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ANALYSIS OF THE EFFECTIVENESS COEFFICIENT OF DECENTRALIZED VENTILATION SYSTEMS WITH HEAT RECOVERY

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Abstract. This article is devoted to studying of decentralized supply-exhaust ventilation systems (DSEVS) with heat recovery, which are an important element for ensuring energy-efficient air exchange in modern hermetic buildings. The problems of natural ventilation, which in modern conditions cannot provide an adequate level of air exchange without heat loss, especially in winter and summer, have been studied, and the effectiveness of mechanical ventilation systems has been substantiated. A comparison of centralized and decentralized systems is made, highlighting the advantages of decentralized systems in terms of ease of installation, space saving and the possibility of installation in already renovated premises. In the work, three samples of DSEVS equipped with copper heat exchangers, which provide high heat transfer, were analysed. The main goal of the study was to identify the strengths and weaknesses of the existing devices and develop recommendations for their improvement, taking into account the climatic features of the regions of Ukraine and Europe.

On the basis of the conducted research, the results of the efficiency of each of the systems, which are sufficiently close to each other, were obtained. This, accordingly, was expected, since the heat exchangers of these systems are made of the same material – copper. During the tests, the need for better tightness of each of the systems was determined, which can improve the results of their efficiency in the future. At the same time, the results of these studies may vary depending on the determination of the real air consumption of each of the devices, as well as the mass balance of the supply and exhaust air flows, which may differ.

The study confirms the effectiveness of countercurrent systems working on simultaneous inflow and extraction as optimal solutions for maintaining a comfortable and energy-efficient microclimate. The obtained results can be directed to the optimization of the design of the DSEVS and the possibility of operation of such systems in combination with natural or other mechanical ventilation systems.

Keywords: decentralized ventilation systems, recuperator, energy saving, air quality, air exchange.

Introduction. Today, people spend a significant amount of time indoors, so indoor air quality has a significant impact on their health. However, this indicator has deteriorated over the past twenty years. The main reason for this is the growing demand for energy conservation and energy efficiency, which has made buildings much more airtight. As a result, natural air exchange is no longer sufficient to ensure optimal ventilation. This has increased the urgency of developing energy-efficient supply and exhaust ventilation systems for buildings. One of the possible solutions is the creation and implementation of decentralized supply and exhaust ventilation systems (DSEVS) using recuperative or regenerative heat exchangers.

Therefore, testing existing decentralized ventilation devices, identifying their strengths and weaknesses, and developing recommendations for the production of a new energy-saving regenerative heat exchanger, taking into account the climatic conditions of the regions of Ukraine and Europe, is an important and urgent task, since such devices play a key role in ensuring the energy efficiency of buildings and improving air quality in the modern environment.

The relevance of this study is due to the advantages of decentralized ventilation systems, which allow to effectively solve the issues of air exchange in the conditions of modern construction and operation of buildings [1-3]. The main advantages are their relatively low cost, which makes such systems more affordable compared to centralized installations. In addition, the compactness of decentralized systems minimizes the required space for their installation, as they do not require the use of air ducts, grilles, and other shaped elements of the air duct network. Another important advantage is the ability to install in buildings that have already been renovated, as such systems do not require significant changes in the construction or design of the premises. Thus, decentralized ventilation systems are one of the options for providing ventilation of premises [4, 5].

Analysis of recent research and publications. The analysis of recent publications covers various aspects of the use of decentralized ventilation systems, research on their efficiency and comparison with other types of ventilation systems, for example, by pressure generation method, purpose, design, etc. Particular attention is paid to the efficiency index, which provides an accurate analysis of energy efficiency.

Natural ventilation ensures air exchange due to natural physical processes - the difference in temperature and pressure inside and outside the building. However, its efficiency varies significantly depending on the season. In summer, when the temperature difference between the room and the outside environment is minimal, air exchange is significantly reduced, which often leads to a decrease in the required air exchange. In winter, on the contrary, a sharp temperature difference increases the intensity of ventilation, which leads to excessive heat loss and increased heating costs [6].

