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Ivan M. Gryshchenko, Svitlana V. Bebko
Kyiv National University of Technologies and Design, Ukraine

FORESIGHT TOOLS TO ENHANCE ENERGY EFFICIENCY IN BUILDINGS BASED ON THE UNIVERSITY ENERGY HUB

The article reveals the essence of the key motivation drivers to save energy and increase the energy efficiency in higher education institutions. In particular, a low level of interest of higher education institutions in the implementation of strategies to reduce energy consumption has been observed. The findings suggest that the lack of interest in energy saving is primarily affected by budget legislation since the energy cost calculation was based on the consumption norms for a particular budgetary institution and the current (planned) electricity and heat tariffs. Recently, it has been decided that from now on universities will not obtain budget funding to cover utility costs; the amount of subsidies from the Ministry of Education and Science of Ukraine for the implementation of the government objectives will comprise regulatory costs for public service provision according to the student contingent. Standard property maintenance costs will not be covered by the Ministry anymore which will impose the burden of paying the utility bills upon the University's gross income. Hence, there is a need to take efforts to enhance energy efficiency and energy saving in higher education institutions which was implemented using a foresight methodology. Within the scope of this study, the foresight project to improve the energy efficiency of buildings in the frameworks of the University energy hub is based on the following calculations: thermal energy consumption for heating public buildings, estimated hourly heating load to ensure heating in the building, verifying the feasibility of heating standby regulation, measuring energy savings through the creation of an automated heat supply station, as well as annual savings in monetary terms. In order to save resources and boost energy efficiency based on the University energy hub using an automated heat supply station, the study offers a mathematical toolkit to justify the choice of minimum and maximum values of optimal microclimate parameters; reduce infiltration, increase the efficiency of indoor air distribution; optimal modes of local air conditioning, preheating and cooling; utilizing of "waste" and natural heat and cold; "combining" microclimate systems with other systems; improving automation devices in technical systems. It is argued that increasing the energy efficiency of heating systems in University buildings on the basis of its own energy hub will contribute to gaining significant savings in thermal energy for heating and significantly reduce carbon dioxide emissions into the environment. In addition, the study reveals that the cost of thermal energy for heating depends upon a building design, modernization quality, reconstruction and insulation, applied building materials, spatial planning solutions, the presence or absence of control and automated systems, maintenance systems and attitude of owner's attitude to innovations. The conclusions summarize that the cost of thermal energy can vary significantly in buildings of the same type.

Keywords: *University energy hub; Foresight; automated heating station.*

Іван М. Грищенко, Світлана В. Бебко
Київський національний університет технологій та дизайну, Україна

