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CASE STUDY

Energy-innovation knowledge common connection point management in preventing outbreak of the Covid-19 pandemicin a University

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ABSTRACT

BACKGROUND AND OBJECTIVES: The new wave of the Covid-19 pandemic has complicated the working conditions of higher education institutions in Ukraine. In this regard, saving energy resources of the university offers an opportunity to get out of the crisis. The purpose of the study is to develop a management system for energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of Covid-19 pandemic.
METHODS: The method of Deutsche Gesellschaft für Nachhaltiges Bauen was used to conduct energy audits, construct energy profiles of university offices. The cluster analysis was used to perform energy certification of university offices according to the indicators of integral energy efficiency potential and the level of annual specific energy consumption. Fuzzy methods made it possible to classify all the buildings into 3 categories (A, B, C) to prioritize their use in the light of Covid-19 pandemic. The system for monitoring the attained level of energy efficiency is based on the use of discriminant analysis.
FINDINGS: Implementation of the weighted strategy has proved that the classes will be given online, 23% of all offices. Category A (administrative, technical, service buildings; laboratories with unique equipment with 24-hour service) will be used in a pessimistic scenario (continuation of Covid-19 pandemic). In the optimistic scenario (end of Covid-19 pandemic), by means of the suggested energy efficiency monitoring system, the probability of using category A officesmakes100%, B offices- 50% and C offices- 13%.
CONCLUSION: Implementation of the developed energy efficiency action plan will offer the opportunity for the University to use reasonably the common connection point of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of the Covid-19 pandemic. The profitability of implementing a weighted energy efficiency strategy is 15%, with a payback period of 6.7 years for the purchase and installation of non-conventional renewable energy equipment. In the future, it would be advisable to convert gradually all of the remaining 14 university buildings to the autonomous use of non-conventional renewable energy sources, using a common connection point for the knowledge management of the energy complexes.

