UDC 658.264

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RESEARCH OF A COMBINED HEAT SUPPLY SYSTEM WITH ALTERNATIVE ENERGY SOURCES

Г. Баласанян, А.Семеній. **Дослідження комбінованої системи теплозабезпечення з альтернативними джерелами енергії.** Запропоновано конфігурацію енергоефективної комбінованої системи теплозабезпечення будівлі навчального корпусу Національного університету «Одеська політехніка» з альтернативними джерелами енергії. Отримано експериментальну базу даних швидкості вітру, що прив'язано до дислокації комбінованої системи теплозабезпечення. Скореговані усереднені дані щодо швидкості вітру метеосайту м. Одеса за опалювальний період. Розглянуто умови щодо використання енергетичного потенціалу вітра для створення комбінованої системи. Отримано розрахункову модель щодо інтегральної повторюємості швидкості вітру за імовірнісним розподілом Вейбула за опалювальний період. На підставі розробленої математичної моделі динаміки теплових процесів елементів комбінованої системи та моделі енергетичного потенціалу вітру досліджено режими роботи системи теплозабезпечення при зміні температури зовнішнього повітря. З застосуванням математичної моделі системи опалення наведено оптимальний за енергоефективністю добовий графік роботи системи опалення у переривчастому режимі. Опрацьовано оптимальні графіки електричного та теплового навантаження елементів комбінованої системи теплозабезпечення у переривчастому режимі опалення. Розроблено добові графіки режимів зарядки-розрядки водяного теплового акумулятора та електричної акумуляторної батареї, що забезпечують оптимальне навантаження елементів системи. Виконано оцінку ефективності використання альтернативних джерел енергії у системі за коефіцієнтом заміщення при зміні температури зовнішнього повітря від 5 до –15 °С. Досліджено енергетичні баланси комбінованої системи з метою обгрунтування раціональних параметрів її елементів та системи в цілому. Підтверджено можливість створення високоефективної автономної системи опалення на базі сучасних енергетичних технологій з використанням альтернативних джерел енергії та з урахуванням їх місцевого потенціалу.
Ключові слова: комбінована система теплозабезпечення, альтернативні джерела енергії, переривчасте опалення, вітроустановка, тепловий насос, математичне моделювання

H. Balasanian, A. Semenyii. **Research of a combined heat supply system with alternative energy sources**. The configuration of an energy-efficient combined heat supply system of the educational building of the Odessa Polytechnic National University with alternative energy sources is proposed. An experimental database of wind speed, which is tied to the dislocation of the combined heat supply system, was obtained. The averaged data on the wind speed of the Odesa weather site during the heating period have been adjusted. The conditions for using the energy potential of the wind to create a combined system are considered. A calculation model was obtained for the integral repeatability of the wind speed according to the Weibull probability distribution for the heating period. On the basis of the developed mathematical model of the dynamics of thermal processes of the elements of the combined system and the model of the energy potential of the wind, the modes of operation of the heat supply system when the temperature of the outside air changes are investigated. With the application of a mathematical model of the heating system, the optimal daily schedule of the intermittent operation of the heating system in terms of energy efficiency is given. The optimal schedules of the electrical and thermal load of the elements of the combined heat supply system in the intermittent heating mode have been worked out. Daily schedules of charge-discharge modes of the water heat accumulator and the electric accumulator battery have been developed, which ensure optimal loading of the system elements. The evaluation of the effectiveness of the substitution coefficient at a change in the outside air temperature from 5 to –15 °C was carried out. The energy balances of the combined system were studied in order to substantiate the rational parameters of its elements and the system as a whole. The possibility of creating a highly efficient autonomous heating system based on modern energy technologies using alternative energy sources and taking into account their local potential has been confirmed.
Keywords: combined heat supply system, alternative energy sources, intermittent heating, wind turbine, heat pump, mathematical modeling

Introduction

All over the world, there is an increased interest in the use of renewable energy sources in various sectors of the economy [1]. According to international experts on climate change, the most popular are combined installations of alternative energy [2]. The operation of combined heat supply systems (CHS) is particularly effective, as the night, seasonal and annual deficit of heterogeneous renewable energy sources can be mutually compensated.

