УДК 615.47-681.5.08 **DOI: 10.30857/2786-5398.2021.5.4**

Ivan M. Gryshchenko, Liudmyla M. Hanushchak-Yefimenko, Valeriia G. Scherbak, Oleksii Yu. Volianyk
Kyiv National University of Technologies and Design, Ukraine

MATHEMATICAL MODELING OF INCREASING ENERGY EFFICIENCY OF THE UNIVERSITY IN THE ENERGY HUB KNOWLEDGE SYSTEM

This study attempts to address the issues of enhancing energy efficiency using mathematical modeling methods. The research findings assert that energy saving is a new challenging task of the 21st century, since thermal and electric power consumption is essential to human life and building a favourable living environment. It is observed that boosting the competitiveness, financial stability, energy and environmental security of Ukraine's economy, as well as improving the living standards and the life quality seem hardly possible without realizing the energy saving potential and increasing energy efficiency through modernization, technological advancements and the transition towards rational and environmentally responsible utilization of energy resources. It is argued that by resolving the above objectives, Ukraine might strengthen its positions among developed economies. The following methods were used to carry out mathematical modeling to enhance the university energy efficiency in the frameworks of the energy knowledge hub: neural network technologies, mean absolute and relative error, mean absolute deviation; statistical comparison of the forecast accuracy based on the mean absolute error, as well as time series forecasting. A model to boost the University energy efficiency has been developed within the knowledge energy hub by implementing neural network patterns based on the experimental data from the Kyiv National University of Technologies and Design for the heating period 2020–2021. In particular, to optimize the operating modes of automatic power supply control for University Building 4, mathematical models with a complex algorithm structure have been employed (offering the increased resource intensity of such tasks). It is argued that making a decision on the feasibility of using an energy hub for University buildings and selecting appropriate equipment should be accomplished with due regard to the structure and the capacity of energy consumers, their types, demands for quality and reliability of electric power supply, their compliance with operating and safety standards, as well as taking into account the results of climate, wind monitoring and monitoring of solar activity. The conclusions resume that to assure the energy quality and the system sustainability, it is considered important to resolve a range of issues related to inconsistency in generation and supply of renewable energy from power plants, ensuring reliability and quality of energy supply through the use of energy storage (batteries) in particular, etc.).

Keywords: *Energy Hub; energy efficiency; university; neural networks.*

Іван М. Грищенко, Людмила М. Ганущак-Єфіменко, Валерія Г. Щербак, Олексій Ю. Воляник
Київський національний університет технологій та дизайну, Україна

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ УНІВЕРСИТЕТУ В СИСТЕМІ ЕНЕРГОХАБА ЗНАНЬ

У цьому дослідженні здійснюється спроба вирішити проблеми підвищення енергоефективності з використанням методів математичного моделювання. Наголошується, що енергоресурсозбереження є одним із важливих завдань XXI століття, оскільки споживання теплової та електричної енергії є необхідною умовою життєдіяльності людини та створення сприятливих умов її побуту. Зазначено, що підвищення конкурентоспроможності, фінансової стійкості, енергетичної та екологічної безпеки української економіки, а також зростання рівня та якості життя населення є *неможливим без реалізації потенціалу енергозбереження та підвищення енергетичної ефективності на основі модернізації, технологічного розвитку та переходу до раціонального та екологічно відповідального використання енергетичних ресурсів. Доведено, що від результатів вирішення цієї проблеми залежить і місце України серед економічно розвинених країн. Для здійснення математичного моделювання підвищення енергоефективності університету в системі енергохаба знань використано такі методи: нейромережеві технології, середню абсолютну та відносну помилку, середнє абсолютне відхилення; статистичне порівняння якості прогнозів на основі середньої абсолютної помилки, прогноз при аналізі часових рядів. Розроблено модель підвищення енергоефективності університету в системі енергохаба знань на основі застосування нейромережевих моделей, навчених на основі використання експериментальних даних Київського національного університету технологій та дизайну за опалювальний період 2020–2021 років. Зокрема, з метою оптимізації режимів експлуатації установок автоматичного керування енергопостачанням корпусу №4 університету застосовано математичні моделі, що мають складну структуру алгоритму (ресурсоємність таких завдань збільшено. Визначено, що прийняття рішення щодо доцільності використання енергохаба для будівель університету та підбір обладнання мають здійснюватися залежно від складу та потужності енергоспоживачів, їх категорійності, вимог до якості та надійності електропостачання, їх відповідності умовам експлуатації та нормам безпеки, а також з урахуванням результатів кліматичного, вітромоніторингу та моніторингу сонячної активності. У висновках резюмується, що для забезпечення якості отриманої енергії та стійкості системи вбачається за доцільне вирішення комплексу завдань, пов'язаних із нерівномірністю вироблення та надходження відновлюваної енергії від енергоустановок, забезпеченням надійності та якості енергопостачання, в тому числі через використання накопичувачів електричної енергії (акумуляторних батарей тощо).*

