Power supply for educational institutions: efficiency and alternatives

Collective monograph edited by M. Sotnyk,
Doctor of Technical Sciences

Accent Graphics Communications & Publishing

Accent Graphics Communications & Publishing

Hamilton, Canada 2020

UDC 629.78: 338.4 C67

Recommended for publication by the Academic Council of Sumy State University (Protocol No. 1 dated August 28, 2020)

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C67 **Power supply for educational institutions: efficiency and alternatives:** Collective monograph /edited by M. Sotnyk, Doctor of Technical Sciences. - Hamilton, Canada, Accent Graphics Communications & Publishing, 2020. - 146 p.

ISBN 978-1-77192-572-3

Proposed methodological approaches to modeling short-term forecasting and longterm planning of electrical consumption in educational institutions based on retrospective data. A logic-structural model and software of the circuit “object of monitoring of electric consumption — factors of influence — regulatory tools” of an automated system for controlling the efficiency of energy consumption in educational institutions have been developed. There are given practical recommendations of feasibility study of introduction of alternative power supply sources in educational institutions, in particular: solar generation, heat pumps, autonomous energy sources, etc.

Proposed scientific and methodological approaches to the introduction of an organizational and economic mechanism for managing the development of renewable energy in educational institutions and a motivation system for employees of the energy management service.

The monograph is a generalization of scientific research conducted by employees of Sumy State University during the state budget research work “Model of an efficiency management and forecasting system for the consumption of electric energy” (State Registration No. 0118U003583).

The monograph is intended for researchers and specialists in the implementation of energy management systems.

UDC 629.78: 338.4

ISBN 978-1-77192-572-3

CONTENTS

INTRODUCTION

Reduction of electricity consumption is possible due to the introduction of new energy-efficient equipment in technological processes and introduction of organizational and technical measures aimed at optimization of modes and regulation of electric and heat consumption.

In the monograph, at the system level, deals with these two aspects of optimizing energy consumption: it summarizes the results of scientific research on managing the efficiency of electric consumption in educational institutions. The specific features of educational institutions as an object of electricity supply were identified, which consist, first of all, in the mode and structure of electricity consumption. It is these features that are taken into account in the development of methodological approaches to modeling short-term forecasting and long-term planning of electricity consumption. The dynamics of internal (technical and economic, structural, regime) and external (meteorological, ecological, energy, macroeconomic) restrictions of electric consumption is investigated and included in the proposed models.

The improvement of the system for managing the consumption and saving of electricity by individual facilities (institutions) and sectors of the economy as a whole provides for the creation of a regional-sectoral organizational and economic model. The scientific and methodical approaches proposed in the monograph for the development of the energy saving management system in the education sector are aimed at forming the organizational foundations and algorithmic base for collecting, processing, analyzing information on the use of electricity, making management decisions and conducting an electrical energy audit, monitoring electricity consumption, improving the electricity limiting system, creation of electric power certificates of objects.

From a practical point of view, the development of analytical tools of an automated software complex for short-term forecasting and long-term planning of electricity consumption, including for educational facilities, consists in adapting the methodology, methodological principles for the generation and processing of incoming information, taking into account factors affecting the amount of electricity consumption contained in "International Performance Measurement & Verification Protocol. Concepts and Options for Determining Energy and Water Savings. Volume I".

The adaptation procedure includes several interrelated steps:

- development of a concept of a management system for electricity consumption and electricity saving and for assessment of electric power efficiency of educational facilities;
- development of a model of a system for managing efficiency and forecasting of electric energy use by consumers;

- development of an adapted model for predicting the electric energy consumption, based on a combination of elements of autoregressive integrated moving average (ARIMA), structural and cointegration (theory by R. Engle and K. Granger) models, etc.;
- development of a methodological support (toolkit) for the creation of a system for controlling the processes of efficient electricity consumption: universal economic and mathematical models of the electric consumption processes of objects in the education sector, methodological materials for the organization of an energy saving management system;
- development of an automated software package for short-term forecasting and long-term planning of electricity consumption based on retrospective data and taking into account the dynamics of external influences (technological, weather, organizational, regulatory);
- development of a recommendation on the implementation of a power consumption and saving management system and assessing the electric power efficiency of complex economic facilities (using the example of the education sector) on the basis of an automated software complex.