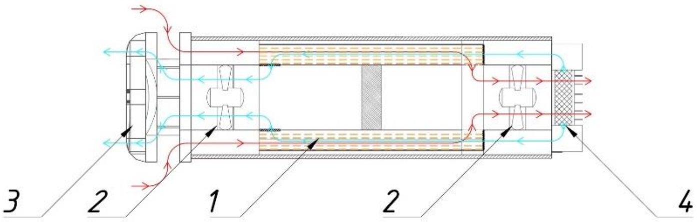
Fluctuations in the efficiency of natural ventilation create an additional burden on other ventilation systems, especially in sealed spaces that require stable air exchange to maintain a healthy microclimate. In such conditions, natural ventilation is not able to provide an adequate level of air quality control, especially in modern buildings with a high level of energy efficiency [7, 8].

These disadvantages make mechanical ventilation systems, especially decentralized ones, a more effective solution, as they provide stable and controlled air exchange regardless of external conditions, maintaining both comfort and energy efficiency of the room.

There are two main types of mechanical ventilation systems: centralized and decentralized. Centralized ventilation systems are complex and multi-component engineering solutions. Their installation takes considerable time and requires many additional elements, such as air ducts, deflectors, grilles, adapters, cabling and wiring products, and fasteners, which significantly increases the total cost of the project and installation work [9, 10]. Since air ducts accumulate dust over time, their maintenance is quite laborious and requires regular intervention to ensure cleanliness and proper operation. In residential premises, centralized ventilation ducts are usually installed in ceiling structures, which often leads to the need for repair work after their installation and lowering of the ceiling structure. In case of a ventilation unit breakdown, a specialist is required to disconnect the ventilation system from the air ducts, which creates additional costs for the user.

In today's built environment, most newly constructed or modernized buildings are equipped with a full or partial mechanical ventilation system, ranging from hybrid options and full supply and exhaust systems to localized, customized ventilation solutions. Ventilation systems are key to maintaining proper indoor air quality and energy efficiency in buildings. Modern design approaches, especially in developed countries, rely heavily on mechanical ventilation systems to improve indoor air quality while minimizing energy losses. In well-insulated buildings located in temperate regions, such as Europe or Ukraine, the combination of infiltration and ventilation can account for about 50% of total heat loss. Studies [11] have shown that the implementation of energy-efficient measures, such as heat recovery systems, increased insulation, and optimized operating modes, can reduce energy consumption by about 50% for both heating and cooling. These measures not only contribute to energy saving, but also meet the increased demand for thermal comfort, which is important in the modernization and reconstruction of buildings. Thus, mechanical ventilation systems with heat recovery are one of the key strategies for optimizing energy consumption and ensuring high quality of the indoor environment, especially in well-insulated buildings where heat loss through natural ventilation is a significant problem [12-14].

The most efficient among mechanical ventilation systems are counterflow type of DSEVSs, which are equipped with two fans and provide simultaneous air supply and exhaust (Fig. 1). Such a design allows achieving a high level of energy efficiency, since the supply air is heated or cooled by the exhaust air, minimizing heat loss, and, at the same time, has a stable efficiency compared to reverse-type systems. The systems discussed in this article are equipped with heat exchangers made of the same material – copper.



a) b)

Fig. 1. DSEVS of a countercurrent type:
a – schematic diagram of the countercurrent type of the DSEVS based on the Prana-150 Standard construction; b – the principle of operation of the countercurrent type of the Vents Breeze 160-E Smart; 1 – heat exchanger; 2 – fans; 3 – air inflow and exhaust grille from the room; 4 – air exhaust and inflow grille from the outside

Purpose and objectives. The purpose of this work is to improve the design of decentralized ventilation systems by preliminary analysis based on research on the efficiency of existing decentralized ventilation devices, to identify the strengths and weaknesses of the presented systems, to create recommendations for manufacturers of these systems, considering the climatic conditions of the regions of Ukraine, and to determine the direction of further research.