ФОРСАЙТ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ БУДІВЕЛЬ НА БАЗІ ЕНЕРГОХАБА УНІВЕРСИТЕТУ

Стаття розкриває суть ключових важелів мотивації до енергозбереження та підвищення енергоефективності закладів вищої освіти. Зокрема, відзначається доволі низький рівень зацікавленості ЗВО до реалізації заходів щодо зниження споживання енергетичних ресурсів. Виявлено, що причина відсутності інтересу до ощадливого енергоспоживання перебуває, насамперед, у площині бюджетного законодавства, адже *розрахунок обсягу коштів на оплату енергетичних ресурсів здійснювався на основі нормативного обсягу споживання ресурсів для конкретної бюджетної установи і наявних (планованих) тарифів на електричну та теплову енергію. Наразі вирішено, що університети не отримуватимуть бюджетного фінансування на оплату комунальних послуг; обсяг субсидій Міністерства освіти та науки України на виконання державного завдання складатиметься з нормативних витрат на надання державної послуги, що залежить лише від контингенту студентів. Нормативні витрати на утримання майна Міністерством не покриватимуться, внаслідок чого в університеті тягар сплати за комунальні послуги повністю перекладається на доходи, що приносять прибуток. Звідси постає необхідність проведення заходів щодо підвищення енергоефективності та енергозбереження для закладів вищої освіти, що й було реалізовано за допомогою форсайт-методики. У межах цього дослідження, форсайт-методику підвищення енергоефективності будівель на базі університетського енергохаба побудовано на таких розрахунках: витратах тепла для опалення громадських будівель, розрахункового годинного теплового навантаження будівлі на опалення, визначенні доцільності організації чергового регулювання опалення, визначення економії теплової енергії від впровадження чергового опалення через створення автоматизованого теплового пункту, а також річної економії в грошовому виразі. З метою економії ресурсів та підвищення енергетичної ефективності на базі енергохаба університету з використанням автоматизованого теплового пункту запропоновано математично обґрунтувати вибір мінімальних та максимальних значень оптимальних параметрів мікроклімату; зменшити інфільтрацію, підвищити ефективність повітря розподілу в приміщеннях; оптимальні режими місцевого кондиціювання, попереднього нагрівання та охолодження; утилізацію «скидних» та природних теплоти та холоду; «комбінування» систем забезпечення мікроклімату з іншими системами; вдосконалення засобів автоматизації технічних систем. Доведено, що підвищення енергетичної ефективності систем опалення будівель університету на базі власного енергохаба дозволить досягти суттєвої економії теплової енергії на опалення та значно знизити емісію діоксиду вуглецю в атмосферу. Крім того, виявлено, що витрати теплової енергії на опалення залежать від проєкту будівлі, якості модернізації, реконструкції та утеплення, застосованих будівельних матеріалів, об'ємно-планувальних рішень, наявності або відсутності систем управління та автоматизації, режиму експлуатації приміщень та ставлення власників до нововведень. У висновках резюмується, що витрати теплової енергії можуть суттєво різнитися в будинках одного типу.*

Ключові слова: *енергохаб університету; форсайт; автоматизований тепловий пункт.*

Иван М. Грищенко, Светлана В. Бебко
Киевский национальный университет технологий и дизайна, Украина

ФОРСАЙТ ПОВЫШЕНИЯ ЭНЕРГОЭФФЕКТИВНОСТИ ЗДАНИЙ НА БАЗЕ ЭНЕРГОХАБА УНИВЕРСИТЕТА

Статья раскрывает суть ключевых рычагов мотивации к энергосбережению и повышению энергоэффективности заведений высшего образования. В частности, отмечается достаточно низкий уровень заинтересованности ЗВО к реализации мер по снижению потребления энергетических ресурсов. Выявлено, что причина отсутствия интереса к экономному энергопотреблению кроется, прежде всего, в плоскости бюджетного законодательства, ведь расчёт объёма средств на оплату энергетических ресурсов осуществлялся на основе нормативного объёма потребления ресурсов для конкретного бюджетного учреждения и имеющихся (планируемых) тарифов на электрическую и тепловую энергию. Принято решение, что университеты не будут *получать бюджетное финансирование на оплату коммунальных услуг; объем субсидий Министерства образования и науки Украины на выполнение государственных задач будет состоять из нормативных расходов на предоставление государственной услуги, что зависит только от контингента студентов. Нормативные расходы на содержание имущества Министерством не будут покрываться, вследствие чего в университете бремя уплаты за коммунальные услуги полностью переводится на доходы, приносящие прибыль. Отсюда возникает необходимость проведения мероприятий по повышению энергоэффективности и энергосбережения для учреждений высшего образования, что и было реализовано с помощью форсайт-методики. В рамках этого исследования, форсайт-методику повышения энергоэффективности зданий на базе университетского энергохаба построено на следующих расчётах: расходе тепла для отопления общественных зданий, расчётной часовой тепловой нагрузке здания на отопление, определении целесообразности организации дежурного режима регулирования отопления, определении экономии тепловой энергии от внедрения дежурного режима отопления в рамках созданного автоматизированного теплового пункта, а также годовой экономии в денежном выражении. В целях экономии ресурсов и повышения энергетической эффективности на базе энергохаба университета с использованием автоматизированного теплового пункта предложено математически обосновать выбор минимальных и максимальных значений оптимальных параметров микроклимата; снизить инфильтрацию, повысить эффективность воздуха распределения в помещениях; оптимальные режимы местного кондиционирования, предварительного нагревания и охлаждения; утилизацию «сбросного» и природного тепла и холода; "комбинирование" систем обеспечения микроклимата с другими системами; усовершенствование средств автоматизации технических систем. Доказано, что повышение энергетической эффективности систем отопления зданий университета на базе собственного энергохаба позволит достичь существенной экономии тепловой энергии на отопление и значительно снизить эмиссию диоксида углерода в атмосферу. Кроме того, обнаружено, что расход тепловой энергии на отопление зависит от проекта здания, качества модернизации, реконструкции и утепления, применяемых строительных материалов, объёмно-планировочных решений, наличия или отсутствия систем управления и автоматизации, режима эксплуатации помещений и отношения владельцев к нововведениям. В выводах резюмируется, что расход тепловой энергии может существенно различаться в домах одного типа.*