One of the main stages is the development of an automated software package for short-term forecasting and long-term planning of electricity consumption. It is the results of forecasting and planning electricity consumption that can be the basis for the development of energy conservation projects based on the principles of Enterprise Content Management (ECM).

At the same time, the choice of one or another model for forecasting the electric energy consumption by consumers depends on the organizational and managerial tasks for optimizing electric consumption that the analyst sets himself. The choice of models depends on both the technical capabilities and the cost-effectiveness of their implementation. In any case, you must follow the general recommendations set out in the Handbook (1997) American Society of Heating, Refrigerating and Air-Conditioning Engineers - (ASHRAE), in particular in section 30 - Energy Eatimating and Modeling Metods.

The development and implementation of the system proposed in the monograph allows us to establish a forecast of electric energy consumption in educational institutions by the types (elements) of their activities: educational process, maintenance of the educational process, scientific research, experimental design, etc. Such a forecast and a system of current monitoring of actual energy consumption should become the basis for the further formation of levers of influence on the encouragement of staff and managers of educational institutions and other institutions to effectively implement energy saving. At the same time, it should be considered as a basic element of the general system for forecasting electricity consumption for a particular region, and, therefore, the formation of energy consumption and generation balances at the regional and state levels. That is, it should become the basic element on which the regional and state system of short-term forecasting of electrical energy consumption, optimization of energy balances, rational consumption of electrical energy and its generation is based and developed. This approach allows, on the one hand, to establish effective control over the electricity consumption, and on the other, to minimize its generation, which should reduce the environmental burden on the environment.

The monograph proposes and justifies the logical-structural model and software of the circuit “object of monitoring electric consumption - factors of influence - regulatory tools” of the system for controlling efficiency and predicting the electric energy consumption for educational institutions. Both the scientific and methodological foundations for the organization and construction of an automated system for short-term forecasting and monitoring of electricity consumption by educational institutions, as well as hardware and software, have been developed. The monograph contains important practical recommendations. In particular, a structural diagram of information blocks of the algorithm for calculating the forecast volumes of electricity consumption was thoroughly developed, the “spectrum” of electric consumption in the educational process was analyzed and the method of analyzing its components was proposed.

Considerable attention is paid to the feasibility study for the introduction of alternative sources of power supply: generation of electric energy with the location of solar panels on the enclosing structures of educational institutions, etc.

The materials presented in the monograph can be useful for specialists in public administration in the formation and implementation of an effective organizational and economic mechanism for managing electricity consumption in educational institutions, built on the principles of renewable energy.

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Placing solar panels on the wall of the building according to the option of their location at an angle of about 45° gives an increase in electric power generation during the peak of solar activity by almost 30% compared to the option of placing panels vertically in one plane on the wall even if the area use factor is increased almost to one.

Technical and economic calculations show that under certain climatic conditions of the northern part of Ukraine, the location of the building, its architectural features, the option of stationary location of solar panels on the roof without single-turn trackers is more attractive.

The comparison of calculation data shows that under certain climatic conditions, building conditions, its architectural features, the option of stationary location of solar panels on the wall with the tilt angle of the panels to the wall, according to the scheme of (Fig. 2.7 b), is more attractive.

2.4. Technical and economic aspects of heating systems organization in buildings of educational institutions on the basis of electricity use by heat pumps implementation.

The use of heat pumps as a generator of low-potential heat energy in heating systems of buildings is really a very promising area of heating systems development of buildings. However, their widespread implementation is currently hampered by several technical, organizational and financial and economic problems.

As you know, the heating system (individual or central) consists of several components: the consumer with its heat load, the heat transport system to the place of application (with possible heat loss) and the heat generator (as boiler equipment using the fuel oxidation reaction - combustion, electricity, or low- potential ambient heat concentration).

When designing and constructing buildings, designers have always solved the technical and economic problem of balancing the capital costs for the construction of enclosing structures and operating costs for their heating.

