of these areas is characterized by excessive energy use: for example, energy consumption in Ukrainian generating companies has increased by 20-30% over the last decades which is 1.5 times higher against the global best practice; in heat and power supply systems exceeds 60%; in the sector of housing and utilities (in public companies including higher education institutions, in manufacturing) - by 30-40%. Recently, the issues of energy efficiency in Ukraine have been receiving considerable attention, as evidenced by the adoption of 13 laws regulating various aspects of energy efficiency and energy conservation. At present, the basic law Universities must comply with in their activities is based on Verkhovna Rada of Ukraine, (1994). However, in most cases, Ukrainian University campus buildings are worn out and energy inefficient challenging the design of a new paradigm to enhance the overall University energy efficiency. Apart from the national regulation, the issues of raising energy efficiency standards are in the focus of a number of international institutions which provide their assistance and support. Thus, in 2017, an agreement was signed between Ukraine and the European Investment Bank (EIB) to attract funding for the implementation of the energy efficiency support project (Poroshenko, 2018). In the frameworks of the above project's Action plan, in accordance with the EIB criteria, 147 buildings of 7 Ukrainian Universities have been selected. In the context of managing energy efficiency in Universities, all body of research studies over the last 10 years can be divided into 3 groups. The first is devoted to providing insights on the specifics of energy consumption and searching for effective tools to enhance energy efficiency of University buildings. To respond to challenges associated with tropical or desert climate, the scientists suggest the methods aimed primarily at cooling and ventilation (Jomoah *et al.*, 2013; Jomoah *et al.*, 2013; Mahlia *et al.*, 2011; Escobedo *et al.*, 2014; Tang *et al.*, 2012; Saidur *et al.*, 2011; Goudarzi *et al.*, 2017; Fadzil *et al.*, 2012, Abidin *et al.*, 2017; Anders, 2012). The second group of studies seeks to find pathways towards energy consumption optimization related to the problems of heating and heat recovery in University buildings (Zhou *et al.*, 2013; Tymkow *et al.*, 2008; Ma *et al.*, 2012; Gong, 2012; Tan *et al.*, 2016; Ruparathna *et al.*, 2016). The third group of research includes scientific endeavours to offer an integrated approach to the issues of University energy efficiency management: in particular, the implementation of thermal modernization projects for existing buildings, the construction of passive house buildings (Kolokotsa *et al.*, 2016; Eriksson *et al.*, 2015; Appleby, 2013; Hassan *et al.*, 2014; 2011, Wu *et al.*, 2016, Malkin et al., 2016), etc. It should be noted that Ukraine's experience in implementing energy efficiency projects within University campuses is multifaceted and multi-dimensional - from large-scale government programmes to individual projects. Among the most effective ones are the following: the development of a comprehensive scientific and technical program of "Energy efficiency and energy saving" at Kyiv National University of Technologies and Design (Gryshchenko *et al.*, 2013); the creation of energy management and power supply system on the basis of a virtual station using solar, wind and biomass at National Technical University of Ukraine "Kyiv Polytechnic Institute" (Fomichov *et al.*, 2013); building a training and demonstration centre for alternative energy with an operating rooftop generator, two solar panels on the facade of the main building at Kharkiv National University of V.N. Karazin; the creation of an energy management system at Odessa National Polytechnic University (Fomichov *et al.*, 2013); the implementation of an autonomous heating system for selected buildings at Kherson National Technical University (Denysiuk *et al.*, 2013); thermal modernization of individual buildings, installation of electric storage heaters at Lviv Polytechnic National University (Lysak, 2016). However, in most cases, scientists believe that an integrated energy management system should be based on international energy efficiency standards. (Lyons *et* al., 2013). Thus, the research by Alshuwaikhat *et al.*, 2008 on structural analysis of energy consumption and energy conservation in the area of education, and green building opportunities offers a modern energy efficiency policy for Universities built on an integrated energy management system. (Chan 2014) discusses further various technical aspects of improving energy efficiency and moving towards a new innovative development level. Some researchers argue that the implementation of an effective energy management system should rely on providing monitoring of energy consumption and energy certification of University buildings (Lu *et al.*, 2010; Renew, 2011). Others suggest using economic and mathematical methods, in particular a multivariate analysis for building energy profiles and conducting energy audits (Jun *et al.*, 2016; Williams *et al.*, 2012; Kaplun *et al.*, 2016, Vourdoubas et al., 2019; Chun 2019) or employing instruments of benchmarking to explore universities' energy and resource efficiency best practices (Ganushchak–Yefimenko *et al.*, 2017). However, there is a lack of coherence between existing theoretical and practical approaches in identifying the most appropriate energy management systems, finding pathways to implement international energy efficiency standards to shape a University energy management framework, ranking the factors that have the greatest impact on the level of energy efficiency within University campuses. In other words, the whole range of issues remains unresolved, debatable, and hence suggests implications for further research. This study has been carried out in Kyiv National University of Technologies and Design in 2018.