Ключевые слова: *энергохаб университета; форсайт; автоматизированный тепловой пункт.*

Introduction. In many countries, according to A. Abu-Rayash, I. Dincer created mechanisms for standardization on the level of energy efficiency, which has become a mandatory requirement for buildings of the public sector: office complexes, educational and cultural facilities, health care buildings [1]. On the share of buildings, according to J. Di Stefano, in Europe accounts for 41% of all energy consumed [2]. Of this energy, 85% is used for heating and cooling, and 15% is consumed as electricity (especially for lighting). On the whole, buildings consume 35% of primary energy to achieve comfortable indoor temperatures and 6% of electricity. According to L. Hanushchak-Efimenko, V. Shcherbak, O. Nifatova, in Ukraine, almost 80% of all buildings, structures and constructions of the country are housing stock [3]. Energy consumption by residential buildings is 23% of primary energy, i.e. almost a quarter of all energy consumption in our country [4].

A measure of energy efficiency, according to J. Liu, Q. Yao, Y. Hu, is the ratio of real consumption to the estimated or estimated amount of energy required to meet various needs in the standard operation of the building [5]. At calculation of energy efficiency (J. Nayak, M. Mishra,

B. Naik, H. Swapnarekha, K. Cengiz, V. Shanmuganathan), the following types of consumption of thermal and electric energy are considered: heating, hot water supply, cooling, ventilation, lighting, other types of energy consumption [6]. Heat and electric energy (K. Shaposhnikova, V. Shimov) to achieve high energy efficiency must be consumed in minimal amounts [7]. The degree of energy efficiency of an individual building, according to V. Shcherbak, L. Hanushchak-Yefimenko, O. Nifatova, P. Dudko, N. Savchuk, I. Solonenchuk [8, 9], is determined by comparing it with normalized values. It can be documented, for example, in energy passport of building. At present, there are building standards for the construction of buildings with low energy consumption. New buildings should only be built according to low-energy standards and equipped with energy-saving functions of an energy efficiency class A automation system [10].

For an automatic building management system, it is necessary to:

class A – indoor climate control with automatic consideration of energy demand;

class B – climate control in the premises without automatic accounting of energy demand;

class C – automation of basic installations in a building, no electronic controllers or thermostatic valves on heating radiators in premises;

class D – no electronic controllers in rooms, no control of energy consumption.

A number of measures can noticeably improve the energy efficiency of existing buildings:

- upgrading utilities with the installation of building automation systems;
- setting comfort temperature limits for heating and cooling;
- equipping the ventilation system with heat recovery means;
- reducing heat loss through the building envelope;
- modernization of old buildings.

The purpose of this study is to propose a methodology for Foresight to improve the energy efficiency of buildings on the basis of Energohab University. Data on energy use was collected and processed in 2021 in Kyiv National University of Technologies and Design (KNUTD).

Matherials and methods. Heat consumption Q for heating public buildings can be determined by aggregate indicators – specific heat characteristic q according to equation (1):

$$Q = \alpha \cdot q \cdot (t_1 - t_2) \cdot \nu, \quad (1)$$

where v – building volume in m^3 according to the external dimensions;

t_1 – average temperature of the heated room (18ºC);

t_2 – design value of the outside air temperature;

q – coefficient, taking into account the change in the specific thermal performance depending on climatic conditions.