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INTRODUCTION

There is a strong potential for energy saving in Ukrainian higher education institutions: the effect of reducing energy costs provides the universities with an opportunity to reduce their dependence on the external funding and increases the autonomy of public institutions. But, in most cases, Ukrainian university buildings are energy inefficient and outdated (Gryshchenko *et al*., 2017). The COVID-19 pandemic has put new demands on the economical use of resources, including energy (Abu-Rayash *et al*., 2020; Wang *et al*., 2021). Universities were forced to reduce all costs, including wages (teachers wages were paid on an hourly basis, administrative and support staff were given unpaid holidays), utility costs, including energy, were reduced by complete disconnection of resources, etc. Furthermore, the Covid-19 pandemic resulted in a significant reduction in funding for budget institutions, particularly those in the social sphere – in the spring of 2020, the Ukrainian government transferred UAH 5 billion from the education sector to the Covid-19 Response Fund. The Covid-19 pandemic has thus become not only an opportunity for Ukrainian universities to save energy, but also a major challenge to optimize internal and external resources. According to studies by (García *et al*., 2020; Nayak *et al*., 2021; Nicola *et al*., 2020; Werth *et al*., 2021) the use of energy saving methods, technologies and materials under the pandemic conditions can be considered as one of the priority areas of university energy efficiency. The results of university energy efficiency research in the COVID-19 pandemic can be conditionally divided into 3 groups. The first group of study Di Stefano, (2000) is devoted to the specific features of energy consumption and the search for methods to improve the energy efficiency of university buildings in the COVID-19 pandemic. For example, Xing *et al.* (2019) presented a multi-criteria optimization model for distributed energy systems under COVID-19 pandemic conditions, involving methods to reduce heat losses in buildings through the development and use of energy-efficient space planning and construction solutions based on the use of energy-efficient equipment and non-conventional energy supply systems. The second group of study Hansen *et al*. (2019) is devoted to searching for the methods to optimize energy consumption in the COVID-19 pandemic related to the need for heating and warm air recovery in university buildings. Fan *et al.* (2020) suggest that energy-efficient technologies and materials that improve the energy efficiency of buildings in the light of the COVID-19 pandemic are one of the priorities for modern global economic development. Amirreza *et al.* (2021) find that the likelihood of possible energy resources in the light ofCOVID-19 pandemic leads to a significant increase in their cost at the existing volumes and rates of consumption growth, taking into account the limited availability of existing and poor progress of alternative energy sources. Most authors (Liu *et al*., 2019; Zhong *et al*., 2020) agree that methods to reduce heat loss in the context of COVID-19 pandemic can be divided into active and passive. According to Chen *et al*. (2020) the use of active heat control methods (manual and automatic) and the installation of heat meters are particularly relevant under the pandemic conditions. However, in the course of the pandemic, the use of passive methods, according to Sovacool *et al*. (2020), improves the thermal insulation of the envelope buildings and the heat distribution network as well as the increase of the heat emission of the radiators and other heat exchangers. However, only the complex of all methods and obligatory individual economic responsibility of the consumer in the light ofCOVID-19 pandemic can result in significant energy saving (Navon *et al.,* 2021). The third group can include scientific developments during the COVID-19 pandemicthat make it possible to consider the problems of energy efficiency management of universities in an integrated manner: introduction of thermo-modernization projects of existing buildings (Soava *et al*., 2021), construction of passive buildings (Shcherbak *et al*., 2019). During development of energy saving measures, it is very important to evaluate the energy saving potential of a building (Balode *et al*., 2021). Many scientists have studied the issue of assessing energy saving potential and efficiency improvement of energy consumption in the course of COVID-19 pandemic. As a rule, the reserves on saving of fuel and energy resources are determined in the course of energy audit (Abu-Rayash *et al*., 2020; Kaplun *et al*., 2016). Some researchers (Edomah *et al.,* 2020; Khan *et al.,* 2021) consider thermal imaging as one of the most advanced energy auditing methods during the present pandemic. This method is used, first of all, in those cases when it is necessary to localize the areas of advantageous heating and ventilation heat losses which are often caused either by design errors, or defects arising at the stages of construction and operation (Jiang *et al*., 2021). At the same timein the course ofCOVID-19 pandemic, the problem of quantitative interpretation of the survey results, which should provide the adoption of justified decisions on strengthening the thermal protection of the inspected buildings, is not completely solved in the building thermal diagnostics. The use of thermal imaging to determine the thermal transmission resistance of the building envelope can determine up to 15% of the transmission heat loss during the heating period. On a practical level, during pandemic constraints it is difficult to account for the thermal inertia and the thermal dynamics of the external and internal environment when a number of thermal imaging survey rules are followed (Zhang *et al*., 2020; Steffen *et al*., 2020).Most university buildings in Ukraine have a strong energy saving potential, when taking into consideration generally the levels of insulation of building structures, the practical absence of process controls (heating, lighting and others) in the buildings. In the course of COVID-19 pandemic, there was an increase in the cost of energy and the energy intensity of basic equipment (Mastropietro *et al*., 2020). Improving the efficiency of energy consumption is therefore a priority for the university (Papageorgiou *et al*., 2017). The following challenges arise when developing implementation plans to improve energy efficiency during the present pandemic: limited financial assets for their implementation (Krarti *et al*., 2021); a large number of measures and available alternative measures that cannot be implemented simultaneously for technical reasons (Jiang *et al*., 2021). Under these conditions improving the energy efficiency of reconstructed residential buildings based on the integrated use of energy saving technologies and renewable energy sources will make it possible to cover the deficit of heat energy for heating, which inevitably arises as a result of infill construction (Huang *et al*., 2021). The need for significant energy efficiency improvements in an economic sense can result in a large-scale reconstruction of outdated buildings. The economic efficiency of this approach involves individual changes: replacement of windows, renovation of facades, roofing, which will result in the improved energy efficiency. On the other hand, it will reduce the use of natural resources at the operational stage of the buildings and reduce the adverse impact on the environment. Analysis of methods to improve energy efficiency in the course of COVID-19 pandemic shows that it is necessary to use a set of both active and passive methods in order to improve the thermal insulation properties of buildings and to create comfortable conditions in the offices. By using active methods, it is possible to save a significant part of the heating costs (10-15%). Passive methods will result in greater savings (30%). Consequently, the combination of these methods will save almost 50% of the costs (Kanda *et al*., 2020; Kuzemko *et al*., 2020). The creation of an energy management service and energy supply system on the basis of the virtual solar plant at Kiev National University of Technology and Design has approved that the integrated energy management system should be based on the international energy efficiency standards: ISO 50004:2014 Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system; ISO 50006:2014 Energy management systems - Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) - General principles and guidance; ISO 50002:2014 Energy audits - Requirements with guidance for use (Shaposhnikova *et al*., 2016; Vieira *et al*., 2020). At the same time, the implementation of an effective energy management system in the course of the COVID-19 pandemic should be based on energy monitoring, energy audits and energy certification of university buildings (Halbrügge *et al*., 2021). Thus, there is a lack of consistency between the existing both theoretical and practical approaches in determining the most appropriate energy management systems, ranking the factors that have the greatest impact on the level of energy efficiency of universities in the context of the COVID-19 pandemic (Edomah *et al*., 2020; Klemeš *et al*., 2020; Ruan *et al*., 2021). In other words, many problems remain unresolved, controversial and require further study. The problem that this project aims to solve is the necessity to develop an integrative approach to energy conservation and energy efficiency management at the university in the context of preventing a new outbreak of the Covid-19 pandemic. The aim of the study is to develop a management system for energy complexes with non-conventional renewable energy sources based on the Common connection point (CCP) in the context of preventing a new outbreak of the Covid-19 pandemic. The objectives of the study are; 1) to conduct energy audit, energy certification of university building offices, 2) to construct energy profiles of university building offices, 3) to develop an energy management plan to increase university energy efficiency, 4) to offer a system to monitor the achieved level of energy efficiency. This study has been carried out at Kyiv National University of Technology and Design (KNUTD) as the case study in 2020.

MATERIAL AND METHODS

The hypothesis of the study is that applying an integrative approach to university energy efficiency management in the context of preventing a new outbreak of the Covid-19 pandemic will increase the university's energy savings and its level of energy autonomy from budgetary funding. The algorithm of the study procedure is as follows: 1 stage –to conduct an energy audit of university buildings (offices) to construct an energy profile; 2 stage –to implement energy certification to classify university buildings by energy consumption and energy losses; 3 stage –to develop an energy management action plan to optimize energy saving in higher education institutions in order to prevent a new Covid-19 pandemic outbreak; 4 stage –to monitor the achieved level of energy efficiency. At the first stage, an energy audit was conducted. The energy audit has resulted in the construction of an energy profile according to the critical criteria. The energy profile tool is the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) method. According to (Shcherbak *et al.*, 2019) the advantage of this method is the easy information collection and processing regarding the technical condition, planning and socio-economic aspects of the operation of university buildings in terms of energy efficiency, and the reliability of the results obtained. The second stage involves energy certification of university buildings. From the point of view of (Kaplun *et al.*, 2016) it is more reasonable to carry out energy certification of university building offices on the basis of the results of energy audit by means of a cluster analysis method. The cluster analysis method in this study is used to rate university buildings according to the level of energy consumption, energy losses, and the possibility to use alternative energy sources. At this stage the energy efficiency potentials of university buildings are calculated according to the key energy saving areas. The thermal energy saving potential for the heating period is calculated using Eq.1.

$$P_{heat} = (P_{cal} - P_{act}) \times \beta_h, \quad (1)$$

Where, P_{cal} is the actual heat consumption for heating the building during the heating period, *J*; P_{act} is the heat input during the heating period, *J*; β_h is the coefficient taking into account extra heat consumption of the heating system related to the heat flow discreteness of the range of heating appliances, *J*.