Analysis of literary data and statement of the problem. For Ukraine (Odesa), an actual problem is the use of CHS by autonomous consumers [3, 4]. Combined alternative energy plants have a rather diverse configuration and combine the most efficient alternative energy sources and traditional energy resources in one system. A combination only from alternative sources is also possible. The choice of configuration is determined by the technically realizable potential of alternative sources and the corresponding load modes of the consumer [5]. Thus, in [6], the author proposed a combined system with a

DOI: 10.15276/opu.2.68.2023.03

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

photovoltaic solar installation, a traditional power grid, and energy storage to optimize load modes. However, the use of such a system during the heating period reduces its efficiency due to insufficient solar insolation. In work [7], the author proposed an autonomous grid wind-solar system, which is recommended for relatively powerful non-gasified consumers. For various configurations of the wind-solar system, the energy efficiency criteria have been substantiated, control algorithms have been developed, and a methodology has been created for operational technical and economic parametric optimization of the constituent elements. However, such a system has limited efficiency when it is used in the heat supply mode, which is due to the significant heat load of the consumer. In the work [8], the authors presented a scheme of combined heat supply using a heat pump and a gas boiler. Simulation of the operating modes of the building's heat supply system using heat pumps and intermittent heating was carried out. The combination of the intermittent heating mode with the use of a heat pump significantly increases the efficiency of the system, but the energy efficiency of the heat pump in the winter period is relatively low, which determines a significant share of traditional energy resources in the balance of the system.

The stated limitations and shortcomings of the combined systems of autonomous energy supply of consumers will determine the ways of finding a more effective configuration of the system with alternative energy sources aimed at increasing the share of renewable energy use for heating in the winter period.

The purpose and objectives of the research

The purpose of the work is to increase the efficiency of heat supply of the educational building of the Odessa Polytechnic National University using CHS and to justify its use for the climatic conditions of Odesa.

To achieve this goal, the following tasks must be solved:

– to form an electronic database of climatic data using the weather station of the educational building;

– justify the choice of an effective configuration of the CHS for the educational building, taking into account the resources of renewable energy sources;

– to conduct a study of energy balances of the CHS in order to substantiate the rational parameters of the system.

Materials and methods of research

The structure of the CHS of the educational building is presented in Fig. 1.

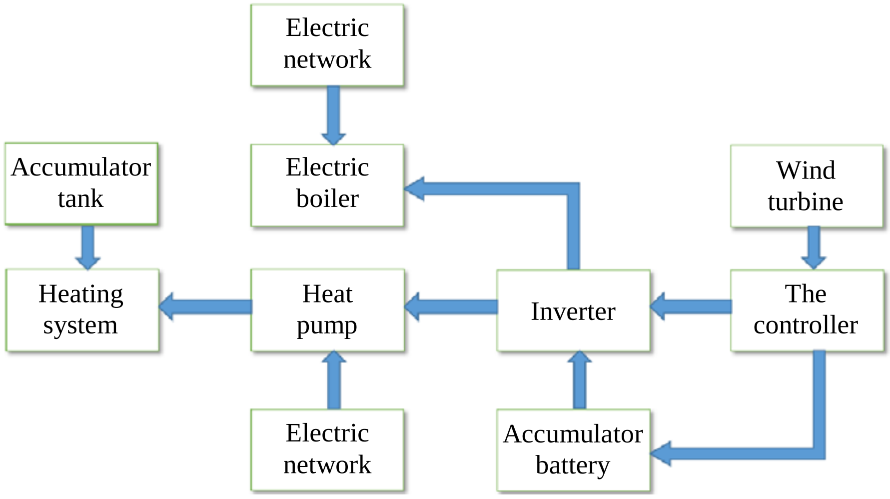

Fig. 1. The structure of the combined heating system (CHS) of the educational building

Purpose of CHS elements: wind turbine (WT) – generator of electricity in the system; the controller – transfers the charge to the batteries and stops the system in case of overload; inverter – converts direct current into alternating current; accumulator battery (AB) – stores electricity and, if necessary, supplies it to the system; electric boiler – a device designed for heating the coolant in a heat accumulator; accumulator tank (AT) – a heat-insulated container designed to store heat to heat the room;

heat pump (HP) – provides heating during working hours; emergency power supply of the system is possible from the power grid.

CHS is used for heating the educational building in intermittent mode.

Intermittent heating mode consists in lowering the temperature of the indoor air in the room during non-working hours, in the morning the rooms are heated to the set temperature before the start of the working day, and further maintenance of a comfortable temperature during working hours. Such a system allows not only to save thermal energy, but also requires small financial costs in relation to other energy-saving measures [9].