MATERIALS AND METHODS

The methodology for this study entails a set of research tools and methods, such as implementation of an integrative approach, multivariate analysis, dendrogram techniques, energy efficiency assessment method; the DGNB system approach of International Classification for Performance Requirements and Performance Categories, and the method of cluster analysis. The integrative approach relies on the International Organization for Standardization, ISO (Satya *et al.*, 2016; Bikshapathi *et al.*, 2011; Syed Fadzil, 2012) and allows to consolidate energy management, energy audit, energy certification and monitoring of the achieved level of energy efficiency (Fig. 1).

The estimation of the achieved level of energy efficiency is carried out by the annual specific energy consumption, using Eq. 1 (Tabunshchykov *et al.*, 2012):

$$q_{st} = \frac{q_{heat} \times G_{st}}{G} + \frac{q_{hw} \times A}{30n}, \quad (1)$$

Where, G_{st} - degree-days of a standard heating period; G - degree-days of the analyzed heating period; A - building floor area, m²; n - staff / inhabitants number; q_{heat} – actual heat consumption per kWh.; q_{hw}

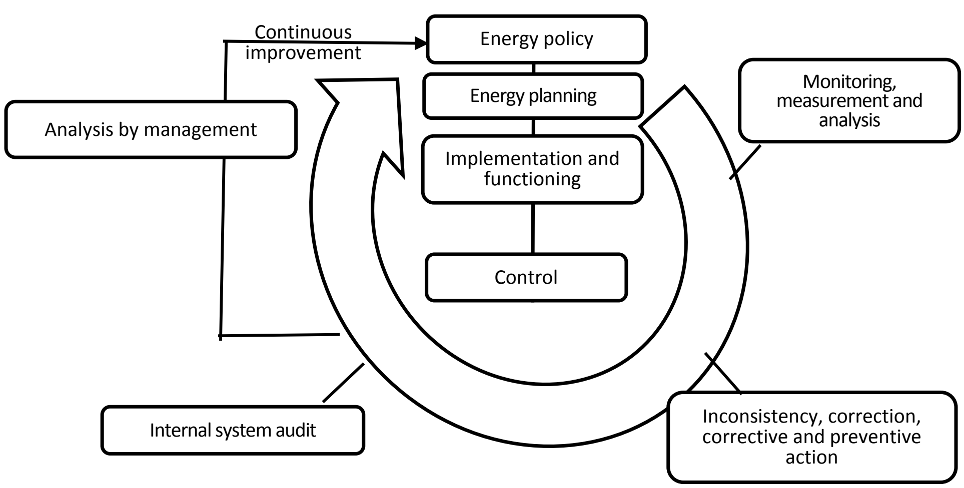


Fig. 1: Use of ISO 50001: 2011 standard for building a University energy management system

- actual hot water consumption kWh/m².

The multivariate analysis method seeks to compare the energy efficiency of selected University buildings by grouping individual factors into incentives and disincentives. The dendrogram toolkit is used to build an energy profile. The DGNB system approach is applied to carry out energy audits, energy certification of buildings and building energy profiles. The key benefits of this method are given in Table 1.

To conduct energy audit, carry out energy certification of buildings and to create the University energy profile, a comparative analysis of the selected international building assessment and certification standards by the level of energy efficiency and sustainable construction principles has been performed. The results reflect the degree of compliance with energy efficiency standards. The following assessment systems have been selected for comparison of the international classification for performance requirements and the construction of performance categories: the LEED assessment standards – Leadership in Energy and Environmental Design (Lützkendorf *et al.,* 2010; Pöyhönen *et al.,* 2019; Zeinal et al., 2012). This method is used mainly in the US; the BREEAM – Building Research Establishment Environmental Assessment Method. This approach is widely implemented in the UK and Europe; the DGNB system – Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB Zertifizierungssystem Neubau Stadtquartiere – the German Green Building Council) was developed in Germany and is adapted and widely applied globally. Within the international DGNB project, there is an easy-to-use building assessment method that includes 16 criteria related to technical solutions, planning and socioeconomic aspects in energy efficiency domain. This method in a short time period enables to get a comprehensive building condition survey. Apparently, the comparison of the LEED, BREEAM and DGNB evaluation criteria at large demonstrate the similarity of methods, however there are certain differences and specifics (Table 1). The key benefit of the DGNB method is its focus on details and a range of technical aspects. Unlike the LEED and BREEAM, the DGNB approach incorporates an economic criterion for cost and profit estimation, while water use performance is not evaluated. The cluster analysis method has been applied to calibrate the university buildings in terms of energy consumption.

Data description

The empirical basis for this study covers the findings from the study of energy auditing of building structural design and the successful energy efficiency action plan performance by Kyiv National Economic University for 2012-2017, the experience of effective of implementation of international ISO 50001: 2011 standards at Kyiv National University of Technologies and Design collected from the Report on the implementation of the topic, 2013t on the implementation of the research on “Rationing of energy costs, as a factor of sustainable development of universities” and the implementation of the complex scientific and technical program “Energy efficiency and energy

Table 1: Criteria for assessing a building by LEED, BREEAM and DGNB standards

The LEED standard criteria	The BREEAM standard criteria	The DGNB standard criteria
Sustainable use of the territory	Use of the territory Transport	Territory planning
Efficient use of water resources	Water	*Not rated:*
Energy and air quality	Energy	Energy consumption Roof insulation Warming of walls Floor insulation The window heat transfer coefficient Air permeability of a building Heating and cooling Use of renewable resources Ventilation
Materials and resources	Materials and wastes Pollution	Green building materials
Indoor climate quality	Health and wellness	Climate of apartment
Innovation and design	Management	Principles of building design related to energy efficiency Quality control
Not rated	Not rated	Total investment Cost and profit estimation

saving” in KNUTD over 2012-2017, as well as statistical data on University facilities assessment for energy efficiency carried out by the Energy Efficiency Center of Kyiv National University of Technologies and Design (Kaplun *et al.*, 2015).