The heat gain potential during the heating period is calculated using Eq. 2.

$$P_{act} = (P_{\text{int}} + P_s) \times \gamma \times \phi \quad (2)$$

Where, P_{int} is the potential for domestic heat gain during the heating period, *J*; P_s is the potential for heat gain through windows from solar radiation during the heating period, *J*; γ is the reduction factor for heat gain due to thermal inertia of the envelope building; φ is the efficiency factor for auto regulation of the heating system, *J*.

The heat saving potential due to the envelope building improvement (increasing the thermal resistance of exterior walls, windows, doors, attic floors and floors) is calculated using Eq. 3.

$$P_{build/env} = 0{,}0864 \times D_d (K_{t1} A_{e1} - K_{t2} A_{e2}) \times \phi, \quad (3)$$

Where, D_d - degree-days of the heating period, *°C-day/year.*; $K_{t1,}$ K_{t2} - heat transfer coefficients of the building before and after improvement of the building envelope, *W/(m²-°C)*; $A_{e1,}$ A_{e2} – surface areas of external envelope structures, including the upper floor (slab) and floor slab of the lower heated room, before and after improvement of the building envelope, *m²*.

The heat gain decrease potential due to the thermal inertia of the internal building envelope (screens behind radiators) is calculated using Eq. 4.

$$P_{\text{int/env}} = \tau \times F \times (K_1 - K_2) \times (t_{rad} - t_{outs})[(t_{ind} - t_{outs}) / (t_{\max} - t_{ind})] \quad (4)$$

Where, τ - duration of the heating period; *F* - surface area of heating devices from the side of the building envelope, m^2; t_{rad} - average air temperature between the wall and the heating device, ^0C; t_{outs} - average outdoor air temperature during the heating period, ^0C; t_{ind} - indoor reference temperature, ^0C; t_{max} - standard outdoor air temperature of the coldest five-day heating period, ^0C; *K1, K2* - heat transfer coefficients through the building envelopes before and after improvement of internal building envelopes, *W/(m²-°C)*.

The savings potential of the building heating system due to the use of autoregulation (introduction of individual heating substations, thermostats) is calculated using Eq. 5.

$$P_{autoreg} = (P_{\text{int}} + P_s) \times \gamma \times \beta_h(\phi_2 - \phi_1), \tag{5}$$

Where, φ_1, φ_2 are the efficiency coefficients of auto regulation of heat supply before and after the implementation of the individual heating substation, thermostats in the building heating system.

The potential for energy savings due the use of non-conventional renewable energy sources (installing a solar panel on the building roof of the university) is calculated using Eq. 6.

$$P_{solar} = \frac{30W}{W_m} P_m, \tag{6}$$

Where, *W* is the average daily electricity consumption of all university buildings, *kWh*; P_m is the capacity of the solar power plant module, *J*; W_m is the amount of energy generated by the solar power plant module using Eq. 7.

$$W_m = \frac{kP_m E}{1000}, \tag{7}$$

Where, *E* is the insolation value for the heating period, *kWh/m²*; *k* is a factor taking into account the correction for the power loss of the solar cells when they heat up in the sun, as well as the oblique incidence of the rays on the surface of the modules during the day.

The integral potential of energy efficiency is calculated using Eq. 8.

$$P_{\text{int}} = \sqrt[6]{P_{heat} \times P_{act} \times P_{build/env} \times P_{\text{int}/envt} \times P_{autoreg} \times P_{solar}}, \tag{8}$$

The third stage includes the development of energy management action plan using the fuzzy method (Skiba *et al*., 2017). This method makes it possible to classify all the offices of the university buildings using ABC analysis. ABC analysis is based on the well-known Pareto principle, which states that 20% of effort yields 80% of the result. The principle of using ABC analysis is as follows. Group "A" includes the offices that give 80% of energy efficiency potential implementation; group "B" offices - 15%; group "C" offices - 5%.A single indicator, the integral energy efficiency potential (Equation 8), was used to apply the ABC analysis. This indicator includes a comprehensive characteristic of the energy efficiency of all offices (buildings) and makes it possible to classify all the offices according to the achieved level of energy efficiency. Energy efficiency improvement plan of university offices is drawn up as follows. There is some set of system object categories (university offices) *C*= {C_A, C_B, C_C}. Each category of offices C_i is characterized by a set of attributes (energy efficiency potentials), it corresponds to a subset of objects having the listed attributes - $O_i = \{o_1^i, o_2^i, ...o_N^i\}$, where *N* is the number of university offices. The state of an object is characterized by a set of values of its attributes (energy efficiency potentials) related to a particular object (room): $P(o_j^i) = \{p_1^i, p_2^i, ...p_N^i\}$. The state of the university's managed energy efficiency system is characterized by a set of attribute values (energy efficiency potentials) of all its objects (offices), using Eq. 9.

$$\overline{U} = \bigcup_{o_j^i \in 0} P(o_j^i) \tag{9}$$

Probable outcomes for each of the offices include its classification to one of the groups according to the value of the integral energy efficiency potential: A, B, C. For each combination of actions, the probable outcomes of all actions are combined into generating options - lists of outcomes, where each object corresponds to one implementation of an action, using Eq.10.

$$Vres(\overline{U}) = (o_j^i, p_j^i) \tag{10}$$

It is followed by a combination of general list actions into private ones that describe the aggregate managing decisions to classify the offices into one of the three C_j categories, using Eq.11.

$$Ags(\bar{U}) = Ag(c_j, o_j^i) \quad (11)$$

The university offices are classified into 3 categories (A, B, C) due to the fact that in case of remote university activity in the context of the Covid-19 pandemic, only category A offices will be used. During the heating season, Category C offices will not be used regardless of the University's activity schedule. Category B offices will be used upon return to normal working conditions. This is shown graphically in Fig. 1.