Ключові слова: *енергохаб; енергоефективність; університет; нейромережі.*

Иван М. Грищенко, Людмила М. Ганущак-Ефименко,
Валерия Г. Щербак, Алексей Ю. Воляник
Киевский национальный университет технологий и дизайна, Украина

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПОВЫШЕНИЯ ЭНЕРГОЭФФЕКТИВНОСТИ УНИВЕРСИТЕТА В СИСТЕМЕ ЭНЕРГОХАБА ЗНАНИЙ

В данном исследовании предпринимается попытка решить проблемы повышения энергоэффективности с использованием методов математического моделирования. Отмечается, что энергоресурсосбережение является одной из важных задач XXI века, поскольку потребление тепловой и электрической энергии является необходимым условием жизнедеятельности человека и создание благоприятных условий его быта. Отмечено, что повышение конкурентоспособности, финансовой устойчивости, энергетической и экологической безопасности украинской экономики, а также рост уровня и качества жизни населения невозможны без реализации потенциала энергосбережения и повышения энергетической эффективности на основе модернизации, технологического развития и перехода к рациональному и экологически ответственному использованию энергетических ресурсов. Доказано, что от результатов решения этой проблемы зависит место Украины среди экономически развитых стран. Для осуществления математического моделирования повышения энергоэффективности университета в системе энергохаба знаний использованы следующие методы: нейросетевые технологии, средняя абсолютная и относительная ошибка, среднее абсолютное отклонение; статистическое сравнение качества прогнозов на *основе средней абсолютной ошибки; прогноз при осуществлении анализа временных рядов. Разработана модель повышения энергоэффективности университета в системе энергохаба знаний на основе применения нейросетевых моделей, обученных на основе использования экспериментальных данных Киевского национального университета технологий и дизайна за отопительный период 2020–2021 годов. В частности, с целью оптимизации режимов эксплуатации установок автоматического управления энергоснабжением корпуса №4 университета применены математические модели, имеющие сложную структуру алгоритма (ресурсоёмкость таких задач увеличена). Определено, что принятие решения о целесообразности использования энергохаба для зданий университета и подбор оборудования должны осуществляться в зависимости от состава и мощности энергопотребителей, их категорийности, требований к качеству и надёжности электроснабжения, их соответствия условиям эксплуатации и нормам безопасности, а также с учётом результатов климатического, ветромониторинга и мониторинга солнечной активности. В выводах резюмируется, что для обеспечения качества полученной энергии и устойчивости системы представляется целесообразным решение комплекса задач, связанных с неравномерностью выработки и поступления возобновляемой энергии от энергоустановок, обеспечением надёжности и качества энергоснабжения, в том числе благодаря использованию накопителей электрической энергии (аккумуляторных батарей тому подобное).*

Ключевые слова: *энергохаб; энергоэффективность; университет; нейросети.*

Introduction. Improving energy efficiency and energy conservation are among the most important areas of economic modernization (J. Di Stefano) [1]. Improving energy efficiency both at the stage of design in decision-making, from the point of view of, I. Gryshchenko, V. Shcherbak, O. Shevchenko, and at the stage of equipment operation is an urgent task [2]. The quality of decisions made at the stage of design of heat engineering installations of higher educational institutions depends on the tools that are used in this area [3]. During the operation of thermal process and power plants (J. Liu, Q. Yao, Y. Hu), there are problems associated with improving the energy efficiency of higher education institutions [4]. For these purposes (K. Shaposhnikova, V. Shimov) mathematical modeling is actively used [5]. Mathematical models of processes are constructed (V. Shcherbak, L. Ganushchak-Yefimenko, O. Nifatova, P. Dudko, N. Savchuk, I. Solonenchuk) based on the solution of systems of differential and sometimes integrodifferential equations. Numerical methods are mainly used to solve such systems [6].