For the efficient use of energy resources and the possibility of regulating the consumption of thermal energy in the heating system in the building 4 of KNUTD it is necessary to install an automated heating unit with outdoor and indoor air temperature sensors. According to an appropriate program the regulator can reduce the temperature in the premises at night and on weekends, which is most relevant for the buildings of the public sector. Automated control of the heating load allows you to save money in the autumn and spring, when a common problem is the presence of overheating associated with the features of the central quality control of the heat load at the heat supply sources. Schematic diagram of installation of automatic heating load regulation system with circulating pumps is given in [4].

Calculated hourly heat load of the building for heating is (equation 2):

$$q_h = \frac{Q}{z \cdot 24}, \quad (2)$$

where Q – annual consumption of heat energy for heating the building;

z – duration of the heating period.

The organization of the standby regulation of heating assumes that the air temperature in the rooms of the building is reduced to 14ºC. The hourly heating load in this case will be (equation 3):

$$q_h^d = q_h \times \frac{(t_a^d - t_o^{av})}{(t_o - t_o^{av})}, \qquad (3)$$

where t_o^{av} is the average outdoor air temperature during the heating period;
t_o – design air temperature in the premises (18ºC).

Saving thermal energy from the introduction of standby heating during the heating period (equation 4):

$$\Delta Q_{du} = Q - Q_{du}, \qquad (4)$$

where Q_{du} – the annual consumption of heat energy for heating the building at the organization of standby heating.

Total savings of heat energy due to the organization of an automated heat point (equation 5):

$$\Delta Q = \Delta Q_{du} + k \cdot Q, \qquad (5)$$

where *k* is the coefficient of efficiency of heat load regulation in the autumn-spring period.

Annual savings in monetary terms (equation 6):

$$\Delta Ec = \Delta Q \cdot T \cdot 10^{-3}, \qquad (6)$$

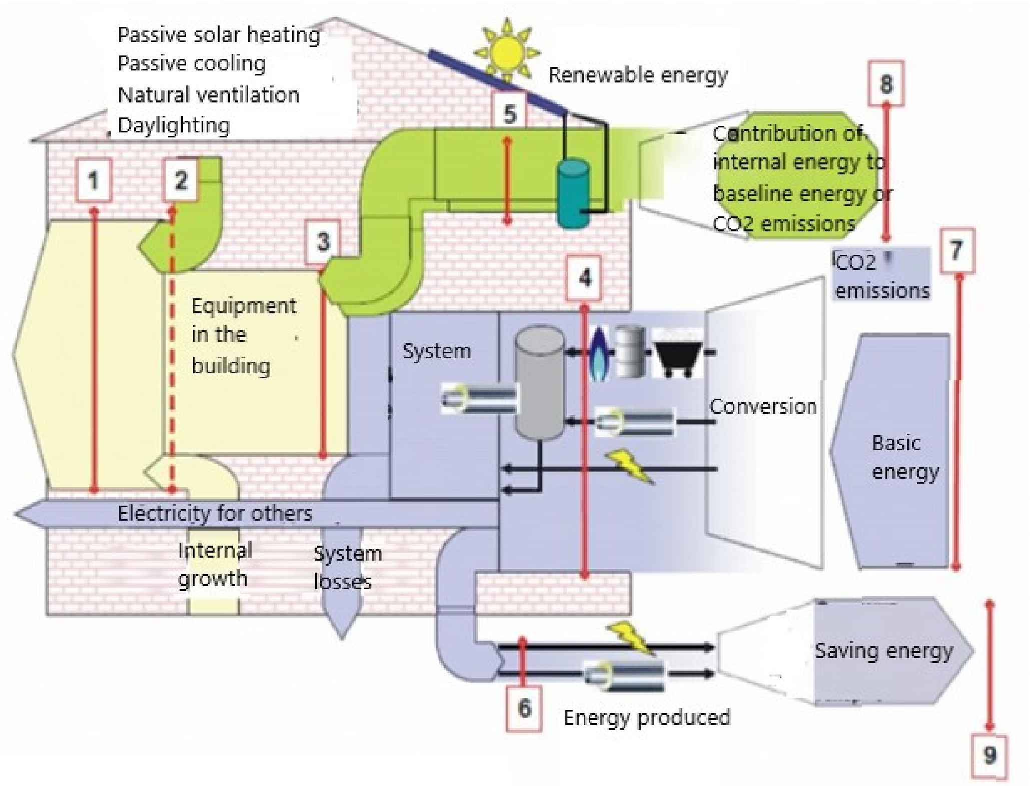
where *T* is the tariff for heat energy.