The proposed configuration of the CHS involves the use of a significant share of alternative energy sources (wind generator, heat pump) in the energy balance of the system.

On the territory of Odesa, the energy potential of wind is moderate. The annual wind speed in Odesa during the heating period is 4...5 m/s.

With the help of the Vantage Pro2 weather station, located on the roof of the educational building of Odessa Polytechnic National University, an experimental database of climate data on wind speed during 2019 – 2022 was obtained. The results of data processing are presented in Fig. 2.

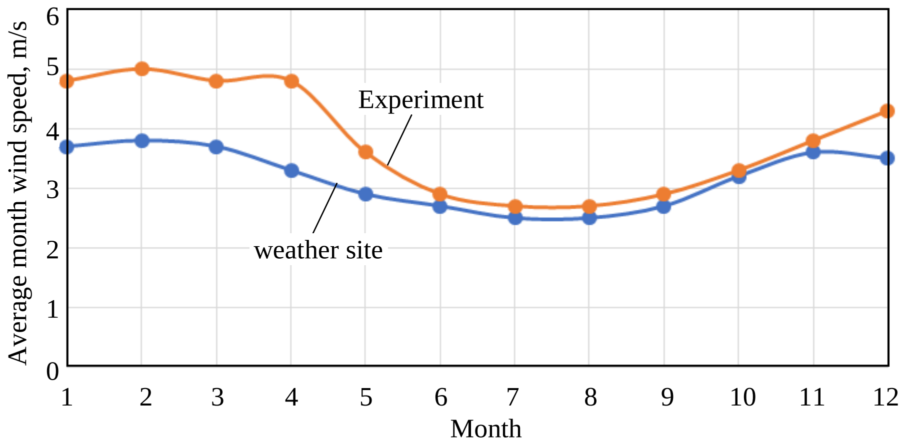

Fig. 2. Climatic data on wind speed in Odesa

Analysis of Fig. 2 shows that compared to the data from the Odesa weather site, the average annual wind speed according to the data of the Vantage Pro2 weather station is 19% higher (3.2 and 3.8 m/s, respectively), and in the heating period (November-March) the average wind speed wind is 24% higher (3.7 and 4.5 m/s, respectively).

Thus, experimental data confirm more favorable conditions for using the energy potential of the wind for the creation of the CHS of the educational building of Odessa Polytechnic National University.

An important energy characteristic of the wind flow is the repeatability of wind speeds, which shows what part of the time during the period of operation of the wind turbine, winds with a certain speed are observed. The repeatability of the wind speed determines the efficiency of using the wind turbine. To predict the energy efficiency of the wind flow, experimental data on wind speed were used, which are approximated by a standard distribution function – the Weibull function [10]:

$$F(V) = 1 - \exp\left(-\left(\frac{V}{c}\right)k\right), \tag{1}$$

where c is the scale parameter; k is a shape parameter;

$F(V)$ is the integral repeatability function of the wind speed, which shows the probability that the wind speed is equal to or below V.

The distribution density is determined by the expression:

$$F(V) = \frac{dF(V)}{dV} = \frac{k}{c}\left(\frac{V}{c}\right)k - \exp\left(-\left(\frac{V}{c}\right)k\right). \tag{2}$$

After double logarithmization of equation (2), we obtain:

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

$$\ln ln\left(ln\left(\frac{1}{1-F(V)}\right)\right) = k \ln ln(V) - kln(c)\,. \quad (3)$$

Expression (3) is the equation of a straight line with unknown coefficients k and c.

To determine them, an empirical dependence of $\ln(-\ln ln(1-F(V))$ on $\ln(V)$ is constructed with the following linear approximation by the method of least squares.

Research results

Fig. 3 shows the distribution of the average daily wind speed by the main months of the heating period (November-March), which is typical for the distribution according to the Weibull function.

In order to find the parameters of the distribution according to the Weibull function (c, k), in accordance with the method (1) – (3), the experimental average daily values of the wind speed for the period November-March were processed and a graph was drawn to determine the coefficients of the Weibull function (Fig. 4). The final linear equation was obtained: $Y= 2.788 \cdot x - 4.4052$, from which the shape parameter k = 2.788, and the scale parameter c = 4.4052 with the coefficient of determination $R^2 = 0.9973$.