Materials and methods of the study. The tests were carried out on a test bench (Fig. 2), consisting of two separate rooms separated by a partition, in which different microclimate parameters are maintained. The study was carried out for three samples of DSEVS: Prana-150 Standard, Klimatronic 160 Basic, and Vents Breezy 160-E Smart (Fig. 3-5), which contained all components and were installed according to the manufacturer's passports and instructions [15-17].

The mass flow rates were measured simultaneously in steady-state conditions. The studies were conducted at a voltage of 230 V, which was maintained by voltage stabilizers throughout the experiment.

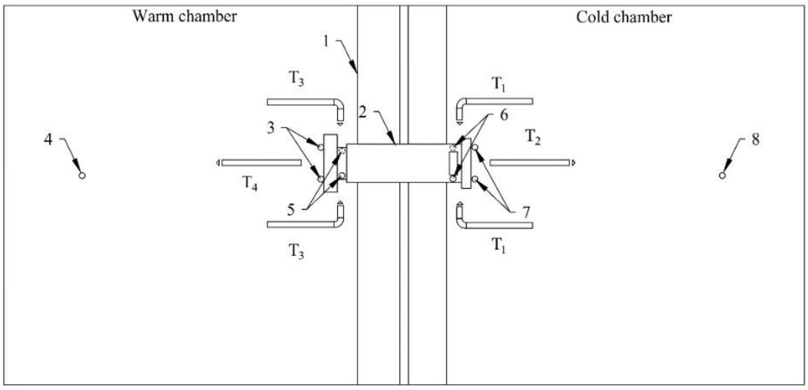


Fig. 2. Schematic of the experimental setup:
1 – partition wall; 2 – DSEVS; 3 – supply air temperature sensors after recovery T4; 4 – air temperature and humidity sensor in the warm chamber; 5 – exhaust air temperature sensors before recovery T3; 6 – supply air temperature sensors before recovery T1; 7 – exhaust air temperature sensors after recovery T2; 8 – temperature and humidity sensor in the "cold" chamber

Fig. 3. DSEVS research process for Vents Breeze 160-E Smart

Fig. 4. DSEVS research process for Klimatronik 160 basic

Fig. 5. DSEVS research process for Prana 150 Eco Life

The main purpose of these studies is to determine the efficiency under the same testing conditions at minimum, average and maximum air flow rates according to the data in the technical data sheets of the devices.

Based on the above, the efficiency of the DSEVS is determined by the formula:

$$\eta = \frac{(T4 - T1)}{(T3 - T1)} \times 100. \quad (1)$$

In the course of this work, DSEVS were tested under close-to-nature conditions, under which DSEVS are exposed to the entire set of factors of both external temperatures and the internal microclimate of the room. The list of temperature and humidity control systems is given in Table 1.

All measurements were performed using a set of measuring equipment (Table 2) connected to a data logger. The parameters of the temperature and humidity conditions are given in Table 3.

Table 1 – Heating and cooling devices

Equipment	Premises	
	"Warm" chamber	"Cold" chamber
Cooling	Air conditioner Cooper&Hunter CH-S12FTXF2-NG	Cooling unit Bitzer AA-BK-64/2EES-3Y
	–	Air cooler Eco GCE 312F8 ED
Heating	Convector heater Noveen CH9000 LCD SMART	–

Table 2 – Measuring devices

Measured variable	Measuring device
Dry thermometer temperature	Resistive temperature sensors PT 100
Wet thermometer temperature	Digital temperature, humidity and atmospheric pressure sensor
Static pressure difference	Piezoresistive pressure sensor
Relative humidity	Digital temperature, humidity and atmospheric pressure sensor
Data management	Data acquisition system
Electricity consumption	Wattmeter ammeter voltmeter Intertek 3680W

Table 3 – Parameters of temperature and humidity conditions

Parameters	Premises	
	"Warm" chamber	"Cold" chamber
Temperature, °C	19-21	6-8
Humidity, %	45-55	65-75

Ensuring the internal air temperature in the warm and cold chambers is taken in accordance with DSTU (National Standard of Ukraine) EN 13141-8:2019 "Ventilation in buildings. Performance testing of components/products for residential ventilation. Part 8: Performance testing of nonchannel supply and exhaust ventilation units (including heat recovery) for mechanically driven ventilation systems designed for a single room" (EN 13141-8:2014, IDT) [18].