The implementation of energy management measures makes it possible to optimize energy conservation in higher education institutions in the context of preventing a new outbreak of the Covid-19 pandemic (Gryshchenko *et al.*, 2017). In the fourth stage, the suggested system for monitoring the achieved level of energy efficiency is based on the method of discriminant analysis. The essence of its use is that the strategy of using a certain room is determined by the maximum value of the discriminant function $f_{i/j}$, where *I* is the strategy of using this room determined in the third stage, *j* is the category of energy certification of this room determined in the second stage.

The performance of the suggested energy efficiency measures (Ganushchak-Efimenko *et al.*, 2018) is determined by the Eq. 12.

$$K_{eff} = \frac{\mathrm{Cos}\,t_1 - \mathrm{Cos}\,t_2}{\mathrm{Cos}\,t_{equip}}, \quad (12)$$

Where, $Cost_1, Cost_2$ - costs of electricity and heating before and after the implementation of energy efficiency measures, *UAH*; $Cost_{equip}$ - cost of complete solar power plant equipment, heating unit, thermostats, design and installation works, *UAH*.

The payback period of the project is determined using Eq. 13.

$$ROI = \frac{\mathrm{Cos}\,t_{equip}}{\mathrm{Cos}\,t_1 - \mathrm{Cos}\,t_2}, \quad (13)$$

Data description

Data collected according to the methodology of the DGNB were used in order to conduct energy audit and construct an energy profile. The empirical data to conduct energy audit and construct an energy profile are presented in Table 1.

The data in Table 1 were collected by the employees of Center for Energy Efficiency of Kyiv National University of Technology and Design (KNUTD) for all university offices (Table 2).

All the coefficients resulted fromEqs.1 to 11 are reference values. All other components of Eq. 1 - 11 are estimated values derived from the data on actual consumption of heat, electricity, the condition of external and internal coverings of the buildings. Data for calculation of Eqs.12 - 13 have been obtained from the financial statements of the university.

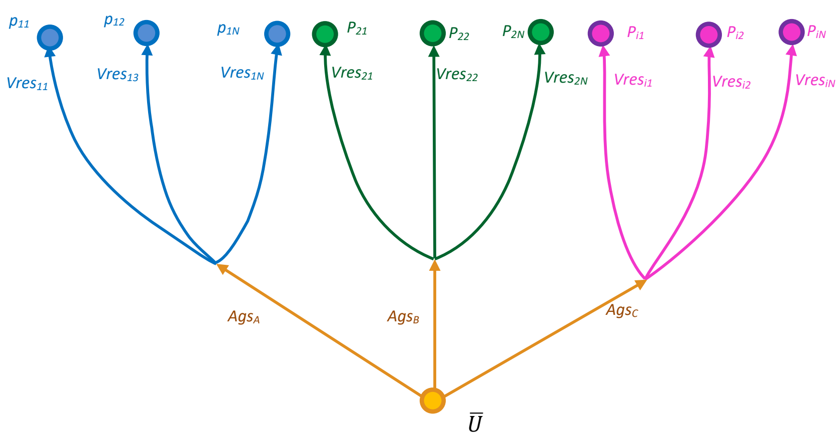

Fig. 1: Converted fragment of a fuzzy hierarchical situation-evidence-based university offices classification network based on the ABC-principle

RESULTS AND DISCUSSION

The first stage involved energy audit of 15 KNUTD buildings (Table 2) was conducted according to 14 key energy efficiency indicators. The list of indicators was selected according to the methodology of DGNB and is shown in Table 1. As a result of this energy audit an energy profile was constructed in Fig. 2.

Fig. 2 shows the practical use of the application package, the "Cluster Method - K-means clustering" tab. Using this method, 15 buildings can be classified into separate energy efficiency groups based on 14 indicators.

The second stage included energy certification of offices based on the calculation of integral energy efficiency potentials for all 880 offices in 15 university buildings. The energy certification of university buildings was carried out on the basis of energy efficiency rating of the offices (Fig. 3).

The results of the energy efficiency potential calculations and their classification are shown on the example of 113 offices of KNUTD Academic Building B4 (Fig. 4).

Fig. 4 shows the practical use of the application package STATISTICA 10, tab "Cluster method - K-means clustering". In this case, this method was used to classify 113 offices of KNUTD academic building B4 into 3 groups A, B, C according to 6 energy efficiency potentials.

The structure of the category A offices group of KNUTD academic building B4 is shown in Table 3.

Table 3 shows that 26 from among 113 offices of KNUTD Building B4 (23%) fell within Category A.

The structure of category B offices group of KNUTD academic building B4 is shown in Table 4.

