DOI: 10.17512/bozpe.2023.12.08

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Recuperators as an important element for energy efficiency in building ventilation systems

Valerii Savin[1*] (*orcid id: 0009-0008-6013-7371*)
Vasyl Zhelykh[2] (*orcid id: 0000-0002-5063-5077*)
[1] Kryvyi Rih National University, Ukraine
[2] Czestochowa University of Technology, Poland

Abstract: The energy efficiency of ventilation systems is very important. The city of Kryvyi Rih in the Dnipropetrovs'k region of Ukraine has a humid continental climate with an average daily temperature of –6.3°C during its coldest month. Consequently, it is necessary to find methods to improve the energy efficiency of ventilation systems. One of the most effective ways to reduce energy consumption in ventilation systems is to use energy-saving technologies to maintain the microclimate of buildings, including the use of recuperators and devices based on renewable energy sources.

Keywords: ventilation, recuperator, heat exchanger, energy efficiency

Please, quote this article as follows:

Savin V., Zhelykh V., Recuperators as an important element of energy efficiency in building ventilation systems, Construction of Optimized Energy Potential (CoOEP), Vol. 12, 2023, 71-78, DOI: 10.17512/bozpe.2023.12.08

Introduction

Good indoor air quality (IAQ) is a priority in any building and, in addition to low energy consumption, is one of the many benefits of a passive house.

The use of heat recovery can help to increase energy savings and energy efficiency in residential buildings and ensure sanitary and comfortable conditions. In conventional ventilation systems, approximately 30-35% of the total heat loss from a building is lost through expelled air. Heat recuperators, which recycle expelled ventilation air in residential premises, are an important form of energy-saving equipment.

[*] Corresponding author: v_a_l_e_r_4ik@ukr.net

The main criteria in measuring the efficiency of ventilation air heat recuperators are:

- The degree of recovery. This is the main indicator when measuring energy savings; this indicator varies widely depending on the manufacturer and model ranging from 40% to over 70%.
- Energy efficiency. The system's energy consumption, which shows how much energy the recuperator consumes in order to utilize and return thermal energy from the room's air.
- Sanitary and hygienic indicators. The air entering the room passes through the recuperator, so it should purify the air from dust and contaminants while not introducing additional pollutants to the room. Air conditioning should also be controlled by the system.
- Automation. The recuperator should be automated, switching on according to given indicators such as temperature or air flow or by other equipment with additional functions, housing design, etc.

1. Materials and methods

Improving ventilation systems plays an important role not only in increasing the energy efficiency in buildings, but also in reducing health problems through providing a better indoor climate. The authors (Chenari et al., 2016) believe that in addition to energy-efficient methods of ensuring optimal microclimate parameters, occupant behavior also affects the level of energy consumption in a building. Consequently, ventilation is interconnected with many factors, such as indoor and outdoor climatic conditions, thermal performance of the building, equipment in the building, and more. Therefore, in order to design modern energy-efficient ventilation systems, it is necessary to make an in-depth analysis of these prerequisites in order to maintain appropriate air quality. In particular, special attention needs to be paid to the possibility of using a mechanical ventilation system with recovery. The authors (Pérez-Lombard et al., 2008) presented an overview of energy-saving technologies in heating, ventilation, and air conditioning systems. They analyzed 212 houses located in America, where solar panels were used. Surprisingly, the greatest savings were shown in the 55% of houses where a ventilation system with heat recovery was additionally used. Another study (Tkachenko & Pavlenko, 2018), provided a calculation of the thermal capacity of a ventilation system and determined the energy-saving effect of using a system with a recuperator. Further studies (Peng Liu et al., 2023), proposed physical models for ventilation systems with heat recovery that take into account changes in air flow velocity, the effect of longitudinal heat conduction in heat exchangers, operating controls, as well as the results of an economic assessment of the proposed technical solutions.

Ground heat exchangers have been the subject of numerous scientific publications. Pan et al. (2020) focused on the analytical modeling of vertical ground heat exchangers (GHEs) and investigated the effect of different boundary conditions of the soil surface on temperature characteristics. A new integral transformation method was introduced in the study and the model was verified analytically and numerically.

The results showed that the use of the Dirichlet boundary condition in the analytical model led to a decrease in the average depth temperatures of the vertical soil heat exchanger compared to the use of the Neumann and Robin boundary conditions. The study also discussed the potential improvement of thermal energy storage by placing isolation caps over wells.