When operating heat and power plants and systems to solve the problems of improving their energy efficiency is often important speed of information processing. The application of neural network models (E. Vieira dos Santos, B. Zampieri, S. da Costa, E. de Lima), trained using experimental data or simulation results obtained on mathematical models, allows to solve these problems [7].

Mathematical models having a complex algorithm structure (the resource intensity of such problems is increased) are difficult to use for optimization of plant operation modes. The optimization problem becomes more complicated (X. Xing, Y. Yan, H. Zhang, Y. Long, Y. Wang, Y. Liang) if the plants are combined in a thermal process system [8]. In this case optimization has multilevel character. As the first level in such a system is considered optimization of operation mode of higher educational institution (L. Ganushchak-Efimenko, V. Shcherbak, O. Nifatova), and as the second level – optimization of plant system operation mode [9]. For a group of installations energy efficiency increases due to the reduction of energy consumption during the transition from one mode of operation to another. In this case the choice of installation for processing of regulation of energy consumption of higher educational institution is optimized. With this formulation of the question the resource-intensiveness of the problem increases many times. To make a decision taking into account two or more levels of optimization (J. Nayak, M. Mishra, B. Naik, H. Swapnarekha, K. Cengiz, V. Shanmuganathan) neural network models can be effectively used [10].

Recently, multiphysics numerical software packages such as Ansys, FlowVision, Phoenics [7] have been increasingly used for modeling thermal engineering and power plants. For mathematical models of heat-engineering and power plants built with the use of these packages, solving optimization problems aimed at improving energy efficiency causes a number of difficulties.

The purpose of the study is to propose a methodology for mathematical modeling of energy efficiency of the university in the system of energy Knowledge Hub. The study was conducted in 2021 on the basis of energy use data of Kyiv National University of Technologies and Design.

Matherials and methods. Nowadays neural network technologies are successfully used for data analysis, so it will be appropriate to compare them with well-developed statistical methods. The most commonly used measure of method accuracy is the mean absolute relative error (MAPE), also known as the mean absolute percentage deviation (MAPD). The error expresses accuracy as a percentage and is determined by equation (1):

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|Z(t)-\hat{Z}(t)|}{Z(t)} \times 100\% \quad (1)$$

where N is the number of function values;

$Z(t)$ is the actual current value of the function:

$\hat{Z}(t)$ is the predicted current value of the function.

The mean absolute error (MAE) is used to compare the quality of forecasts in statistics. The mean absolute error is a common measure of prediction error in the analysis of time series and is determined by equation (2):

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|Z(t) - \hat{Z}(t)\right| \quad (2)$$

In statistics, one way to quantify the difference between predicted and true values is to use the root mean square error (MSE) or the square root of the RMSE, which are determined by equations (3), (4):

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(Z(t) - \hat{Z}(t)\right)^2 \quad (3)$$

$$RMSE = \sqrt{MSE} \quad (4)$$

Results and discussion. Energy saving in the budgetary sphere is of particular importance for higher education institutions, since increasing the efficiency of energy resources use is directly related to the efficient use of budget funds. In cities it is especially important to implement resource saving by budget institutions on the basis of transition from calculated heat consumption to actual heat consumption, as in this case the main beneficiary – the budget of the higher educational institution – is clear. The set of works should include not only implementation of energy saving measures and technologies, but also measures of organizational plan, such as:

- formation of a legal basis for the development of the market of energy services in the budgetary sphere;
- creation of a system for categorizing the energy efficiency level of budgetary organizations;
- definition of regulatory requirements for the minimum level of energy efficiency of public sector facilities that have undergone major repairs;
- introduction of requirements for energy efficiency parameters for energy-consuming products and equipment into the public procurement system;
- energy inspections and certification of public sector facilities.

Energy inspections and certification of public sector facilities are carried out to:

- identifying the energy saving potential;
- definition of the main energy saving measures;
- definition of the public sector facilities, where the energy saving measures shall be implemented first of all;
- setting of normative indicators of energy consumption (limiting energy consumption).

Realization of the energy saving potential in the heating system of higher education institutions is connected with three main directions:

- metering of heat energy for heating needs;
- adjustment of heating systems for an optimal distribution of the heat carrier;
- improving heat protection characteristics of buildings.