Traditionally, in civil engineering and public construction, in deciding, standard proven technical solutions were applied, according to which building enclosing structures had a certain thermal resistance (and hence the corresponding thermal capacity of the building) for which the systems of thermal energy generation and transportation to the building were used, to maintain comfortable temperature conditions relative to indoor air temperature. Heat losses of the building depend on the temperature difference between outdoor and indoor air, and to ensure comfortable conditions it is necessary to change the amount of coolant that passes through the heating system at its constant temperature (quantitative regulation) or change the temperature of the coolant at the fixed amount of coolant (qualitative regulation). Traditionally (and this is justified from a technical point of view) the method of quality control is used when regulating the amount of heat supplied to the building. The temperature schedule of the coolant supply in district heating networks is 150-70 °C, 130-70 °C, 110-70 °C, 95-70 °C, or other. Accordingly, the hydraulic model of the network and the heating system of the building is calculated. Under these conditions (for example, 110-70 °C), the temperature of direct and return heating agents at ambient temperature -30 °C should be 70-50 °C. This temperature regime of the heating network is critical in terms of the quality operation of centralized hot-water supply system. According to existing norms and rules, hot water at the inlet to the consumer must be at a temperature not lower than 50 °C. Heat exchangers operated in such systems are designed based on the minimum temperature of direct coolant about 70 °C. That is, under such conditions, further decrease in coolant temperature in heating mains at the entrance to the central heating points and buildings in which individual heating points are installed is impossible. Is it possible to solve this problem by heating the building without providing it with centralized hot water supply?

One of the main criteria that should be considered when deciding on the possibility of using current collectors in heating systems of a building as a heat energy generator - a heat pump is the climatic indicator of the heating season. Given the technical characteristics of heat pumps available on the market, it is advisable to analyze the time intervals of their possible operation under climatic conditions, which are characterized by several ranges of ambient temperature, because it changes the heat load of the building and the coefficient of performance in the heat pump.

The peculiarities of climatic conditions of the North-East and North of Ukraine are further analyzed, under which the option of electricity use for heating buildings by means of a heat pump as a heat generator is considered.

The results of the analysis are given according to the initial data of Sumy Regional Center for Hydrometeorology (for the last five years), the temperature variation range of mean daily ambient temperatures during the heating season, which is grouped by three temperature ranges:

- 1st range - above -3 °C;
- 2ndrange—3...-10°C;
- 3rd range-below-10 °C.

These ranges are classified by their length during each month of the heating period. Figures 2.8-2.12 show pie charts of the percentage of these ranges.

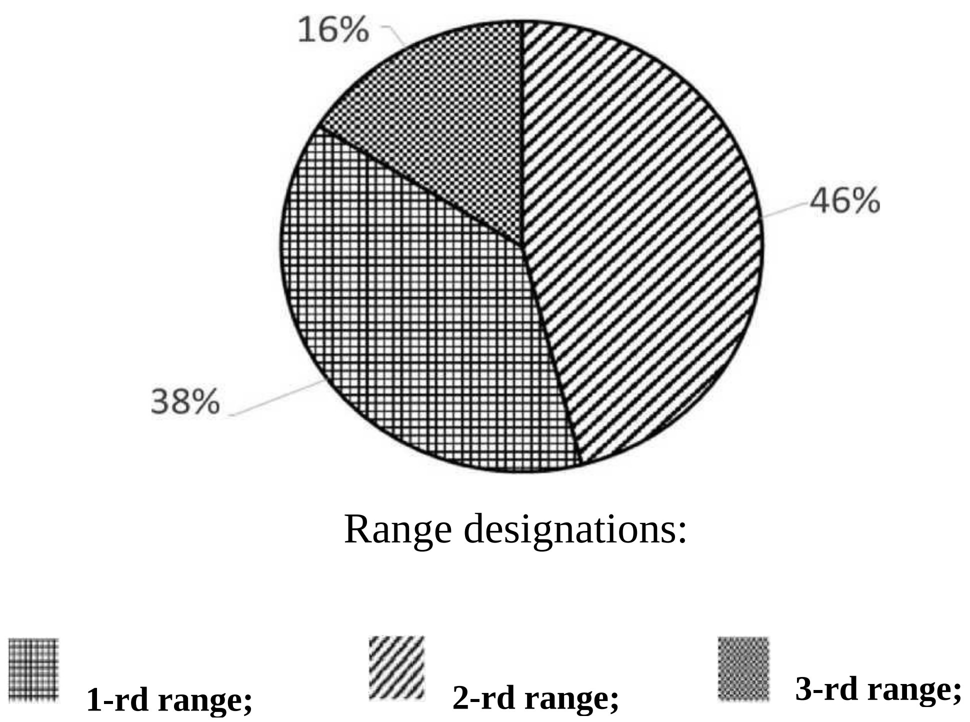


Figure 2.8 The average ratio of ambient air temperature ranges in percent in January