RESULTS AND DISCUSSION

International standards are proved to be a powerful tool for disseminating of new technology and good practice. They contribute to further world markets development and provide effective support in coordinating government policy on energy efficiency and renewable energy at the macro-, meso- and microlevels. Thus, the application of international energy efficiency standards in the area of higher education facilitates smooth implementation of energy efficiency action plans and other energy-saving measures, providing a consistent and clear management efficiency framework, promotes new opportunities to making wider use of best practices, etc. The above approach also helps to justify and select the most appropriate energy efficiency indicators system, the forms of presentation of energy consumption testing results and the use of the best practice of energy efficiency management. Currently, global good practices evidence that very often several international standards are simultaneously used to improve energy efficiency. Among the most commonly applied international standards are: the European Committee for Standardization (CEN), the harmonized EU - EN standard 16001: 2009), along with about 15 country-specific standards like ANSI / MSE 2000: 2008 – for the United States; AS / NZS 3598: 2000 – for Australia and New Zealand; GB / T23331: 2009 – for China; DS / INF 136: 2001 – for Denmark ; IS 393: 2005 – for Ireland; KSA 4000: 2007 – for Korea; SS 627750: 2003 – for Sweden; ANSI 739: 1995 IEEE – for the United Kingdom, etc. Based on best practices in energy efficiency, a new international standard has been developed in 2011 that sets the requirements for creating, implementing, maintaining and improving the ISO 50001: 2011 energy management system. The purpose of this standard is to provide organizations with a systemic approach to achieving energy efficiency and continuous improvement, including energy efficiency, energy security, energy use and consumption. The dynamics of international standards for energy efficiency is as follows: ISO 9001 → ISO 14001: 2004 → OHSAS 180001 → ISO 22000 → ISO 22301 → ISO / IEC 27001 → ISO 28000 → ISO 30000 → ISO 39001 → ISO 5000 → ISO 55001. For some countries, the evolution of energy efficiency standards looks as follows (Fig. 2).

The integrative effect of ISO 55001 is ensured by the social responsibility of ISO 260000, the ISO 31000: 2018 risk management methodology, based on the principles of ISO 9001 - Quality Management System and ISO 14001 - Environmental Management System. The main mission of the ISO 50001: 2018 standard - Energy management systems (ISO 50001, 2018) is a requirement to “... the improvement of energy management and energy efficiency” by giving organizations autonomy over mechanisms to improve their energy efficiency performance. There are no quantitative estimations in this standard; each organization chooses its own pathway to attain the company’s goals. With this structural approach, organizations are more likely to see their financial benefits as rewards. The organization identifies appropriate energy efficiency indicators for monitoring and measuring energy efficiency. The methodology for identifying and reviewing indicators should be regularly analyzed and recorded. The most effective pattern to implement the above international standard is the vector interaction of its separate components: “Plan → Implementation → Verification → Action (Law)”, the integrated use of which allows to constantly improve and provide guidelines to implement successful energy management in the

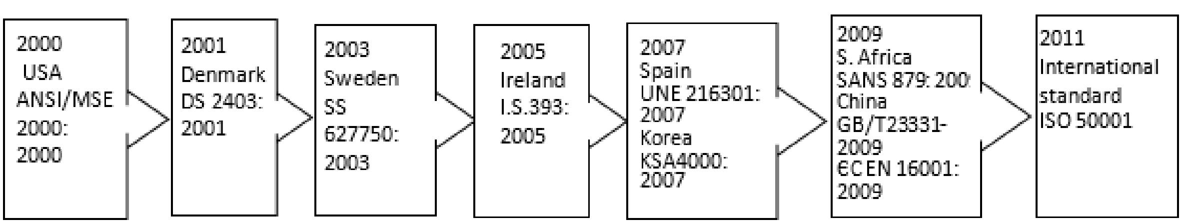


Fig. 2: Evolution of standards for energy management, energy auditing and energy efficiency

daily practice of organizations (Fig. 3).