Table 1: System of indicators for conducting energy audits and constructing an energy profile

Indicators	Identification
costs for the entire life history of the building	x_1
use of renewable energy sources for heat and electricity	x_2
indoor climate	x_3
use of environmentally friendly materials	x_4
use of heat energy	x_5
building design principles relating to energy efficiency	x_6
quality control of energy use	x_7
roof insulation	x_8
wall insulation	x_9
floor insulation	x_{10}
heat transfer coefficient of windows	x_{11}
air permeability of the building	x_{12}
ventilation	x_{13}
heating and cooling	x_{14}

Table 2: The main buildings of the KNUTD and their technical specifications

Designation	Building name	Area	Building volume	Year built	Rated energy consumption	Specific energy consumption	Average workload (%)
B1	Academic Building No. 1	32066,8	132132,3	1970	0,025	228,7	28,13
B2	Academic Building No. 2	5366,9	20570,7	1965	0,023	242,7	38,88
B3	Academic Building No.3	5239,9	17815,3	1968	0,029	238,9	29,99
B4	Academic Building No.4	18029,1	78311,8	1976	0,025	213,7	31,78
B5	Academic Building No.5	1785,1	6243,7	1966	0,034	247,5	56,05
B6	Academic Building No. 8	878,5	2749,6	1914	0,039	263,8	21,78
B7	Build. No.6	745,3	3320,5	1976	0,039	233,1	32,44
B8	Build. No.7	559,2	3010,2	1960	0,039	267,8	41,17
B9	Dormitory No. 2	4981,14	14098,1	1970	0,032	245,3	68,6
B10	Dormitory No. 3	4884,6	13879,8	1962	0,032	231,9	44,8
B11	Dormitory No. 4	6225,4	20763,4	1996	0,024	153,5	87,0
B12	Dormitory No. 5	4920,2	13926,5	1975	0,032	200,1	67,3
B13	Dormitory No. 6	4862,1	14325,7	1977	0,032	197,8	55,8
B14	Dormitory No. 7	10514,1	44286,9	1984	0,026	178,3	59,7
B15	Dormitory No. 8	5524,3	15873,8	1996	0,030	219,8	41,9

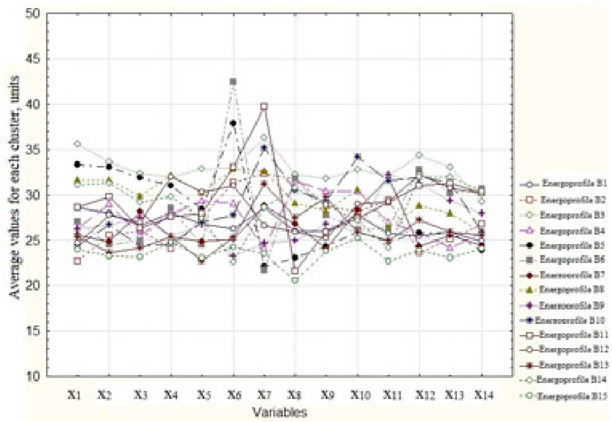

Fig. 2: Energy profiles of 15 KNUTD buildings; graph of average values for 14 indicators (STATISTICA 10 listing)

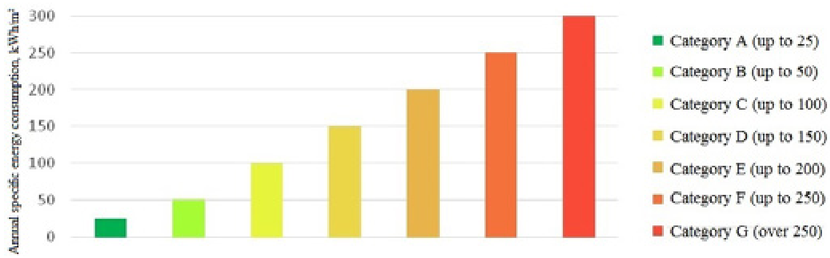

Fig. 3: Energy efficiency levels of buildings according tothe estimated annual specific energy consumption

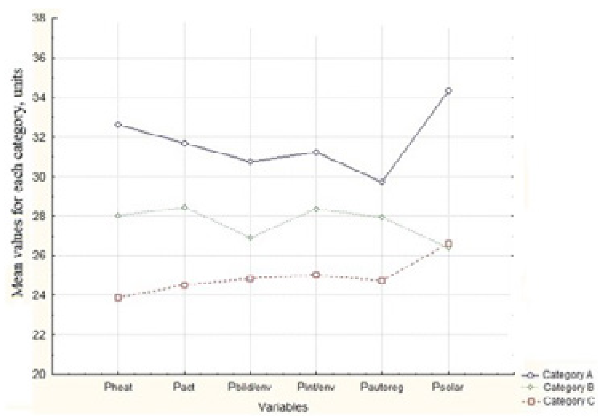

Fig. 4: Energy Efficiency Potential Rating of 113 offices of KNUTD Academic Building B4 (STATISTICA 10 listing)

Table 4 shows that 40 from among 113officesof KNUTD academic building B4 (35%) fell within category B. The structure of category C offices group of KNUTD academic building B4 is shown in Table 5.

Table 5 shows that 47 from among 113 offices of KNUTD academic building B4 (42%) fell within category C. The results of energy certification of 113 offices of KNUTD building B4 according to categories A, B, C are shown in Table 6.

The third stage involved the development of energy management action plan using the fuzzy sets method. The nodes in the upper layer of the network are evaluated (Fig. 1) by means of an evaluation model of the managed system state. Managing decisions are evaluated through the evaluations of the nodes to which they lead, convolved according to the chosen decision evaluation strategy. The possible strategies are as follows. Pessimistic strategy: the decision is evaluated by the worst-case estimate of the nodes to which it leads. Optimistic strategy: the decision is evaluated by the best estimate of the nodes to which it leads. Risk reduction strategy: the decision is evaluated by the sum of the fuzzy transition probabilities of the resulting nodes with an estimate below the threshold. Strategy to increase the winning probability: the decision is evaluated by the sum of the fuzzy transition probabilities to the resulting nodes with an estimate above the threshold. A weighted strategy that averages the outcome estimates according to their probabilities (analogous to the mathematical expectation). The maximum estimates of the managing decisions coming from every node are arguments for estimating the lower level transitions. Once the estimates of the transitions originating from the root node have been determined, an inference sub-tree is constructed, where the group transition with the maximum estimate is selected for every node. The arbitrary output sub-graph is evaluated by the deviation of the estimates of the selected transitions from the maximum estimates (Fig. 5).