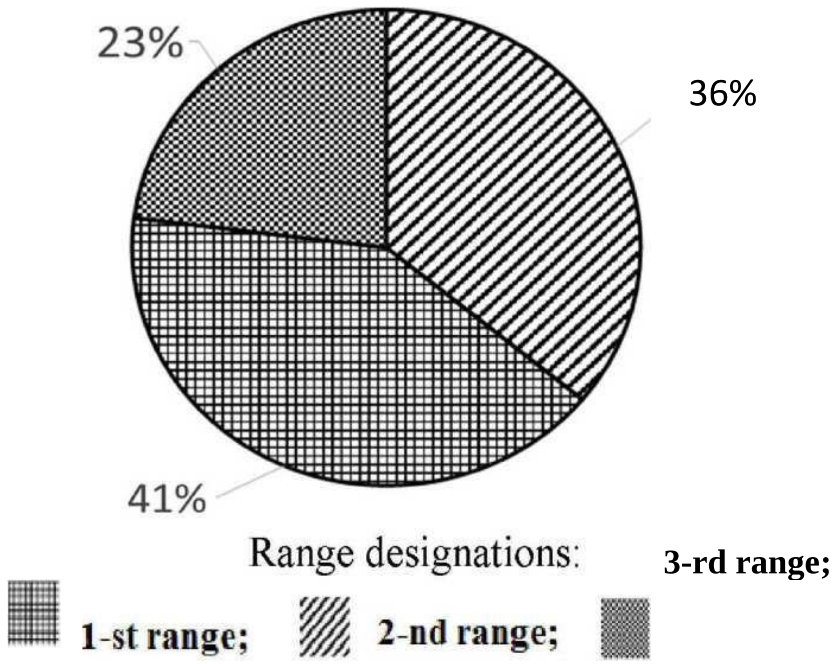
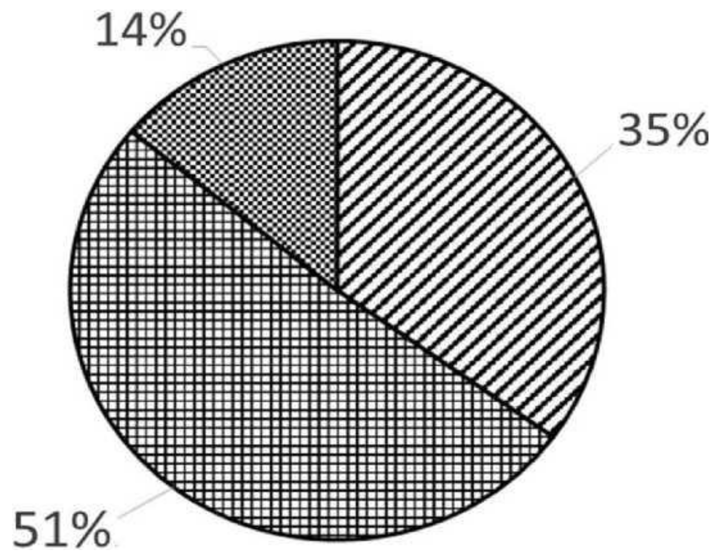


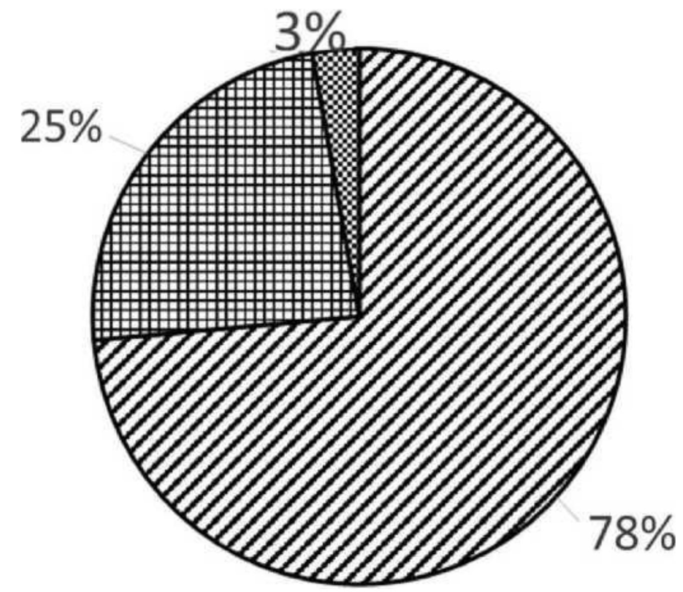
Figure 2.9 The average ratio of ambient air temperature ranges in percent in February