The "Planning" component is the following sequence of actions: conducting energy analysis, identifying a baseline, a set of energy efficiency indicators, goals and objectives according to the chosen baseline. The design of an "Action Plan" required to achieve the desired performance indicators will help achieve energy efficiency to comply with the organization's energy policies. The "Implementation" component is the consistent implementation of the "Action Plan" in the area of energy management. The Verification component is the implementation of a system for continuous monitoring and measurement of business processes and key characteristics of the organization's activities to gain the desired level of energy efficiency. The "Action (Law)" component is a system of continuous improvement of the level of energy efficiency and energy management framework. The standard also provides the requirements for the installation, implementation, maintenance and improvement of all components of the entire energy management system, enabling organizations to build their tailored systemic approach to ensure further energy efficiency enhancement subject to energy use specifics or the amount of energy consumed. In this study, we shall provide a case from Kyiv National University of Technologies and Design (KNUTD) that describes the methods and suggests possible ways to implement international energy efficiency standards for energy certification and conducting energy audit. At the stage of energy analysis according to ISO 50001: 2018, it is critical to build a primary energy profile of all KNUTD buildings, which will be the starting point for all further actions. It must create the so-called energy baseline for a certain period of time, anticipate all areas of significant energy use and predict its possible effects. This energy baseline will serve a reference point to evaluate and monitor future changes in energy consumption, thus reflecting the energy efficiency. The basic assessment of energy profile covers the following stages: identification of buildings, equipment, processes and personnel working in the area of energy consumption; setting a system of energy efficiency indicators; developing methods to evaluate the impact factors; conducting a scheduled analysis of significant energy use factors; identification and localization of priorities for energy parameters improvement. The Energy Profile of KNUTD buildings was constructed using the energy efficiency assessment method by standard annual consumption according to Eq. 1 and in the form of a dendrogram (Fig. 4).

The application of ISO 50001: 2011 allows to classify the building energy efficiency by annual specific energy consumption. Category A refers to buildings with low energy consumption, category B is for energy efficient buildings, categories C and D are for average and above average energy consumption, category E is for energy-intensive consumption, categories F and G refer to high and ultra-high energy consumption. The classification of energy efficiency is established according to the classification of buildings due to functional purpose. The value of the total specific energy consumption

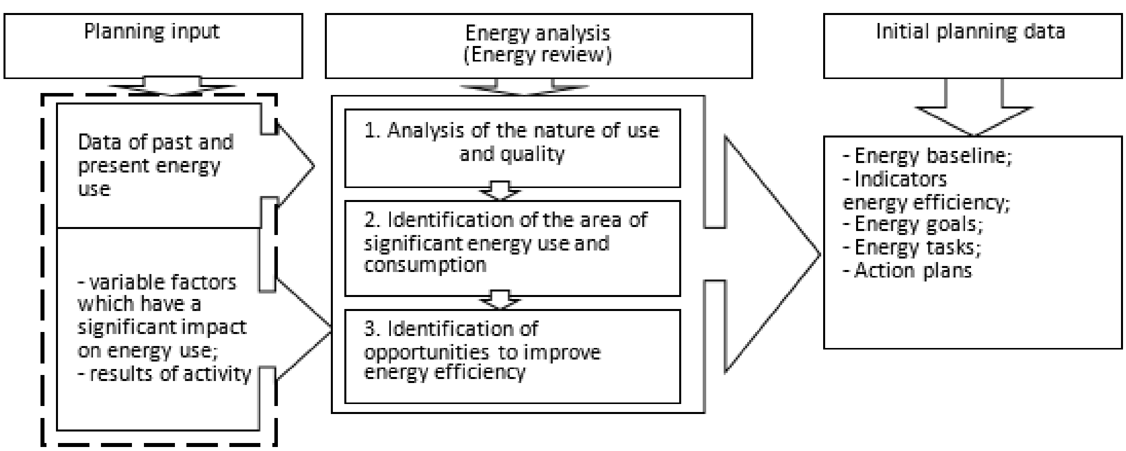


Fig. 3: Conceptual diagram of the energy planning process according to ISO 50001: 2018

for the energy efficiency class of educational buildings is as follows:

A - <[0-17] kW × h/m-3;
B - <[18-30] kW × h/m-3;
C - <[31-33] kW × h/m -3;
D - <[34-42] kW × h/m -3;
E - <[43-50] kW × h/m -3;
F - <[51-58] kW × h/m -3;-3;
G - >[58] kW × h/m -3;3.

According to Fig. 4, category G includes dormitory 4 and educational building 7; to category F belongs dormitory 7; to category E – educational buildings 6, 8, 4, and 3; to category D – dormitories 8 and 6, educational building 5, and dormitory 5; to category C – dormitories 3 and 2, educational buildings 2 and 1. The results from the dendrogram construction demonstrate that KNUTD buildings fail to meet the requirements for energy efficiency, thus triggering a need to develop an action plan to increase its level. For the minimization of energy consumption in buildings it is necessary to:

1) Choose those rooms, which air-conditioned (heating) volume is smaller;

2) Due to the fact that the largest number of audiences are in the educational building No 4 (the most energy-consuming), it is proposed to install rooftop solar power plants on the roof;

3) It is proposed to install recuperates - surface type heat exchangers for energy-consuming dormitory buildings;

4) Make external and internal insulation of walls, premises

To attain the objective of building an effective action plan to enhance the KNUTD campus buildings energy efficiency, we shall employ the method of multivariate analysis. This approach enables to group the selected impact factors into incentives and disincentives by the level of energy efficiency and, accordingly, to design a plan of relevant actions. The results of the multivariate analysis are presented in Fig. 5.