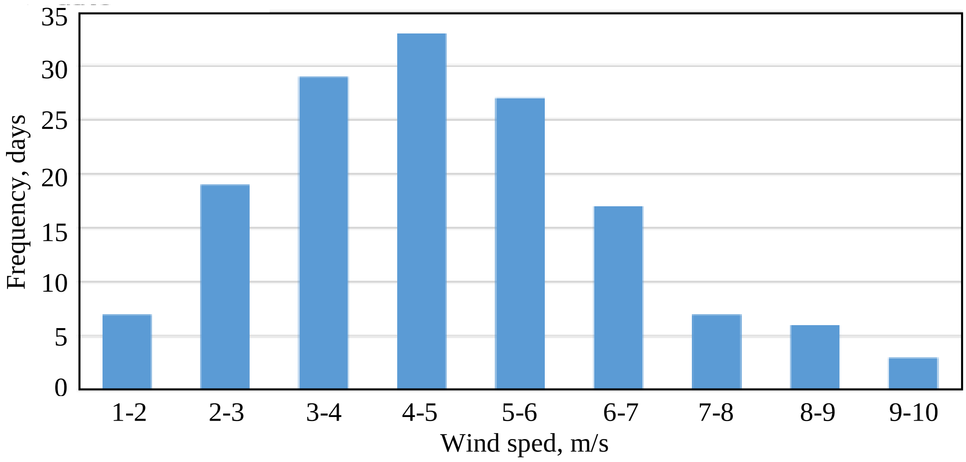

Fig. 3. Distributions of average daily wind speed for November – March

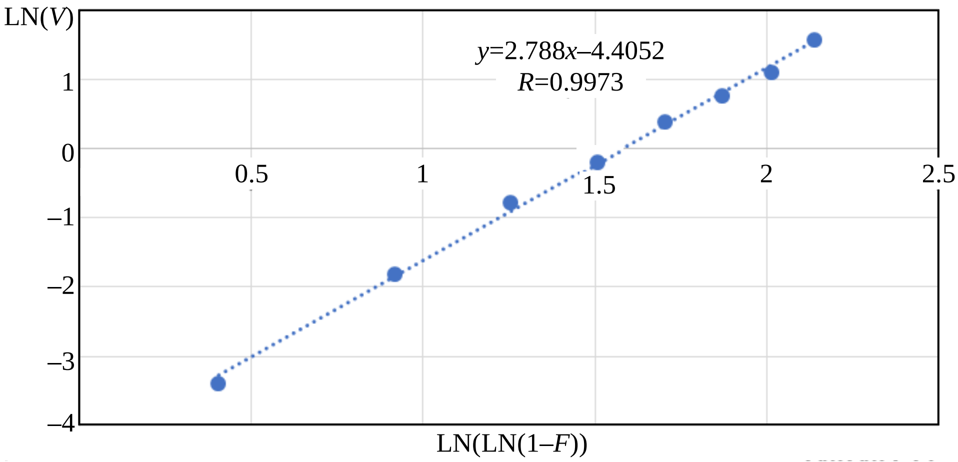

Fig. 4. Linearization of the Weibull function

In Fig. 5 the graphs of the integral repeatability of the wind for the period from November to March are given, which are built according to the experimental data and according to the obtained calculation model and testify to the significant approximation of the experimental data to the model of the integral repeatability of the wind.

Based on the developed model of the dynamics of thermal processes of the CHS elements and the model of the energy potential of the wind, according to experimental data, the operating modes of the combined heat supply system were investigated when the temperature of the outside air changes from 5 to –15 °C.

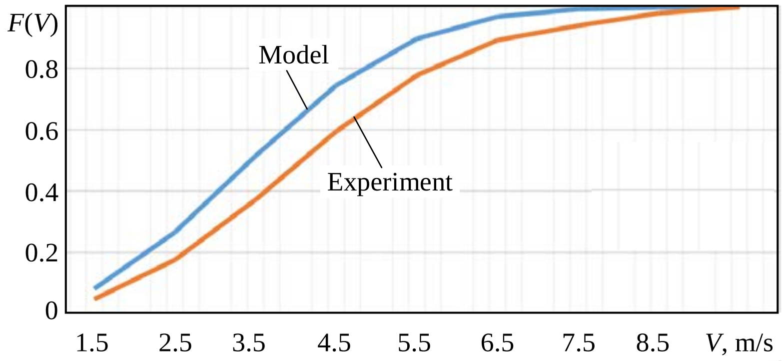

Fig. 5. Integral repeatability of wind speed

The determining factor regarding the load modes of alternative sources in the CHS is the daily schedule of the heating system in intermittent mode, which is obtained using the mathematical model of the heating system, which was developed previously [11]. The optimal load schedule of the heating system in intermittent mode at its maximum power (for t_{out}=–15 °C) is shown in Fig. 6. Morning heating is carried out from 4 to 8 a.m., working heating from 8 a.m. to 3 p.m., respectively.