Results and discussion. The automation system of the university building No. 4 collects information to control energy consumption and other equipment. In addition, effective control of energy consumption is provided.

The energy efficiency of a building is defined as the calculated or actually measured amount of energy consumed for various needs during standard building operation. Building automation and building services controls affect energy efficiency in many ways. Building automation systems provide efficient automation for controlling heating, ventilation and cooling, hot water, lighting, etc., thus increasing operational efficiency and reducing energy costs. Sophisticated integrated processes and energy-saving functions are configured according to the specific conditions of the building and the user's needs, thus avoiding unnecessary energy consumption and CO2 emissions. Building automation systems, especially building services management, provide information for building operation and maintenance and energy management [4]. This includes functions for trending energy consumption, alarming, and identifying energy losses.

The building automation system of university building No.4 and engineering communications management is calculated by means of simulation modeling (Fig. 1). It is based on heat flow models, e.g. a heat flow model to maintain the set temperature in the rooms.

The general calculation process is to go through the energy flows from left to right according to the model described above. The model shown (Fig. 1) is only a schematic illustration and does not describe all possible options. For example, an underground heat pump uses electricity and renewable energy from ground heat. The electricity generated in the building by the solar panels can be used both in the building itself and transmitted to the grid. The rooms are sources of energy demand. Appropriate ventilation and air conditioning installations, heating and lighting systems must guarantee comfortable indoor conditions in terms of temperature, humidity, air quality and light. Energy is supplied according to the needs of the user, thus minimizing energy losses during generation and distribution. The different functions of building automation systems are consistent with a supply and demand model, for example installations that regulate the transmission of thermal energy to consumers (heating batteries, chilled ceilings, air conditioning systems with variable airflow) can use different carriers (water, air, electricity). Therefore, various building automation systems can be used to implement this function. Demand-driven control is based on the presence of people in the room from a presence detector or a time sensor. Occupancy information is used to control heating, cooling and ventilation and air conditioning.



The conventional symbols of Figure 1: 1 – energy needed to meet the user's needs for heating, lighting, cooling, etc. at the level adopted in the calculations; 2 – "natural" energy gain - solar heating, ventilation cooling, daylighting, etc. together with internal gain (people, lighting, electrical equipment, etc.); 3 – total energy consumption in the building, derived from (1) and (2), taking into account the characteristics of the building itself; 4 – delivered energy separately for each energy carrier, including all auxiliary energy used for heating, cooling, ventilation, hot water supply and lighting, taking into account renewable sources and combined energy production, expressed in energy units or consumption; 5 – renewable energy produced in the building itself; 6 - generated energy produced in the building and supplied to the market, it may also include some energy (5); 7 – represents basic energy use or CO_2 emissions produced by the building; 8 – represents basic energy or emissions caused by on-site energy generation and use, this value is not subtracted from value (7); 9 – represents basic energy or CO_2 emissions reduction associated with exported energy, which is subtracted from value (7).
Source: [4].

Fig. 1. **Model of energy flows of the building**

Special monitoring functions must be installed in the building automation system to detect errors.

1. Temporary operating schedules. This is especially necessary in buildings with non-permanent occupants. The monitoring functions should include, at a minimum, a displayed schedule

or time indicator when the fans are on and the cooling system is running, the heating system is in normal mode, and the lights are on.

2. Inserts. The monitoring features should include a graph or indicator that allows you to see an overall picture of the different temperature inserts of heating and cooling.

3. Simultaneous heating and cooling. If the system results in simultaneous heating and cooling, the monitoring functions should be set to avoid or minimize simultaneous heating and cooling. Switching between heating and cooling should also be monitored.