The evaluation of the accuracy of neural network modeling in comparison with linear and multiple regression modeling shows the advantage of neural networks in solving energy efficiency problems (table 1).

Table 1

Accuracy results of energy efficiency parameter forecasting in the multipurpose computational complex based on energy Hub University

Criteria for determining the accuracy of methods	MAPE	MAE	MSE	RMSE
Linear regression	16,94	6,887	72,24	8,499
Multiple regression	6,585	2,789	17,91	4,232
Neural network (multilayer perseptron)	3,901	1,621	8,423	2,902

The analysis allowed to formulate the signs, in which the modeling of objects is preferable to conduct with the use of neural network technology.

Energy efficiency of energy Hub University depends on how complex mathematical models, how many factors they take into account, and often descriptions of overly detailed numerical mathematical models become unaffordable at this stage to solve by modern computers.

There is a lack of data for modeled objects when solving energy efficiency problems, or it is not clear how they change within the object under study. In this case it is very difficult to formalize the problem.

When using numerical mathematical models, it takes quite a long time to get a result in many cases. Therefore it is problematic to use them to make a decision on management of energy efficiency system of the university.

Sometimes the problem of saving of energy resources in systems, for example, when there are resource restrictions for decision-making, because of its high resource-intensiveness cannot be solved at all.

It is necessary not only to consider real possibilities of mathematical modeling, but also to compare expenses for modeling with the received effect (with increase of complexity of model the increase of expenses can exceed increase of effect).

Analysis of the stages of neural network models development when performing the presented problems of energy efficiency of the Hub University allows to identify the preferred neural network technology toolbox from the significant variety of neural network modeling technologies (Fig. 1).

From the analysis of the stages of development using neural network technology in solving the problems of improving energy efficiency on the basis of energy Hub University, the following conclusions can be made:

- when selecting the type of the problem most often have to solve the prediction problem;

- in determining the feature space is not limited, if a mathematical program is used as a teacher, and is limited when using experimental data for training; sometimes it is difficult to choose the feature space due to the vagueness of the interaction of features;

- when presenting the expected result of a neural network, most often it can be presented with a certain error; when training a neural network with experimental data, there is a limit to the set of these data;

- in practice, when solving the problems presented, it is best to use the type of neural network built on a multilayer perseptron;

- when selecting data to form a training sample most often the data is limited;

- in the presented cases for practical purposes it is better to use existing neural network programs, rather than develop your own;

- to analyze the results, the data must, at least, be presented in tabular form or visually in the form of graphs.

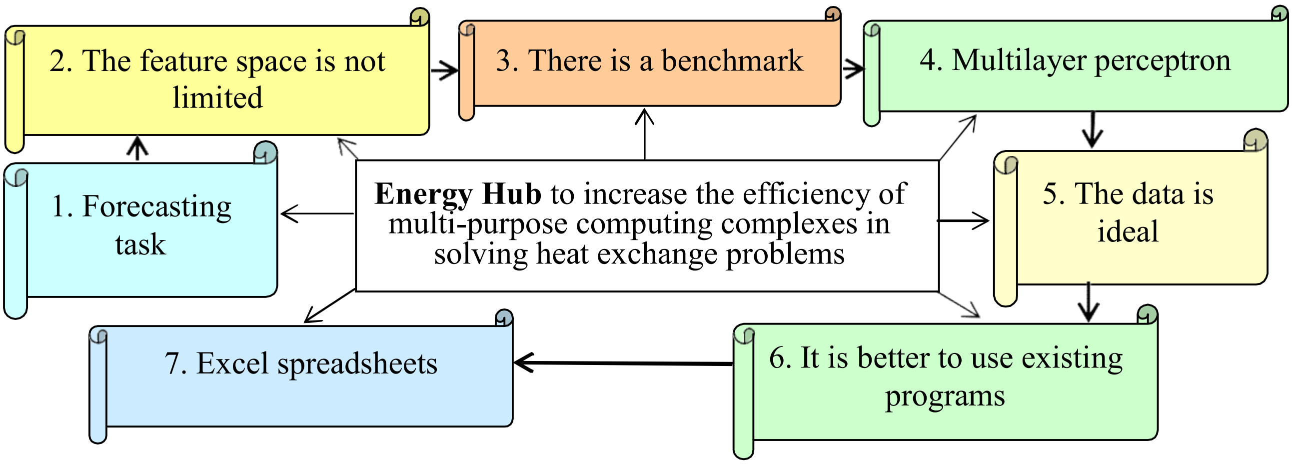

Fig. 1. **An example of an analysis of the stages of development of neural network technology to improve the efficiency of multi-purpose computing complexes in solving the problems of heat exchange based on the energy Hub of the University**

Experimental researches [3] in one of the buildings (fig. 2) showed that installation of heat energy meters allows to save 7% of expenses paid for heat energy. Values of calculated heat consumption by a building show that with implementation of energy-saving measures it is possible to reduce heat consumption by another 12.5%.