The energy management plan to improve the energy efficiency of the university is presented in Table 7.

According to the weighted strategy, outcome estimates have been averaged based on the probability of their occurrence. It means that in a

Table 3: The structure of Category A offices group B4 of the KNUTD academic building (STATISTICA 10 listing)

Members of cluster number 1 (Data_ABC) and distances from respective cluster center. Cluster contains 26 cases													
Case No.	C_1	C_4	C_8	C_13	C_15	C_17	C_21	C_22	C_23	C_27	C_36	C_38	C_40
Distance	2,62	3,51	3,82	2,30	1,54	5,79	3,15	3,54	1,83	2,54	1,60	2,12	5,35
Case No.	C_45	C_47	C_49	C_51	C_53	C_55	C_57	C_58	C_59	C_74	C_95	C_99	C_103
Distance	1,91	2,217	3,536	3,047	2,404	3,763	3,303	3,130	5,461	3,313	3,682	9,445	5,307

Table 4: The structure of category B group offices of KNUTD academic building B4 (STATISTICA 10 listing)

Members of cluster number 2 (Data_ABC) and distances from respective cluster center. Cluster contains 40 cases										
Case No.	C_5	C_6	C_7	C_9	C_11	C_12	C_20	C_28	C_29	C_30
Distance	2,187	2,3160	2,5555	2,3113	2,0193	3,0281	3,5198	1,5902	1,6714	2,3149
Case No.	C_32	C_34	C_35	C_37	C_43	C_44	C_46	C_48	C_50	C_52
Distance	1,520	1,9872	2,8181	2,3457	4,1016	5,1931	4,5922	2,7539	1,2416	4,0800
Case No.	C_54	C_56	C_61	C_65	C_66	C_67	C_79	C_81	C_82	C_84
Distance	2,893	3,4271	4,5223	2,7658	2,0742	6,5260	1,4172	3,4108	3,1505	3,3346
Case No.	C_92	C_96	C_101	C_102	C_104	C_105	C_107	C_111	C_112	C_113
Distance	3,245	1,2659	3,6594	3,1049	2,7800	2,7238	3,4511	1,9286	2,0129	3,0617

Table 5: The structure of Category C offices group B4 of the KNUTD academic building (STATISTICA 10 listing)

Members of cluster number 3 (Data_ABC) and distances from respective cluster center. Cluster contains 47 cases										
Case No.	C_2	C_3	C_10	C_14	C_16	C_18	C_19	C_24	C_25	C_26
Distance	1,9616	1,6096	1,5591	2,40379	1,47362	2,2345	2,7229	2,8112	1,6891	2,4268
Case No.	C_31	C_33	C_39	C_41	C_42	C_60	C_62	C_63	C_64	C_68
Distance	1,3078	2,5628	1,1275	1,13783	2,08440	1,7166	3,4863	6,5185	3,6726	3,7203
Case No.	C_69	C_70	C_71	C_72	C_73	C_75	C_76	C_77	C_78	C_80
Distance	3,6603	1,5009	3,6647	3,74253	3,52055	3,7136	3,2354	3,3711	1,8664	5,0750
Case No.	C_83	C_85	C_86	C_87	C_88	C_89	C_90	C_91	C_93	C_94
Distance	2,8804	0,7783	3,0476	3,17184	3,30961	3,5671	2,9974	3,3115	3,5823	2,9531
Case No.	C_97	C_98	C_100	C_106	C_108	C_109	C_110			
Distance	1,7752	3,0426	2,4980	2,305041	3,251413	3,2113	2,4021			

Table 6: Energy certification of 113 offices of KNUTD building B4 according to categories A, B, C (STATISTICA 10 listing)

B4 KNUTD offices codes	Category / number of offices	Integral energy efficiency potential value / Annual specific energy consumption level
C_1; C_4; C_8;C_13;C_15;C_17;C_21;C_22;C_23;C_27;C_36;C_38;C_40; C_45; C_47; C_49; C_51; C_53; C_55; C_57; C_58; C_59; C_74; C_95; C_99; C_103	A /26	High level of integral energy efficiency potential / Low level of annual specific energy consumption
C_5; C_6; C_7; C_9; C_11; C_12; C_20; C_28; C_29; C_30; C_32; C_34; C_35; C_37; C_43; C_44; C_46; C_48; C_50; C_52; C_54; C_56; C_61; C_65; C_66; C_67; C_79; C_81; C_82; C_84; C_92; C_96; C_101; C_102; C_104; C_105; C_107; C_111; C_112; C_113	B /40	Average level of integral energy efficiency potential / Average level of annual specific energy consumption
C_2; C_3; C_10; C_14; C_16; C_18; C_19; C_24; C_25; C_26; C_31; C_33; C_39; C_41; C_42; C_60; C_62; C_63; C_64; C_68; C_69; C_70; C_71; C_72; C_73; C_75; C_76; C_77; C_78; C_80; C_83; C_85; C_86; C_87; C_88; C_89; C_90; C_91; C_93; C_94; C_97; C_98; C_100; C_106; C_108; C_109; C_110	C/47	Low level of integral energy efficiency potential / High level of annual specific energy consumption