Range designations:

1-st range; 2-nd range; 3-rd rang

Figure 2.10 The average ratio of ambient air temperature ranges in percent in March



Range designations:

1 st range; 2-nd range; 3-rd range;

Figure 2.1 The average ratio of ambient air temperature ranges in percent in November

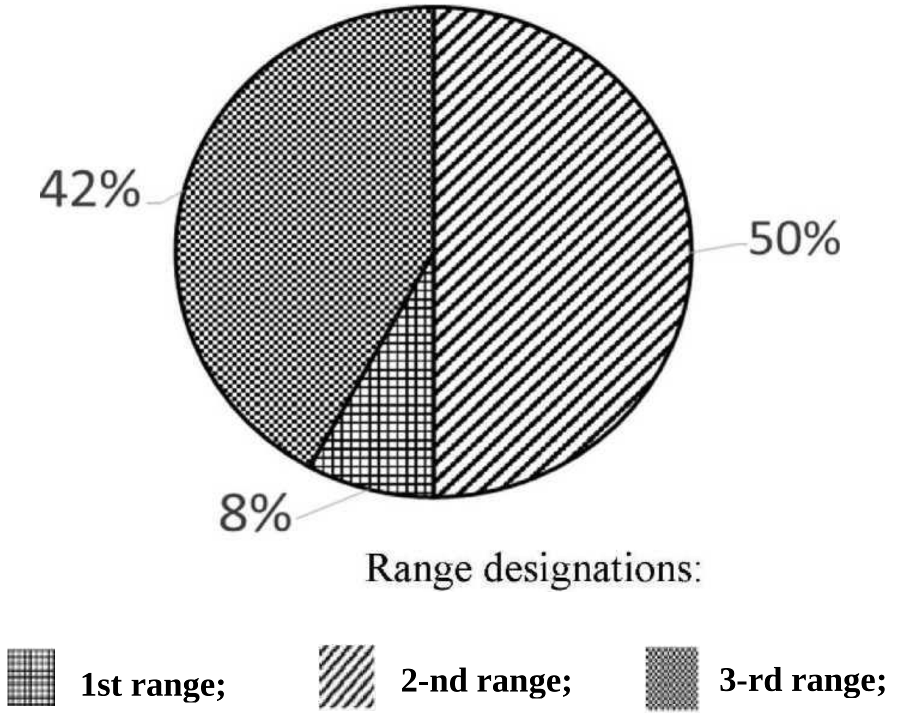


Figure 2.12 The average ratio of ambient air temperature ranges in percent in December

The average percentage of ambient air temperatures in April and October is in the first range.

Given that, according to current regulations, the standard length of the heating season for cities in this climate zone is 195 days, the number of days with the average daily ambient temperature during the heating period, differentiated by temperature ranges, is (table 2.4).

Table 2.4 - Differentiation of the heating period according to the ranges of ambient air temperatures and the level of the heat load of the building

Temperature range, °C	Number of days in the range, days	Coefficient of the heat load of the building K_{hbat} (average)
1st range - above -3 °C;	93	0.49
2nd range--3...-10 °C;	72	0.58
3rd range - below -10 °C.	30	0.6 ... 1

A detailed elaboration of the 2nd range indicates that the number of days in which the average daily ambient temperature is in the range - 3 °C - 6 °C is about 50% of the total number of days in the range.

These results are necessary for further technical and economic calculations to determine the feasibility of electricity usage in heating systems of buildings with the application of heat pumps.