Research results. Based on the statistical processing of the results of experimental studies (Table 4), a graphical dependence of the DSEVS efficiency on changes in air flow was constructed (Fig. 6).

Table 4 – DSEVS Research results

Parameter	Designations	Unit of measurement	Values of indicators for DSEVS		
			Vents Breezy 160-E Smart	Klimatronik 160 Basic	Prana 150 Eco Life
Efficiency factor	η	%	78-56	89-53	88-52
Consumption*	N	W*h	4.4-9.2	3.4-22.5	3.2-15.6
Air flow rate** (according to the manufacturer's data sheet)	L	м^3/h	15-57	20-70	5-52

* – Electricity consumption is based on measurements made during the research;

** – air flow rate is indicated in the measurement range, without taking into account the maximum air flow rate (boost mode).

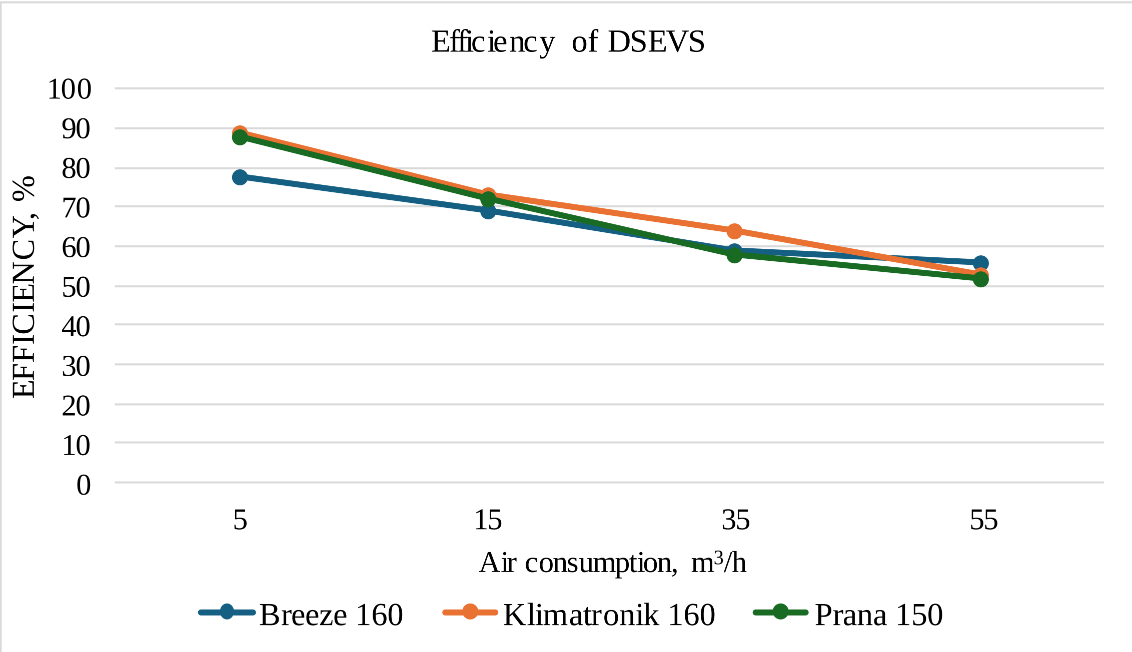


Fig. 6. Efficiency of decentralized supply and exhaust ventilation systems (DSEVS) with heat recovery

As the analysis of the results shows, the efficiency of the studied DSEVS is quite similar, since all models show a decrease in efficiency with an increase in air flow. The highest efficiency over the entire range of air flow rates, especially at low air flow rates, was shown by the Klimatronik 160 Basic system, while the lowest efficiency among the three models at each stage was recorded for the Vents Breeze 160-E Smart system. With an increase in air flow rate to 55 m^3/h, the efficiency of all three models approaches 60-65%, leveling the differences between them.