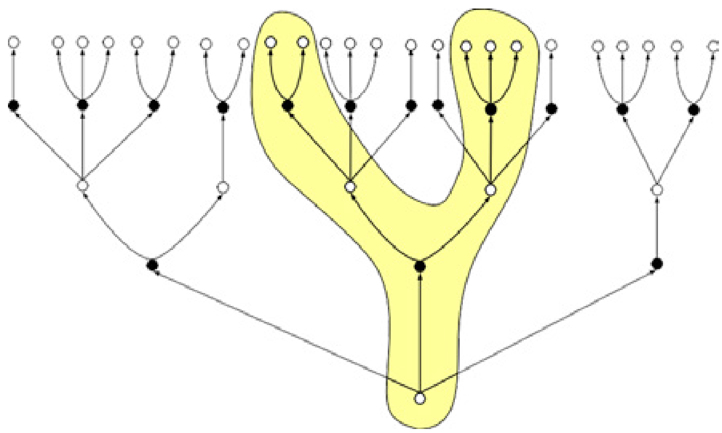

Fig. 5: Fuzzy hierarchical situation-evidence network and the ABC-principle output sub-graph of university offices classification

pessimistic scenario (continuation of the Covid-19 pandemic) classes will be given online. In this case only the Category A offices will be used: administrative, technical, service offices; laboratories with unique equipment with 24-hour service. In an optimistic scenario (completion of Covid-19 pandemic) category A and B offices will be used under the conditions of returning to normal working conditions. Category C offices with low integral energy efficiency potential will not be used during the heating season. The system for monitoring the achieved level of energy efficiency was presented in the fourth stage (Table 8) and the impact of the suggested energy efficiency measures was assessed.

The use of the suggested energy efficiency monitoring system has shown that the probability of using the optimistic strategy for Category A offices makes 100%, for B offices- 50% and for C offices- 13%.

The cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, floor insulation) will be K_{eff}= (3317257 – 2030212)/ 8580300 = 0,15, where 3317257 UAH - costs of electricity and heating before implementation of energy-efficiency measures; 2030212 UAH - cost of electricity and heating after implementation of energy-efficiency measures; 8580300 UAH - cost of complete solar plant equipment, heating substation, thermostats, design and installation works. Payback period of the project is as follows: ROI = 8580300 / (3317257 - 2030212) = 6.67 years. Calculations showed that the cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, insulation of floors) will be 15%. The payback period for the purchase and installation of non-conventional renewable energy equipment will make 6 years and 8 months. As a discussion, it should be noted that as opposed to (Xing *et al.*, 2019), who suggested using a multi-criteria optimization model for distributed energy systems in the context ofCOVID-19 pandemic, our study suggests using anCCP. The use of CCPin university energy management makes it possible to conduct the interactive monitoring of the energy efficiency of individual room groups (A, B, C) and adopt timely decisions on their utilization strategy. The authors (Zhong*et al.*, 2020; Chen *et al.*, 2020; Sovacool*et al.*, 2020; Navon*et al.*, 2021; Soavae*t al.*, 2021; Kanda *et al.*, 2020; Kuzemko *et al.*, 2021; Kanda *et al.*, 2020; Khan *et al.*, 2021; Edomah *et al.*, 2020; Zhang *et al*, 2020) believe that either active or passive management techniques should be used to reduce heat loss and energy savings under COVID-19 pandemic conditions. In contrast to these authors' views, we have suggested a synergistic sequential integration of energy audits, energy certification, energy management and monitoring of achieved energy efficiency under theCOVID-19 pandemic. Moreover, according to (Huang *et al.*, 2021) energy-saving technologies and renewable energy sources, including solar panels, should be used either during construction or in the course of building renovation. Our approach of using non-conventional renewable energy sources in the context of preventing a new outbreak of the Covid-19 pandemic would significantly improve the energy efficiency of the university.

Table 7: Energy management action plan to improve the energy efficiency of the university

Category of KNUTD offices	Integral energy efficiency potential value / Annual specific energy consumption level	Energy management strategy		
		Pessimistic	Optimistic	Weighted (probabilistic)
A	High level of integral energy efficiency potential / Low level of annual specific energy consumption	100% use of administrative, technical, office space; laboratories with unique 24-hour service equipment		
B	Average level of integral energy efficiency potential / Average level of annual specific energy consumption	It is possible to use category B offices under the condition that:$P_{solar} \geq P_{autoreg}$	100% utilization of category B offices	It is possible to use category B offices under the condition that: $P_{solar} = P_{act}$
C	Low level of integral energy efficiency potential / High level of annual specific energy consumption	Category C offices will not be used	Category C offices can be used provided that: $P_{solar} \geq P_{autoreg}$	Category C offices can be used provided that: $P_{solar} = P_{act}$