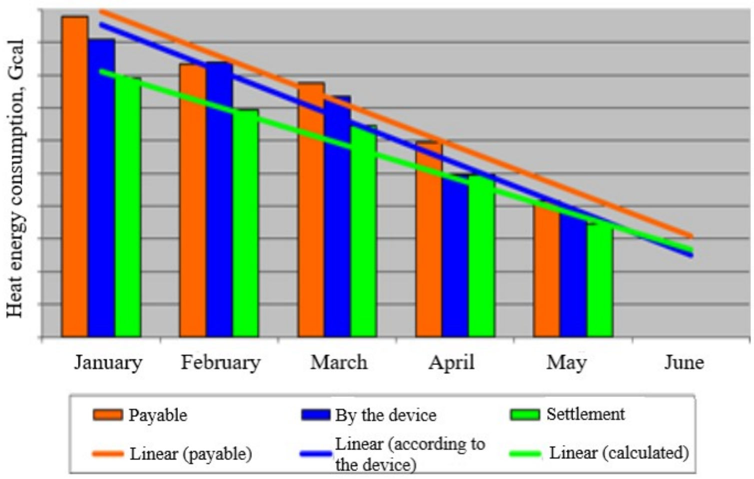

Fig. 2. **Results of experimental studies of energy efficiency of KNUTD building No. 4 (2021)**

It should be noted that a significant proportion of the generalized heat transfer of the building is heat going to heat the air infiltrating through the exterior envelope. This is due to the fact that a significant part of the exterior enclosures are windows, which by their design features have an increased air permeability. The degree of glazing of the facade is 23.5%. The effect of thermal protection of the attic floor by filling in with a layer of keramzite gravel is estimated by the reduction of heat loss by 4.2%. The installation on the facades of the external thermal insulation made of expanded polystyrene slabs with a thickness of 30 mm will reduce heat consumption by another 10%. We recommend insulating the basement walls and the walls of the warm attic from the inside by applying thermal insulation materials, equipping radiators with thermostatic valves, installing heat meters in apartment buildings, automated individual heat points with weather control and calculation of the hydraulic mode of heating networks. Thus, varying by various measures on improvement of heat protection of buildings and constructions and their heating systems, it is possible to provide 40–50% of energy saving.

Installation of automatic regulating valves made it possible to reduce the flow of heat carrier at night and on weekends and holidays. Analysis of data from the operation of control devices during the heating period of 2020–2021 showed that heat energy savings amounted to 10%. Roofs were repaired using modern technologies, double-glazed windows were installed, and old cast-iron radiators were replaced. The efficiency of the entire heat accounting and control system amounted to 40%.

Organizational measures (without costs): reducing the heating period; renting out the premises with tenants paying for utilities, charging the losses in the external heating system of buildings to heat supply organizations; allocating energy costs necessary to perform work under economic contracts; turning off supply ventilation; turning off part of the service buildings at the beginning and end of the heating period. Organizational and technical measures (costly): installation of meters and transition from estimated heat consumption to actual consumption, repair of roofs, installation of double-glazed windows and vestibules, optimization of supply ventilation, replacement of radiators.

Energy saving measures (costly): installation of valves with a daily control cycle; organization of a weekly control cycle (weekdays and weekends), up to complete shutdown of heating systems on weekends in September and May; transition to local electric water heaters. Thermal imaging survey of the heating system of the building, carried out in 2020 during the energy survey [3], showed significant heat losses in the heating system (Fig. 3).