The results of multivariate analysis are interpreted as follows: those indicators that are included in a certain factor are highlighted in red, their absolute value reflects the magnitude of the impact, the sign before the indicator reflects the direction of influence (“+” - stimulating effect on the level of energy consumption, “-” – acts as a disincentive). The total absolute magnitude of the effect on the dependent variable of each of the obtained factors (indicator Prp.Totl) displays the specific gravity - the degree of influence; “Expl.Var” indicator is its factor

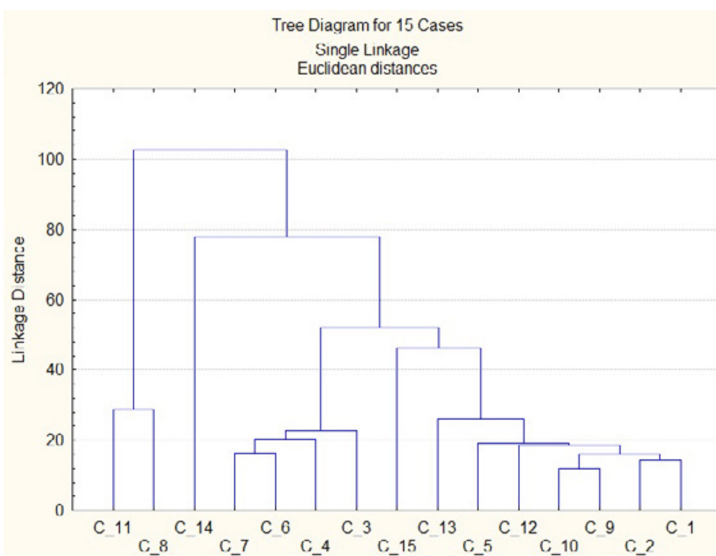


Fig. 4: Dendrogram of building energy efficiency calibration by annual specific energy consumption

Legend: C_1 - educational building 1; C_2 - educational building 2; C_3 - educational building 3; C_4 - educational building 4; C_5 - educational building 5; C_6 - educational building 8; C_7 – educational building 6; C_8 – educational building 7; C_9 - dormitory 2; C_10 - dormitory 3; C_11 – dormitory 4; C_12 - dormitory 5; C_13 - dormitory 6; C_14 - dormitory 7; C_15 - dormitory 8.

Variable	Factor Loadings (Unrotated) (13) Extraction: Principal components (Marked loadings are > ,700000) Factor 1	Factor 2
Var1	0,97873	0,088905
Var2	-0,68224	-0,643662
Var3	0,91134	0,355655
Var4	-0,58761	0,794255
Var5	0,85777	0,327940
Var6	0,81136	0,350298
Var7	0,93955	0,009116
Var8	0,93621	0,310466
Var9	0,78030	-0,462613
Var10	0,86047	-0,307206
Var11	0,82906	0,145650
Var12	-0,62885	0,542723
Var13	-0,94554	0,226378
Var14	-0,93143	-0,305478
Var15	0,92088	0,175814
Var16	0,90114	-0,330896
Expl.Var	11,60624	2,415378
Prp.Totl	0,72539	0,150961

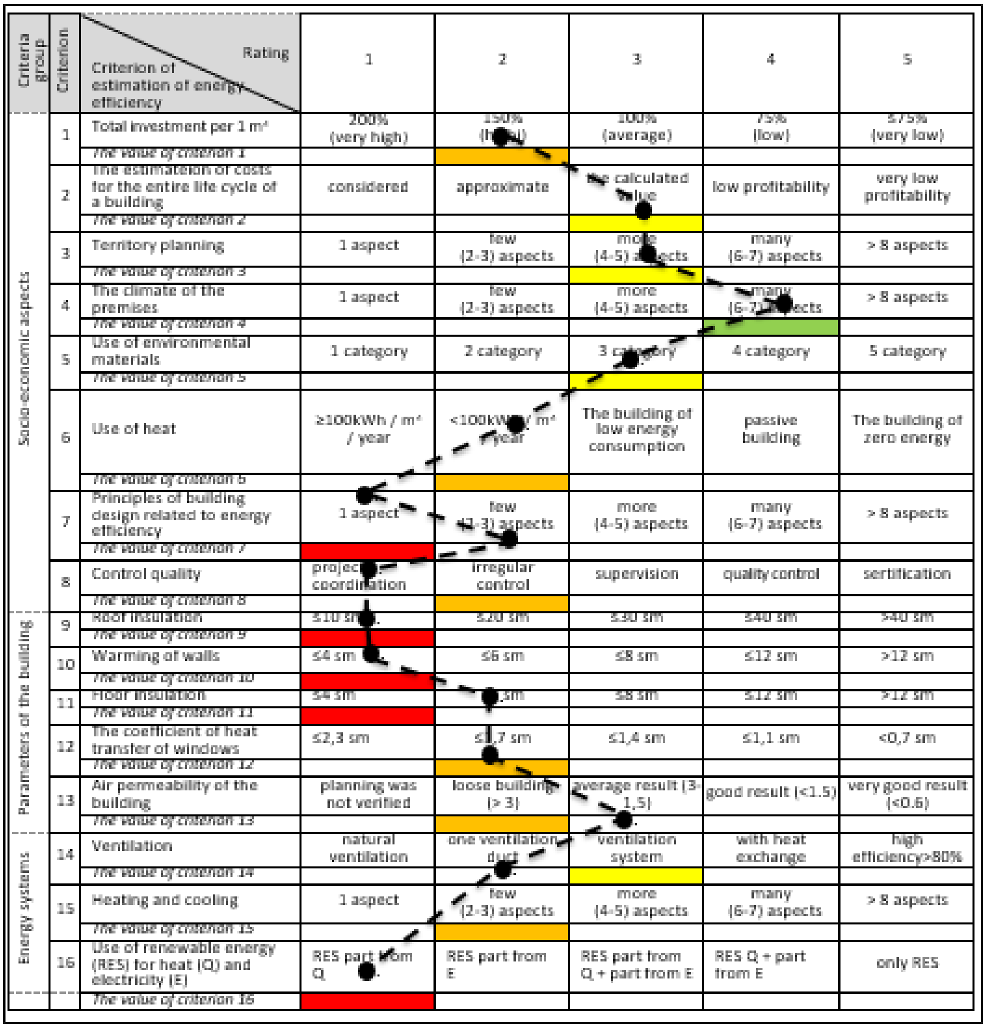
Fig. 5: Results of multivariate analysis to estimate energy efficiency of KNUTD buildings (Listing of STATISTICA10 program)