Considering the technical characteristics of the heat pumps models present on the market, the fact that the appropriate maximum (from a technical and economic point of view) temperature of the coolant leaving the heat pump is about 40 °C. In this case, the coefficient of performance (COP) is about 2. Further increase in this temperature is not expedient, because COP approaches its value close to 1. In such circumstances, it is economically impractical to use heat pumps, because they lose their economic advantages over traditional heat generation (currently the cost of 1 kW of heat energy obtained from traditional district heating systems is an average of UAH 1,2, the cost of 1 kWh of electricity at a single rate is about UAH 2,5). That is, the replacement of traditional heat generation units with heat pumps without modernization of enclosing structures in consumer buildings, changes in hydraulic regimes and modernization of heating networks, reconstruction of heating systems of buildings is practically impossible. That is, the critical ambient temperature for the heat pump used in traditional heating systems (without thermal modernization of buildings and their heating systems) is -3 °C, the heat pump operation is appropriate in the first range of ambient temperatures. The length of this period is about 90 days (about half of the heating season). As already mentioned, the next problem is a hot water heating system. It is necessary to switch to an individual water heating system in an electric water heater, which at the cost of electricity used at a single rate, cannot compete with the thermal energy of district heating systems.

The source of thermal energy for accessible heat pump designs can be ground source heat, surface water heat, atmospheric air heat, wastewater heat and other man-made sources. Given the application of these sources, educational institutions are very limited in their choice due to the existing adjacent areas, the existing architectural and planning situations around the buildings of educational institutions. In the conditions of real development of settlements, it is problematic to allocate a land plot for the arrangement of downhole facilities and a collector necessary for the arrangement of circulating systems of the ground “heat exchanger”. According to calculations, it is necessary to use a land area of about 6 thousand square meters for the heat pump operation on the system “soil - water” in the heating system of the building with a maximum heat load of about 0,2 Gcal/h. The use of heat from surface water bodies is unattainable for many households in educational institutions. As you can see, even a surface analysis shows the problematic use of electric energy in heating systems of buildings of educational institutions using heat pumps according to the “soil-water” scheme.

The most available and economically feasible option is the heat pump use according to the “air-water”, or “air-air” scheme. Although the energy efficiency of this option of heating is slightly worse than discussed above, its economic performance is better. The capital expenditures for its implementation are smaller in volume, but technically and economically, these schemes have the same drawbacks regarding the optimal temperature range of the coolant and their problematic use at low ambient temperatures. However, in some cases, it is advisable to use such schemes under conditions of small rooms sizes and special modes of heating. It should be noted once again that heating systems that are designed for traditional heat generators and traditional temperature schedules of the coolant cannot operate using these heat pumps without reconstruction (it mainly concerns the development of heating surfaces of heaters).

An attractive source of low potential thermal energy can be the heat of effluents generated in showers, catering establishments. It is known that the amount of heat that can be accumulated in the body, as well as taken from the body, is proportional to its mass and the temperature difference (initial and final) during its cooling. Given the dynamics of effluents formation and their energy parameters draws attention to the fact that they are energy-intensive enough, but intermittent during the formation period and cannot, due to this circumstance, serve as a continuous source of thermal energy. Calculations show that the operation of heat pumps in thermal energy utilization systems is technically feasible (with a high value of COP - about 4 ... 5) in water preheating systems for hot water supply. That is, it is proposed to introduce pre-heating of cold water (1st stage) with subsequent heating according to the existing technology in the institution.

A simple calculation shows that if cold water enters the first stage of heating with a temperature of about 15 °C and it is heated to a temperature of about 30 °C (in the summer period), the thermal energy coming from the central heating system should be about 35% in summer and about 12% in winter. At the same time, the consumption of electric energy in such a process will be (in absolute figures - kW of thermal energy in kWh of electric energy) four times less, which is economically feasible even considering the difference in tariffs for electric and thermal energy. However, to make a final decision on the possibility of implementation, it is necessary to analyze further the cost of all elements of the life cycle of such a technology. As already noted, the period of the heating season during which the use of a heat pump to generate heat energy is technically justified is about 93 days; this can include part of the 2nd range (about 36 days, although the heat pump efficiency will be decreased by reducing COP to 2,5). This fact should be considered when calculating the economic feasibility of implementing measures to equip heating systems with heat pumps.