4. Prioritize the energy sources with the best energy performance. If several energy generation systems with different energy characteristics can be used for the same function (e.g. a heat pump or a solar thermal storage system operating as both a primary and a secondary source), the monitoring functions must be set to control the prioritization. The monitoring functions allow the current climate conditions, internal temperature, internal heat production, types of hot water use and lighting, and indoor air quality to be taken into account. The monitoring function can be used to prepare and display energy consumption schedules, report current room temperature and air quality readings. In buildings where there is no permanent presence of people, these functions should be different for periods of presence and absence.

One of the most important target indicators of effective energy use for budgetary institutions is the specific values of energy resources consumption [5, 8].

During the examination of the technical condition and efficiency of operation of different heating systems of the university building No.4 the following works were carried out:

- analysis of the heating system operation modes;
- analysis of the state of thermal insulation and heat losses in the internal heating networks;
- analysis of data about the volumes of energy resources used;
- analysis of financial costs of energy resources;
- analysis of the data from the instrumental inspection of the energy supply systems;
- thermal imaging survey of buildings (Table 1).

Table 1

Structure of consumption of energy resources of building №4 of KNUTD

Building	Energoresource	Dimension	2018	2019	2020	2021
Building No. 4 of KNUTD	Electricity	thousand kW·h	18.2	16.4	14.2	16.1
		UAH mln	2.7	2.6	2.5	2.4
		tons of fuel equivalent	6.3	5.7	4.9	5.1
	Heat	Gcal	45.3	75.4	86.3	82.4
		UAH mln	2.3	3.8	3.5	2.8
		tons of fuel equivalent	6.7	11.2	12.8	12.2
	Total	UAH mln	5.0	6.4	6.0	5.2
		tons of fuel equivalent	13	16.9	17.7	17.3

The data array of monthly electricity consumption by buildings in graphical form is shown in Fig. 2. It should be noted that if the electricity consumption of building No. 4 of KNUTD during the year can be conditionally considered more uniform. At the same time, in summer, especially during the transition period (in June and September), there is an increase in electricity consumption (in some years two or three times), which is caused by additional heating of the premises with electric heaters (Fig. 2). Usually, the heating period ends in the last decade of May and begins in the second decade of September.

In order to compare the volumes of consumed energy resources for the building No. 4 of KNUTD building let's convert all the values to one indicator – tons of fuel equivalent: 1000 kWh =

0.3445 tons of fuel equivalent (electric power); 1 Gcal = 0.1486 tons of fuel equivalent (heat energy).

From the presented in Fig. 3 values of the consumed energy resources, reduced to the units of fuel equivalent, it is clear that the power consumption for the building of the building № 4 KNUTD on the average 2–3 times higher than the consumption of energy resources (electricity and heat) for the other buildings of the university. Thus, the implementation of energy-saving measures and measures to equip buildings with technical means, designed to save energy resources, it is necessary to implement after their economic justification for the end user.