Legend: Var1 - total investment per 1 m²; Var2 - cost estimate for the entire building life cycle; Var3 - territory planning; Var4 - use of renewable energy sources for heating and electricity production; Var5 – indoor climate maintenance; Var6 - use of green building materials; Var7 - use of heat energy; Var8 – use of energy efficient building design principles; Var9 - quality control; Var10 - roof insulation; Var11 - wall insulation; Var12 - floor insulation; Var13 – window heat transfer coefficient; Var14 - air permeability of buildings; Var15 - ventilation; Var16 - heating and cooling.

load. It is argued that disincentives reduce energy efficiency level by 25% (Pallant, 2005). The results of the analysis evidence that the dependent variable (the actual level of energy efficiency) is explained by 2 factors, which includes 14 out of 16 indicators under study. Hence, let us consider the functional content and the degree of influence of each of the two factors. The first factor entails the indicators which reflect the actual state of energy efficiency actions implementation and accounts for 72.539% of the variance. The second factor refers to a single indicator: the use of renewable energy for heating and electricity production. The effect from the latter accounts for 15.0961% of the variance. 12 out of 14 indicators have a stimulating (increasing) impact on energy efficiency. Indicators: Var13 – window heat transfer coefficient; Var14 - building air permeability – acts as a disincentive, having a decreasing effect on energy efficiency. The integral indicator of energy efficiency is as Eq. 2.

$$I_{energy\ efficiency} = 1/11{,}60624x\ (0{,}97873Var1 + 0{,}91134Var3 + 0{,}85777Var5 + 0{,}81136Var6 + 0{,}93955Var7 + 0{,}93621Var8 + 0{,}78030Var9 + 0{,}86047Var10 + 0{,}82906Var11 - 0{,}94554Var13 - 0{,}93143Var14 + 0{,}92088Var15 + 0{,}90114Var16) + 2{,}415378x\ (0{,}794255Var4) \quad (2)$$

The calculated integral indicator of energy efficiency is universal, since in the process of its calculation the energy efficiency class of buildings was considered. It was determined by the indicator of total specific energy consumption for heating, cooling and hot water supply. Thus, this approach can be implemented for both educational buildings and dormitories. The KNUTD building energy profiles were constructed using the DGNB method. A fragment of the energy profiles of one of the buildings is shown



Criteria group	Criterion	Criterion of estimation of energy efficiency / Rating	1	2	3	4	5
Socio-economic aspects	1	Total investment per 1 m²	200% (very high)	150% (high)	100% (average)	75% (low)	≤75% (very low)
		The value of criterion 1					
	2	The estimateion of costs for the entire life cycle of a building	considered	approximate	the calculated value	low profitability	very low profitability
		The value of criterion 2					
	3	Territory planning	1 aspect	few (2-3) aspects	more (4-5) aspects	many (6-7) aspects	> 8 aspects
		The value of criterion 3					
	4	The climate of the premises	1 aspect	few (2-3) aspects	more (4-5) aspects	many (6-7) aspects	> 8 aspects
		The value of criterion 4					
	5	Use of environmental materials	1 category	2 category	3 category	4 category	5 category
		The value of criterion 5					
	6	Use of heat	≥100kWh / m² / year	<100kWh / m² / year	The building of low energy consumption	passive building	The building of zero energy
		The value of criterion 6					
	7	Principles of building design related to energy efficiency	1 aspect	few (2-3) aspects	more (4-5) aspects	many (6-7) aspects	> 8 aspects
		The value of criterion 7					
	8	Control quality	project coordination	irregular control	supervision	quality control	sertification
		The value of criterion 8					
Parameters of the building	9	Roof insulation	≤10 sm	≤20 sm	≤30 sm	≤40 sm	>40 sm
		The value of criterion 9					
	10	Warming of walls	≤4 sm	≤6 sm	≤8 sm	≤12 sm	>12 sm
		The value of criterion 10					
	11	Floor insulation	≤4 sm	[illegible] sm	≤8 sm	≤12 sm	>12 sm
		The value of criterion 11					
	12	The coefficient of heat transfer of windows	≤2,3 sm	≤1,7 sm	≤1,4 sm	≤1,1 sm	<0,7 sm
		The value of criterion 12					
	13	Air permeability of the building	planning was not verified	loose building (> 3)	average result (3-1,5)	good result (<1.5)	very good result (<0.6)
		The value of criterion 13					
Energy systems	14	Ventilation	natural ventilation	one ventilation duct	ventilation system	with heat exchange	high efficiency>80%
		The value of criterion 14					
	15	Heating and cooling	1 aspect	few (2-3) aspects	more (4-5) aspects	many (6-7) aspects	> 8 aspects
		The value of criterion 15					
	16	Use of renewable energy (RES) for heat (Q) and electricity (E)	RES part from Q	RES part from E	RES part from Q + part from E	RES Q + part from E	only RES
		The value of criterion 16					