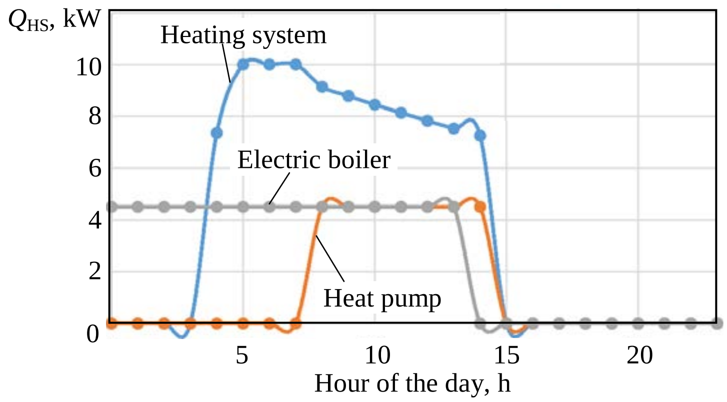

Fig. 6. Daily schedule of heat load of CHS elements in intermittent mode at t_{out}=–15 °C

According to the daily schedule of operation of the electric boiler (Fig. 6), from the beginning of the day, the electric boiler is switched on to charge the heat accumulator to a temperature of 80 °C. The thermal and electric power of the electric boiler (4.5 kW) exceeds the power generated by the WT during these hours, so the power deficit is partially covered by the AB discharge. From 4:00 a.m. to 8:00 a.m., the room is heated and the heat accumulator (AT) is discharged from 80 °C to 50 °C. Then, from 8:00 a.m. to 3:00 p.m., the heating process continues – the heat pump works (heat capacity – 4.5 kW) and the electric boiler continues to work, because the load of the heating system exceeds the capacity of the heat pump (Fig. 6).

Fig. 7 shows the daily schedule of electrical load of CHS elements. Consumption of electricity from the power grid begins at 8 o'clock, i.e. the heat pump is turned on and the electric boiler continues to work, while the battery is already fully discharged. After 3 p.m., the heat pump is turned off and a small load from the external power grid is directed to charging the battery.

Fig. 8 shows the daily schedule of energy accumulation in CHS elements (AT, AB). AT charging takes place before the onset of the morning flood. At 4 o'clock in the morning, heating begins and AT discharge occurs until 8 o'clock in the morning, when the heat pump is turned on and then the heating mode takes place. Accordingly, the AB discharge starts at 0 o'clock and is used to power the electric boiler, and from 8 o'clock in the morning additionally also to power the heat pump. The battery is fully discharged at 9 o'clock, and its charging begins at 3 o'clock, after the heat pump is turned off, and continues until the end of the day due to power from the wind turbine and the power grid.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

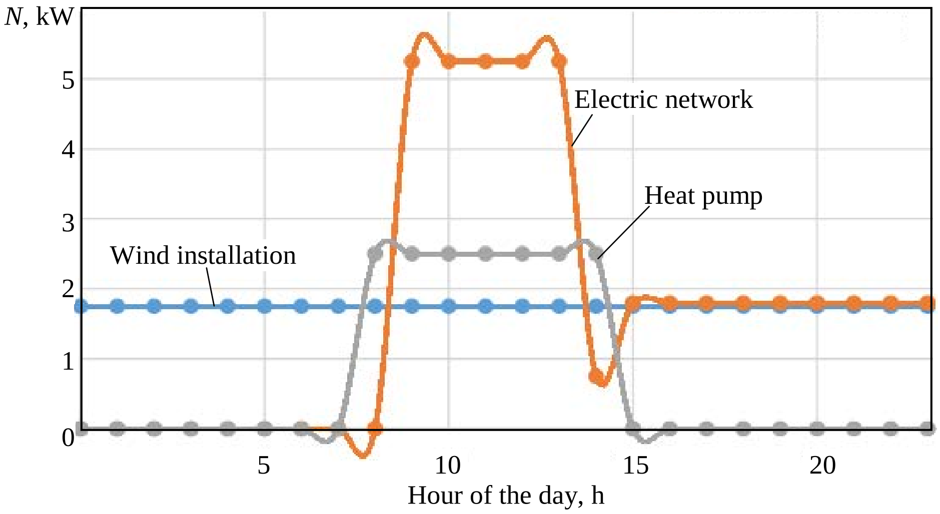

Fig. 7. Daily schedule of electric load of CHS elements in the intermittent mode at t_{out}=–15 °C