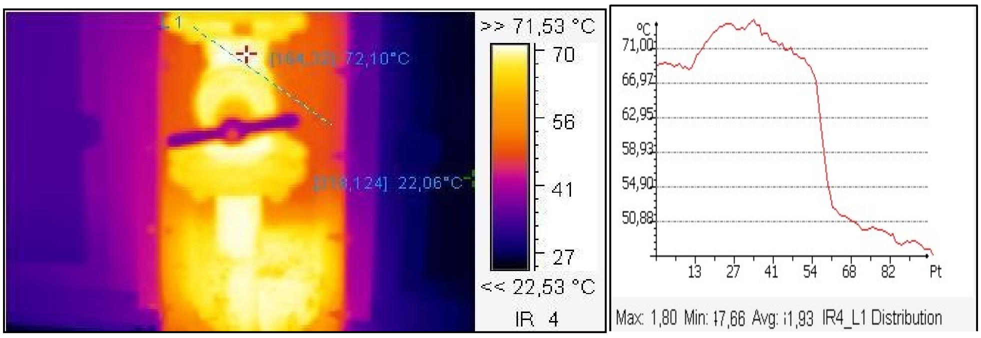

Fig. 3. **Sections of the coolant pipeline and gate valve**

When reconstructing the heating unit of the university building, an automatic system for regulating the heat supply was installed, using sensors not only outside the building, but also at 3-4 points inside. This makes it possible to take into account not only the temperature of the outside air, but also solar radiation, wind power, heat generated by people and equipment.

In the course of the project the following measures are taken (Table 2):

- conducting an energy audit in the university buildings and social facilities;
- improving the energy efficiency of heat sources;
- renovation of heat, power, water and sewage networks;
- a set of works to improve energy efficiency and to carry out the capital repair of academic buildings;
- a set of works to improve energy efficiency in the buildings of the social sphere;
- installation of metering devices with the introduction of data transfer systems.

Table 2

Design efficiency of energy-saving measures

Energy saving measures	Benefit for the end user	Energy savings, %	Payback period, year
Heating units in university buildings	Energy efficiency of the heating system	15–25	3,5
Installation of elevator unit on the pump unit (with heat metering)		10–15	0,5
Arrangement of heat supply unit with automatic regulation		35	1
Replacement of the elevator unit on the pump unit (with heat metering)		15–25	2
Replacement of elevator unit for pumping unit (with heat accounting)		15–25	3
Replacement of the elevator unit under the independent heating scheme with heat exchangers and heating (with heat accounting)		15–25	3,5
Internal heating systems	Reducing heat consumption and improving comfort	10–30	3,5
Heating networks	Reducing costs for the utility	20–40	3
Exterior insulation of residential buildings	utility	50–70	30
Thermal insulation of building envelopes	Reducing heat	до 30	20
External insulation of roofs	consumption and increase comfort	2–5	25
Insulation of district heating pipes	Decrease of heat consumption in heating systems	15–25	3
Institutional developments	Decrease in heat consumption and increase comfort	5–15	4

As recommendations, it was proposed:

- switch to a closed hot water system with the installation of a circulation pump in the scheme;
- to improve thermal insulation with the help of such materials as polyurethane foam, mineral wool Isover and modern thermal paints;
- to carry out an overhaul (reconstruction) of the heating system;
- to carry out a thermal and hydraulic balancing of the system;
- to install thermostatic valves on heating radiators and supply ventilation calorifiers.

Conclusion. Energy-efficiency programs prioritize the implementation of low-cost and fast-payback energy-saving measures. The main goal of the programs is to reduce budget expenditures for power supply to municipal buildings by rationally using all energy resources and increasing their efficiency. The program-targeted method is the most optimal for solving this problem. It allows to solve tasks on the scale of the whole oblast, to use efficiently the financial means allocated for these tasks, to attract investments for realization of energy saving measures, to develop the system of energy service rendering both at the stage of measures introduction and at the stage of maintenance of the introduced equipment.

References

1. Di Stefano, J. (2000). Energy efficiency and the environment: the potential for energy efficient lighting to save energy and reduce carbon dioxide emissions at Melbourne University, Australia. *Energy,* 25(9): 823–839.

2. Gryshchenko, I., Shcherbak, V., Shevchenko, O. (2017). A procedure for optimization of energy saving at higher educational institutions. *East.-Eur. J. Enterp. Technol.,* 6(3/90): 65–75.

3. Kaplun, V., Shcherbak, V. (2016). Multifactor analysis of university buildings' energy efficiency. *Actual Probl. Econ.,* 12(186): 349–359.