Fig. 6: Energy profile for KNUTD buildings based on DGNB energy audit (Fragment: assessment of educational building 4)

in Fig. 6. The 16 evaluation criteria for the DGNB method are conventionally divided into 3 groups. The assessment is performed according to each criterion's parameters - percentages, credit points or scores on a five-point scale. With reference to the results from 1 to 5, the row in the table is colored from green to red. A score of 5 indicates the best result and the given row is colored green. Energy audit conducted by means of DGNB method has enabled to eliminate 17% of the G category classrooms (extra energy intensive) from the University heating facilities. The proposed approach provides an opportunity to improve the methodology of energy efficiency determination of buildings used in Ukraine. Unlike the existing methodology (Zubko, 2018; Ascione *et al.,* 2019), the new approach, besides the features of determining the energy efficiency of buildings, the rooms of which have different functional purposes and defining the energy efficiency class, allows us to build the energy profiles of buildings, which become the basis of the development of increasing energy efficiency indicators' strategy as the most important component of Ukrainian universities' energy autonomy.

Built on the results of expert evaluations

The energy profile parameters of the KNUTD buildings (Fig. 6) have been assessed as follows: total investment performance is estimated by the volume

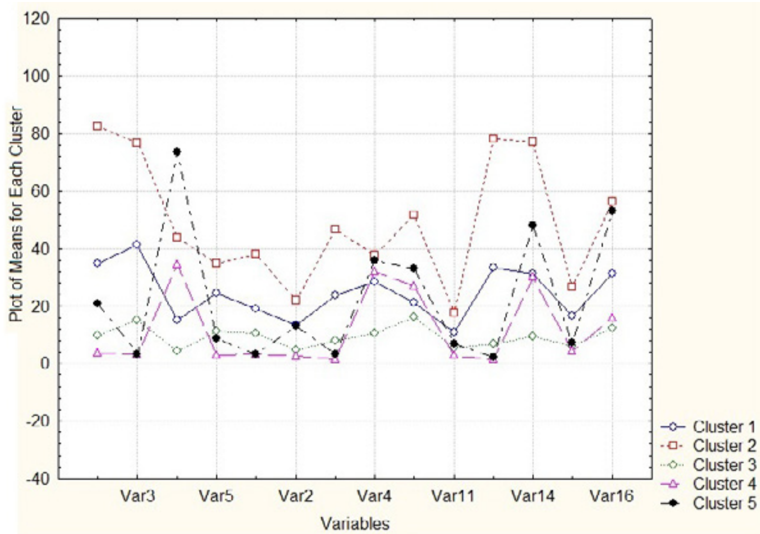


Fig. 7: Results of cluster analysis of energy efficiency of KNUTD buildings (Listing of STATISTICA10 program)

of investments compared to the national average (100%); the overall cost calculation – subject to the invested assets or the effects obtained over the entire life cycle of the building. The same approach is used for energy consumption estimation. The best results meet the standards of passive house or zero energy consumption. The quality control assessment is carried out depending on the specified degree of quality control during the building construction. A high rating can be obtained if a building quality control has been carried out or planned, but the highest score is given if, in addition to the building quality control, energy certification has been performed by an independent expert company. Building parameters are characterized by numerical values. The insulation of the roof, walls and the floor is evaluated by the thickness of the insulation material in centimeters. Thermal transmittance of windows is characterized by a heat transfer coefficient. The building's air permeability is determined by the degree of compaction. To conduct the energy systems assessment, the ventilation system and its energy efficiency, along with heating and cooling systems, as well as the use of renewable energy for heating and electricity production are analyzed. The building assessment results, displayed in the table with green and red rows, reflects its overall condition from different perspectives and represents the basic energy profile of the building under study. The cluster analysis method was used to classify energy profiles by the level of energy consumption and energy efficiency of University buildings. The calibration method of cluster analysis of 15 University buildings by 16 performance indicators identified 5 clusters in terms of energy consumption and energy efficiency (Fig. 7).