Conclusions. The article presents the results of studies of the efficiency of decentralized ventilation systems with heat recovery. Particular attention was paid to ensuring the same experimental conditions, including the microclimate parameters of the "warm" and "cold" chambers. Based on the research, the results of the efficiency of each of the systems were obtained, which turned out to be quite close due to the use of heat exchangers made of the same material – copper.

However, the efficiency of a heat exchanger depends not only on the material, but also on many other factors: material thickness, heat transfer surface area, aerodynamic characteristics of air flows, balance of supply and exhaust air, etc. The tests also identified the need to increase the tightness of the systems, which could potentially improve their efficiency.

The studies found that one of the systems demonstrated the highest efficiency. However, the study found that the exhaust air flow rate was higher than the supply air flow rate, which affected the results. This indicates the need to further determine the actual supply and exhaust air flow rates through the system for each device more accurately.

The results obtained can be used to optimize the design of decentralized ventilation systems with recovery, their integration with natural or mechanical ventilation systems, and to develop recommendations for manufacturers. Further research should be directed at improving heat exchangers, in particular with regard to their design characteristics, and adapting systems to the specific climatic conditions of different regions.

After conducting tests and analyzing the results, the directions and prospects for further research have been formed, which will help to better define the detailed problems of these DSEVS designs and formulate steps for their optimization. The priority of the next research is to determine the actual air flow rates of each DSEVS, and if the results differ from the data specified in the technical passport, it is necessary to repeat the efficiency tests at the same air flow rates and the balance of air masses of supply and exhaust air. After that, the prospect of further research is to test with changes in pressure in each of the chambers and obtain repeated results.

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АНАЛІЗ КОЕФІЦІЄНТУ КОРИСНОЇ ДІЇ ДЕЦЕНТРАЛІЗОВАНИХ СИСТЕМ ВЕНТИЛЯЦІЇ З РЕКУПЕРАЦІЄЮ ТЕПЛОТИ

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Анотація. Дана стаття присвячена дослідженню децентралізованих припливно-витяжних систем вентиляції (ДПВСВ) із рекуперацією тепла, які є важливим елементом для забезпечення енергоефективного повітрообміну в сучасних герметичних будівлях. Вивчено проблематику природної вентиляції, яка в сучасних умовах не може забезпечити належний рівень повітрообміну без втрат тепла, особливо взимку та влітку, і підведено до обґрунтування ефективності механічних систем вентиляції. Проведено порівняння централізованих та децентралізованих систем, підкреслюючи переваги останніх у простоті монтажу, економії простору та можливості встановлення в уже відремонтованих приміщеннях. У роботі аналізуються три зразки ДПВСВ, оснащені мідними теплообмінниками, що забезпечують високу теплопередачу. Основна мета дослідження – виявлення сильних та слабких сторін наявних пристроїв і розробка рекомендацій для їх удосконалення, враховуючи кліматичні особливості регіонів України та Європи. Аналіз отриманих даних свідчить про досить близькі показники ефективності досліджуваних систем. Такий результат був прогнозований, оскільки всі системи використовують ідентичний матеріал для теплообмінників – мідь. Однак, виявлення необхідності поліпшення їхньої герметичності відкриває перспективи для подальшого підвищення їх ефективності. Варто зазначити, що точні значення ефективності можуть змінюватися в залежності від реальних умов експлуатації, зокрема, від фактичного споживання повітря кожним пристроєм та балансу повітряних потоків у системі. Дослідження підтверджує ефективність протиточних систем, що працюють на одночасний приплив і витяжку, як оптимальних рішень для підтримки комфортного та енергоефективного мікроклімату. Отримані результати дослідження можна застосувати для удосконалення конструктивних особливостей децентралізованих вентиляційних систем з функцією рекуперації тепла з урахуванням специфіки різних регіонів. Це дозволить ефективніше інтегрувати їх із природними або механічними системами вентиляції, а також розробити більш досконалі рекомендації для виробників такого обладнання.

Ключові слова: децентралізовані системи вентиляції, рекуператор, енергозбереження, якість повітря, повітрообмін.

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