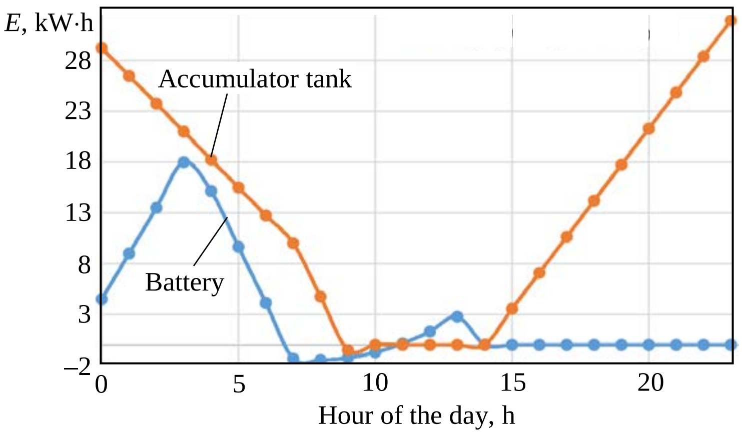

Fig. 8. Daily schedule of energy accumulation in CHS elements in intermittent mode at t_{out}=–15 °C

The given graphs reflect the estimated (averaged) mode of operation of the wind turbine and the heat pump. The actual generation of electricity by the wind turbine may differ significantly from the calculated mode, but this affects only the consumption of electricity from the power grid, which accordingly increases when the wind speed decreases from the calculated value, or may be completely absent when the calculated speed is exceeded.

The operating mode of the investigated system characterizes the capabilities of the CHS at the maximum heat load at the external air temperature t_{out}=–15 °C. At the average daily temperature t_{out}=0 ºC and above, in the calculated mode, the system works completely autonomously without consuming electricity from the network and consumes only energy from alternative sources.

The efficiency of combined systems with alternative energy sources is usually evaluated by the replacement factor K_{sub}, which reflects the share of alternative energy in the overall energy balance of the system [12].

For the CHS under investigation, K_{sub} was calculated when the external air temperature t_{out} changed from 5 to –15 °C (Fig. 9). K_{sub} has a minimum value of 0.6 at an air temperature of –15 °C, respectively. At t_{out}=0 °C and above, the substitution coefficient is equal to 1, that is, the system works autonomously at the expense of only alternative energy sources.

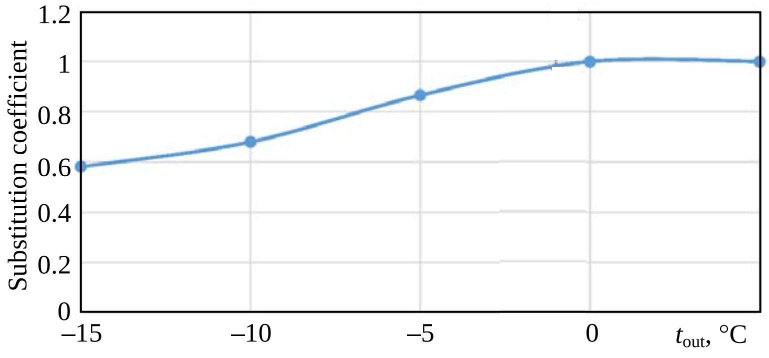

Fig. 9. Dependence of the substitution coefficient on the external air temperature t_{out}

Conclusions

1. An electronic database of climatic data on wind speed was created with the help of the weather station of the educational building of Odessa Polytechnic National University for the period 2019 – 2022.

2. An effective configuration of the combined system for heat supply of the building of the thermal engineering laboratory is proposed, taking into account the resources of renewable energy sources.

3. Based on the results of optimizing the load modes of the CHS when the outside air temperature changes from –15 °C to +5 °C, the optimal parameters of the modes of operation of the main elements of the CHS were obtained.

4. The presented results of modeling the modes of operation of the combined energy supply system confirm the possibility of creating highly efficient autonomous heating systems based on modern energy technologies using alternative energy sources and taking into account their local potential.

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Received August 12, 2023

Accepted September 28, 2023