The data in Fig. 7 confirm that 68% of the University buildings belong to a 5th class out of 7 energy consumption and energy efficiency categories. Thus, according to the cluster analysis results (Fig. 7), buildings of cluster 2 belong to category G - extra energy intensive; buildings of cluster 5 belong to category F - very energy intensive; buildings of cluster 1 belong to category E - energy intensive; buildings of Cluster 4 refer to category D - above average energy consumption; buildings of Cluster 3 belong to category C - with average energy consumption. The findings revealed no energy efficient and low energy buildings that can be referred to categories A and B. Thus, the application of the instruments of cluster analysis has provided for an unambiguous and accurate estimation of energy consumption and energy efficiency achieved in the University buildings under study. The comparison of the two methods of energy efficiency analysis: constructing a dendrogram for calibrating the level of buildings energy efficiency by annual specific energy consumption and conducting the cluster analysis has proved that both methods complement each other effectively. However, carrying out the multivariate and cluster analyses enabled to identify the most influential factors affecting energy consumption as well as to design an action plan to enhance the University energy performance. The development and implementation of an action plan on energy efficiency contributed to enhancing the University energy efficiency by 13%. The receiving of ISO 9000 certificate had enabled the development of a roadmap for the creation of a comprehensive university energy efficiency management system, which saved 13%. The most effective factors were: 1) benchmarking the most effective energy efficiency programs of Ukrainian universities and applying their best practices; 2) use of thermal imagers and temperature sensors to find places with high heat losses.

CONCLUSION

This study provides an in-depth analysis on the feasibility of implementing the international energy efficiency standards for conducting energy certification and energy auditing of universities, using the Case study from Kyiv National University of Technologies and Design. It has been proven that the implementation of these standards must become part of the University energy management system that will promote better energy efficiency performance. This study offers for implementation a framework for marking the buildings subject to their energy efficiency classes by calculating the annual specific energy consumption indicators. Energy profiles of the investigated buildings have been constructed using the DGNB method, their visualization is performed using the dendrogram toolkit. To conduct energy audit, the application of the multivariate analysis method is suggested which allows to classify individual factors of energy consumption into incentives and disincentives with reference to energy efficiency. Further classification of energy profiles by energy consumption and energy efficiency of buildings was carried out by means of cluster analysis. For the purpose of cluster analysis, only those indicators were used, which according to the results of the multivariate analysis were identified as having an impact on energy consumption and energy efficiency of buildings. The results from cluster analysis have verified that all KNTUD buildings in terms of energy consumption and energy efficiency belong to five categories of the low energy efficiency level: G - extra energy intensive; F – highly energy intensive; E – energy intensive; D – with above average energy consumption; C – with average energy consumption. The findings revealed no energy efficient and low energy buildings belonging to categories A and B. This challenges further endeavours on designing a strategy to enhance energy performance as a critical component of the energy autonomy of Ukrainian universities. The implementation of energy-saving and energy-efficiency action plan will enhance the University capacity to reasonably implement international energy efficiency standards.

ACKNOWLEDGEMENT

The authors are grateful to the training center “Energy Efficiency Center” staff members and to the Director of the Project Office of Kyiv National University of Technologies and Design Oleh Shevchenko for their assistance in organizing and conducting fieldwork.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
ANSI 739:1995 IEEE	Recommended practice for energy management in industrial and commercial facilities
ANSI/MSE 2000:2008	American National Standards Institute / A Management System for Energy
AS/NZS 3598	Australian/New Zealand Standard Energy audits
BREEAM	Building Research Establishment Environmental Assessment Method
CEN	European Committee for Standardization
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German society of sustainable building)
DS/INF 136:2001	Energy. Management - Guidance on Energy Management.
E	*Electricity*

EIB	European Investment Bank
EN	European National
EU	European Union
Expl. Var	*Explanatory Variable*
Fig.	Figures
GB/ T23331:2009	Chinese Guides for energy management in industrial enterprise
IS 393:2005	Energy Management Systems- Specification with Guidance for Use
ISO 260000	Guidance on social responsibility
ISO 31000:2018	*Risk management - Guidelines*
ISO 50001:2018	Energy management systems
ISO 9001	*Quality management*
ISO/CD 50001	Energy Management Systems - Requirements and Guidelines for Use
KNUTD	Kyiv National University of Technology and Design
KSA 4000:2007	Energy Management Systems- Specification with Guidance for Use
kWh/m²	Kilowatt-hour per square meter
LEED	Leadership in Energy and Environmental Design
m²	Square meter
Prp.Totl	Percentage of The Total Variance Explained
Q	*Heat Energy*
RES	*Renewable Energy Sources*
SANS 879: 2009	Energy Management – Specifications. South African Bureau of Standards
SS 627750:2003	Energy Management Systems- Specification
UNE 216301: 2007	Energy management system. Requirements

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HOW TO CITE THIS ARTICLE

Shcherbak, V.; Ganushchak-Yefimenko, L.; Nifatova, O.; Dudko, P.; Savchuk, N.; Solonenchuk, I., (2019). Application of international energy efficiency standards for energy auditing in a University buildings. Global J. Environ. Sci. Manage., 5(4): 501-514.

DOI: 10.22034/gjesm.2019.04.09

url: https://www.gjesm.net/article_36421.html