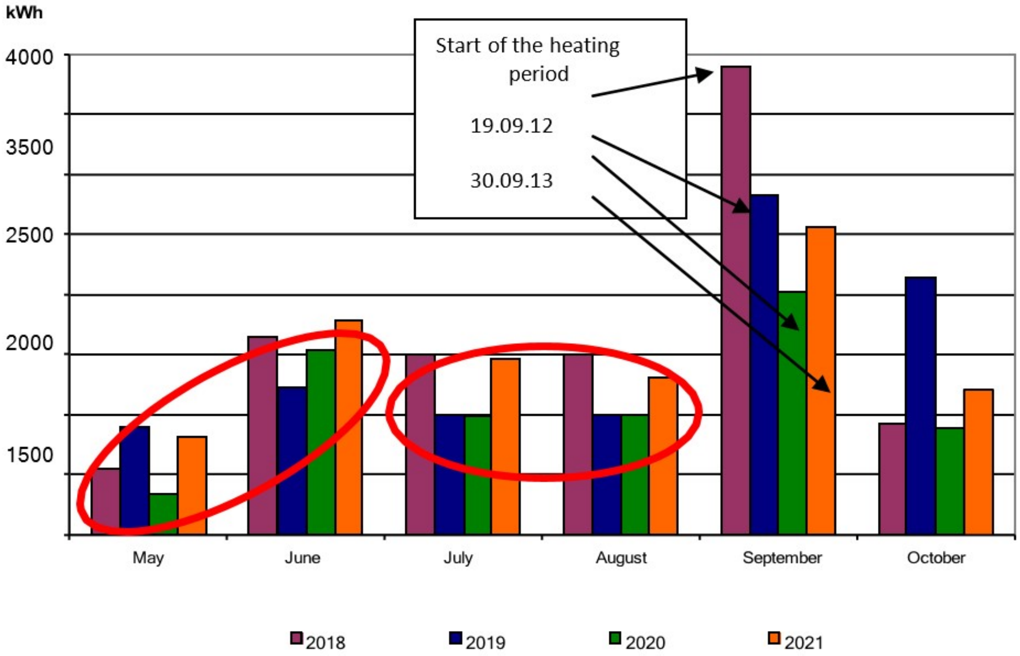


Fig. 2. **Electricity consumption in the spring-summer-autumn period by the building No. 4 of KNUTD**

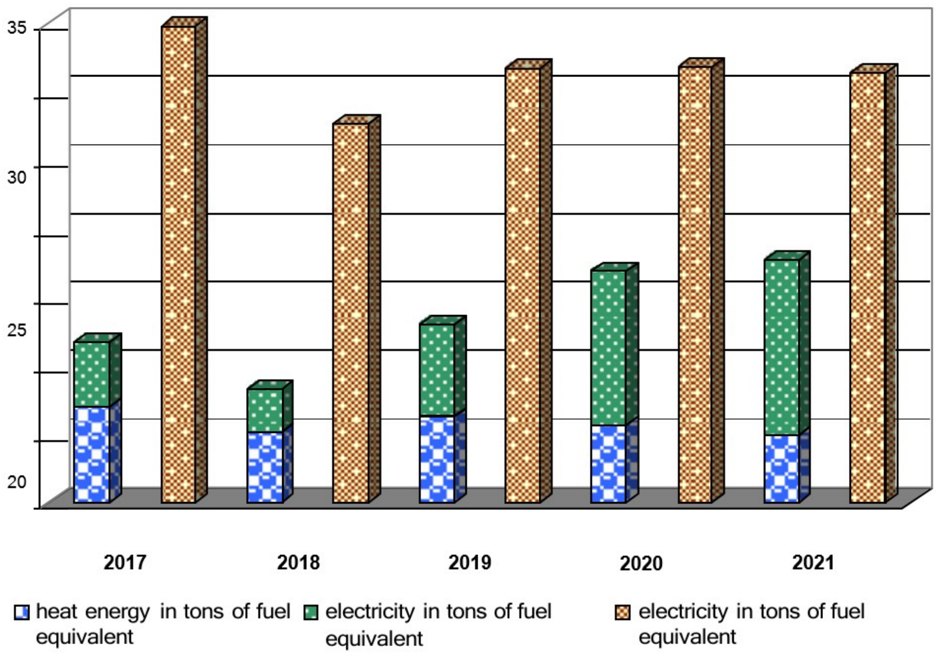


Fig. 3. **Volume of energy resources consumed by KNUTD buildings**

Conclusion. To improve the efficiency of energy cost management of budget organizations, it is necessary to establish a system of information support for this activity. Today, as in the whole country, it is difficult to assess the efficiency of energy use in the public sector. Even where there is data on total energy consumption, as a rule, there is no information on the area of budget buildings or there is only sketchy data. The best projects can be presented at national, regional and municipal competitions "Energy Stars" and thus disseminate best practices. It is necessary to organize advisory assistance to budgetary organizations, they should be provided with methodological recommendations on developing programs and on conducting energy audits, on creating a monitoring and reporting system. Annual reports should be submitted to the relevant authorities on the results of target implementation, which should contain an assessment of energy savings resulting from the implementation of programs; the degree of proximity to the target setting; an assessment of the effectiveness of the implementation of allocated funds.

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