Then there is the question of effective supply of thermal energy to the building when the ambient temperature drops below - 10 °C. Alternatively, it is proposed to consider combined heat supply in the 3rd range of ambient air temperatures using another high-potential heat source. It can be a separate boiler that uses traditional fuels or a district heating system. This option may be acceptable in the case of additional equipment of local educational facilities connected to the existing central heating system, heat generators using heat pumps. In this case, the centralized heat supply system (or a secluded boiler, which in its heat capacity satisfies the building's maximum heat load during peak loads) should be a backup source and provide the educational institution with thermal energy when the ambient temperature drops below - 7 °C. The decision point regarding the operation of the heat pump, or switching the heating system to a high potential heat supply source, must be the fulfilment of the conditions: the cost of 1 kW of thermal energy supplied to the building heating system and generated by the installation of a heat pump is equal to the cost of 1 kW of thermal energy from a highly potential source of thermal energy.

If we consider the above, then at an electricity tariff of about UAH 2,5/ kWh and a tariff for thermal energy from a highly potential source of UAH 1,29/ kW, the coefficient of excess electricity tariff (provided that all other technical indicators of the system are equal) over the heat energy tariff is 2,5/1,29 = 1,93. That is, if the heat pump reaches COP of 1,93 or less, its further use under the considered conditions is not economically feasible.

Another condition that limits the heat pump use is the thermophysical properties of enclosing structures and the sanitary and hygienic requirements for indoor air temperature. The maximum thermal load of the building and the design parameters calculation of the heating system depend on these parameters, and the thermal schedule for supplying the coolant to the heating system of the building is also selected. According to this schedule, the temperature parameters of the heating system are coordinated with the ambient air temperature. If we compare the above cost indicators of heat and electric energy, consider the calculated minimum COP value of the heat pump, and also determine the ambient air temperature at which the heat pump reaches a certain COP value, it is quite simple to examine the temperature of the heat carrier at the outlet of the heat pump. Compared with the heat supply schedule, it will be a critical indicator of the ambient air temperature, which should become the point of decision-making on changing the heat supply source to the building, provided that the combined heat supply system operates.

Based on the above analysis, the express method of the technical and economic evaluation of the indicators of capability and limits of heat pumps operation in buildings heating systems of educational institutions are proposed in the following steps:

step 1 - the determination of climatic features of the heating season in educational institution (differentiation of ambient air temperatures by ranges of temperature indicators);

step 2 - the definition of specific cost indicators of thermal energy from possible and available sources of its generation (electric energy, thermal energy from high-potential sources: separate boiler installations, district heating systems etc.);

step 3 - the determination of the minimum operational value of COP of the heat pump ($COP_{cnHcflZ}$), based on the specific cost of heat for different types of energy resources and generation systems;

step 4 - using the information on the thermal building schedule of coolant supply to the heating system, the calculated value of COP_{cnfiW} and passport data of the heat pump to define the agreed ambient temperature $T_{critical}$ °C, which makes a management decision on further feasibility of heat pump operation;

step 5 - based on the results of step 1 and step 4, to determine the possible service life of the heat pump during the heating season with differentiation of the average calculated value of COP in each of the temperature ranges for use in in-depth economic calculations on the expediency of heat generation systems implementation using heat pumps operation;

step 6 - the use of calculation results of technical and economic indicators in heat pump operation for short-term forecasting and monitoring of electricity consumption in heating systems of buildings.

In the event that the limited indicator of the heat pump used at the temperature point is $T_{v.}$, °C is the temperature of the coolant at the outlet of the heat pump; you must select a new point T . °C which corresponds to the required coolant temperature according to the temperature schedule of the coolant supply to the building heating network and determine the COP at this point. It is also necessary to clarify the temperature range of the estimated period of heat pump operation during the heating season and to conduct clarifying technical and economic calculations of its performance.

It should be noted that due to their technical capabilities, heat pumps offered on the Ukrainian market are limited by the installed heat capacity and cannot always provide heat to large facilities.

Unfortunately, the domestic industry practically does not offer heating systems with heat pumps, which by design features fully meet the climatic conditions of our heating season, and those existing on the market are mostly adapted to the climatic conditions of the Western Europe.

There are many environmental problems related to the use of heat pumps that arise during their operation.

It should be noted that the use of heat pumps, at first glance, seems a profitable measure, if you do not consider the range of problems associated with their use in the existing infrastructure of heating systems.

Only a comprehensive analysis of such a project, conducted on the basis of value determination of its life cycle, can give an answer as to the feasibility of its implementation in specific operating conditions.

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