Table 8: A system for monitoring the level of energy efficiency achieved

Strategy	Category of KNUTD offices		
	A	B	C
Pessimistic	$f_{P/A}$= -32,7+ 0,11x_1 + 0,43x_2 + 2,63 x_3 – 59,54x_4– 3,17x_5+ x_6 +0,03x_7 +0,02x_8 + 0,15x_9-0,13x_{10} -0,03x_{11} +0,52x_{12} + 0,13x_{13} + 0,04x_{14}	$f_{p/B}$ = -17,6+ 0,03x_1+x_2+0,96x_3-0,3x_4+0,29x_5+ 0,03x_6 +x_7+0,96x_8-0,3x_9+0,29x_{10}-0,09x_{11} - 0,09x_{12} +0,13x_{13} -0,18x_{14}	$f_{p/C}$ = -12,8+ 0,02x_1+0,06x_2+0,7x_3-0,03x_4+0,03x_5+0,02x_6 +0,06x_7 +0,7x_8 -0,03x_9+0,03x_{10}-0,19x_{11} ++ 0,53x_{12} -0,17x_{13} -0,1x_{14}
Optimistic	$f_{O/A}$ = -19,1+ 0,8x_1+0,32x_2-0,28x_3-0,18x_4+0,13x_5+0,8x_6+0,32x_7 -0,28x_8-0,18x_9+0,13x_{10}+ 0,01x_{11} - 0,44x_{12} + 0,72x_{13}-0,01x_{14}	$f_{O/B}$ = 37,1-0,28x_1+0,29x_2+x_3+ 0,04x_4-0,01x_5- 0,28x_6+0,29x_7+x_8+ 0,04x_9 -0,01x_{10}-0,05x_{11} +0,4x_{12} + 0,05x_{13} + x_{14}	$f_{O/C}$ = -21,2+ -0,28x_1+0,29x_2+x_3+ 0,04x_4-0,01x_5+0,22x_6 + 0,96x_7 +0,33x_8 - 0,33x_9 +0,33x_{10} -0,1x_{11} ++ 0,19x_{12} -0,5x_{13} +0,13x_{14}
Weighted (probabilistic)	$f_{W/A}$ = -17,5+ 0,32x_1+0,3x_2+0,4x_3-0,53x_4+0,43x_5- 0,28x_6 + 0,29x_7 + x_8 + 0,04x_9 -0,01x_{10} - 0,05x_{11} +0,22x_{12}+ x_{13} +0,4x_{14}	$f_{W/B}$ = -16,5+ 0,22x_1 + 0,33x_2 + 2,63x_3 – 59,54x_4– 3,17x_5+0,3x_6 + 0,29x_7 + x_8 + 0,04x_9 +0,24x_{10} - 0,29x_{11} - 0,23x_{12} + 0,23x_{13} - 0,11x_{14}	$f_{W/C}$ = -32,7+ 0,11x_1 + 0,43x_2 + 2,63x_3 – 59,54x_4– 3,17x_5+0,32x_6 + 0,3x_7 + 0,4x_8 - 0,53x_9 + 0,43x_{10} - 0,17x_{11} + 0,15x_{12}-0,03x_{13} -0,1x_{14}

CONCLUSION

The article suggests a new scientific and practical integrative approach to create university energy-innovative CCP of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of Covid-19 pandemic on the example of KNUTD. The novelty of the developed scientific and practical integrative approach consists in synergetic sequential integration of energy audit, energy certification, energy management, monitoring of the achieved level of energy efficiency. The proposed approach will address the university's energy conservation and efficiency in the context of preventing a new outbreak of the Covad-19 pandemic. Energy audit performance on critical DGNB indicators made it possible to construct energy profiles of 15 university buildings. The energy certification of 880 university offices was conducted by cluster analysis on 6 energy efficiency potentials: potential of heat energy saving during the heating period, potential of heat gain during the heating period, potential of heat energy saving due to improvement of building envelope, potential of heat gain reduction due to the thermal inertia of internal building envelope, potential of heating system saving due to use of automatic control of building's heating system, potential for saving electricity through the use of non-conventional renewable energy sources. The energy management action plan, using the fuzzy sets method, was based on the rating of university buildings using ABC analysis. For this purpose, group "A" offices were classified as those that give 80% of the implementation of the integral energy efficiency potential; group "B" offices - 15%; group "C" offices - 5%. The results of the weighted strategy shows that in a pessimistic scenario (continuation of the Covid-19 pandemic), classes will be given online, only offices of category A (administrative, technical, service offices; laboratories with unique equipment with 24-hour maintenance) will be used - 23% of the total offices. In case of an optimistic scenario (end of the Covid-19 pandemic), under the condition of returning to a normal work rhythm, 58% of offices with category A and B will be used. Monitoring of the weighted energy efficiency strategy performance has shown that the cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, floor insulation) will make 15%. The payback period for the purchase and installation of non-conventional renewable energy equipment will make 6.7 years. Thus, the implementation of the suggested plan of measures for energy saving and energy efficiency will make it possible for the university to use reasonably the CCP of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of pandemic Covid-19. The prospect of further research is the economic and technical feasibility to implement the plan regarding gradual conversion of all university buildings to autonomous use of non-conventional renewable energy sources using CCP.

AUTHOR CONTRIBUTIONS

V. Shcherbak substantiated the research methodology, validation, conceptualization, I. Gryshchenko supervised the project administration, L. Ganushchak-Yefimenko collected and analyzed literature, wrote the initial draft; O. Nifatova did the research, observation, visualisation; V. Bobrovnik did the reviewing and editing; M. Verhun did the software, the validation, the formal analysis.

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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
°C-day/year	Degree-days of the heating period
⁰C	Degrees Celsius
CCP	Common connection point
COVID-19	Coronavirus Disease 2019
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
EnB	Measuring energy performance using energy baselines
EnPI	Energy performance indicators
Eq.	Formula of calculation
Expl.Var	Explanatory Variable
Fig.	Figure
ISO	International Organization for Standardization
J	Joule, the unit of measure of work, energy and quantity of heat in the International System of Units
KNUTD	Kyiv National University of Technology and Design
kWh	Kilowatt-hour
kWh/m²	Kilowatt-hour per square meter
m²	Square meter
Prp.Totl	Percentage of the total variance explained
STATSTICA	Statistical analysis software package
UAH	Hryvnia
Var	Variable
W/(m²-°C)	Watt per square meter Celsius

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