4. Liu, J., Yao, Q., Hu, Y. (2019). Model predictive control for load frequency of hybrid power system with wind power and thermal power. *Energy,* 172: 555–565.

5. Shaposhnikova, K., Shimov, V. (2016). ISO 50001-Energy management system. The concept implementation of energy management systems. *Sci. Soc.,* 3(2): 63–68.

6. 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 Journal of Environmental Science and Management*, 5(4): 501–514. doi: 10.22034/GJESM.2019.04.09.

7. Vieira, E., dos Santos, B., Zampieri, N., da Costa, S., de Lima, E. (2020). Application of the Proknow-C methodology in the search for literature about energy management audit based on international standards. In: Thomé, A., Barbastefano, R., Scavarda, L., dos Reis, J., Amorim, M. (eds). Industrial engineering and operations management. IJCIEOM 2020. *Springer Proc. Math. Stat.,* 337: 463–475.

8. Xing, X., Yan, Y., Zhang, H., Long, Y., Wang, Y., Liang, Y. (2019). Optimal design of distributed energy

Література

1. Di Stefano J. Energy efficiency and the environment: the potential for energy efficient lighting to save energy and reduce carbon dioxide emissions at Melbourne University, Australia. *Energy.* 2000. No. 25(9). P. 823–839.

2. Gryshchenko I., Shcherbak V., Shevchenko O. A procedure for optimization of energy saving at higher educational institutions. *East.-Eur. J. Enterp. Technol.* 2017. No. 6(3/90). P. 65–75.

3. Kaplun V., Shcherbak V. Multifactor analysis of university buildings' energy efficiency. *Actual Probl. Econ.* 2016. No. 12(186). P. 349–359.

4. Liu J., Yao Q., Hu Y. Model predictive control for load frequency of hybrid power system with wind power and thermal power. *Energy.* 2019. No.172. P. 555–565.

5. Shaposhnikova K., Shimov V. ISO 50001-Energy management system. The concept implementation of energy management systems. *Sci. Soc.* 2016. No. 3(2). P. 63–68.

6. Shcherbak V., Ganushchak-Yefimenko L., Nifatova O., Dudko P., Savchuk N., Solonenchuk I. Application of international energy efficiency standards for energy auditing in a University buildings. *Global Journal of Environmental Science and Management.* 2019. No. 5(4). P. 501–514. doi: 10.22034/GJESM.2019.04.09.

7. Vieira E., dos Santos B., Zampieri N., da Costa S., de Lima E. Application of the Proknow-C methodology in the search for literature about energy management audit based on international standards. In: Thomé A., Barbastefano R., Scavarda L., dos Reis J., Amorim M. (eds). Industrial engineering and operations management. IJCIEOM 2020. *Springer Proc. Math. Stat.* 2020. No. 337. P. 463–475.

8. Xing X., Yan Y., Zhang H., Long Y., Wang Y., Liang Y. Optimal design of

systems for industrial parks under gas shortage based on augmented ε-constraint method. *J. Cleaner Prod.,* 218: 782–795.

9. Ganushchak-Efimenko, L., Shcherbak, V., Nifatova, O. (2018). Assessing the effects of socially responsible strategic partnerships on building brand equity of integrated business structures in Ukraine. *Oeconomia Copernicana*, 9(4): 715–730.

10. Nayak, J., Mishra, M., Naik, B., Swapnarekha, H., Cengiz, K., Shanmuganathan, V. (2021). An impact study of COVID-19 on six different industries: Automobile, energy and power, agriculture, education, travel and tourism and consumer electronics. *Expert Syst.,* 10.1111/exsy.12677: 1–32.

distributed energy systems for industrial parks under gas shortage based on augmented ε-constraint method. *J. Cleaner Prod.* 2019. No. 218. P. 782–795.

9. Ganushchak-Efimenko L., Shcherbak V., Nifatova O. Assessing the effects of socially responsible strategic partnerships on building brand equity of integrated business structures in Ukraine. *Oeconomia Copernicana.* 2018. No. 9(4). P. 715–730.

10. Nayak J., Mishra M., Naik B., Swapnarekha H., Cengiz K., Shanmuganathan V. An impact study of COVID-19 on six different industries: Automobile, energy and power, agriculture, education, travel and tourism and consumer electronics. *Expert Syst.* 2021. 10.1111/exsy.12677. P. 1–32.