The results of a thorough scientific review based on theoretical studies were presented in Cai et al. (2017), Pan et al. (2020), Zhelykh (2021). The study (Larwa & Kupiec, 2020) determined the long-term changes in ground temperature caused by heating and cooling buildings using heat pumps in combination with ground heat exchangers. The study developed a mathematical model to present the heat transfer process and investigated the temporal changes in ground temperature, temperature profiles, and heat fluxes under different heat extraction and supply conditions. The results showed that changes in the average annual soil temperature initially affect only the near-surface layer, but eventually spread to greater depths. The study also introduced the concept of soil evaporation temperature to describe the heat exchange between the soil surface and the environment. However, the presence of a working ground heat exchanger strongly affects the soil temperature near the heat exchanger tubes, and this temperature is crucial in terms of heat transfer from or to the ground (Lis & Savchenko, 2022).

2. Results and discussion

This paper compares the efficiency of mechanical ventilation systems. As an example, a typical country house with a living area of 120 m^2 and an assumed internal air temperature of +22°C, located in the Kryvyi Rih district of the Dnipropetrovs'k region (Ukraine), was evaluated. The cost of the average heat output of the ventilation system for the following options was calculated:

1 – supply and exhaust ventilation system with an electric supply air heater;

2 – supply and exhaust ventilation system with heat recovery;

3 – supply and exhaust ventilation system with heat recovery and geothermal air collector.

The construction site is located in a humid continental climate zone; the duration of the period with a daily air temperature below +8°C is 171 days; the average temperature of the period with an average daily temperature below +8°C is –3.5°C; the average daily temperature of the coldest month is –6.3°C (January) (SSU-A C V.1.1-27:2010).

In regards of the first variant, with a supply and exhaust ventilation system with an electric supply air heater, the supply air was taken from the street by a supply air fan 6 and, through air valve 1. The air was cleaned in a supply air filter 4, after which it was heated to the desired temperature in an electric heater with a built-in temperature sensor 5 and, after passing through a silencer 3, was supplied using an extensive supply ventilation system to the premises. The exhausted air was removed from the premises, passed through the silencer 3 and was expelled from the building by the exhaust fan 2 (Fig. 1).

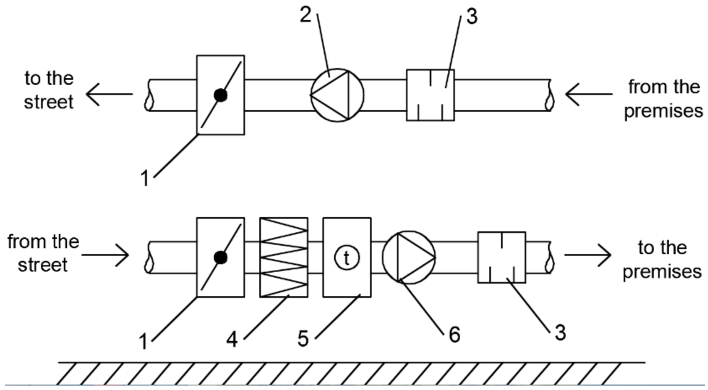


Fig. 1. Schematic diagram of a supply and exhaust ventilation system with an electric heater: 1 – air valve, 2 – exhaust fan, 3 – silencer, 4 – supply air filter, 5 – electric heater with built-in temperature sensor, 6 – supply fan (*own research*)

Calculations were carried out to determine the required average heat output of the supply and exhaust ventilation system in order to heat the supply air to a comfortable temperature of +22 °C, $N_{h.}$ [kW]:

$$N_{h.} = G \cdot \mathrm{C} \cdot \rho \cdot (t_{out} - t_{ind}), \tag{1}$$

where:
G – the supply air flow rate [m^3/s];
t_{out}, t_{ind} – outdoor and indoor air temperature, respectively;
ρ – the air density, ρ = 1.197 kg/m^3;
C – the heat capacity of air, C = 1.005 kJ/(kg·°C).

The required average heat output for the heating period $N_{h.per.}$ (kW) was determined from the following dependence:

$$N_{h.per.} = N_{h.} \cdot n \cdot S, \tag{2}$$

where:
n – the number of hours of operation of the air handling unit per day, on average 16 hours;
S – the number of days of the heating period [days].

The supply air is heated in an electric heater. The cost of energy consumed during the heating period was determined from the following relationship:

$$\mathrm{B}_1 = N_{h.per.} \cdot E \tag{3}$$

where E – the cost of electricity; in Kryvyi Rih as of March 01.2022, the cost of electricity is E = 1.68 UAH/kWh.

After the calculations, the following results were obtained: N_h = 3.07 kW; $N_{h.per.}$ = 8399.52 kW; B_1 = 14111.19 UAH/h.per.

The second option was considered – a supply and exhaust ventilation system with heat recovery (Fig. 2).

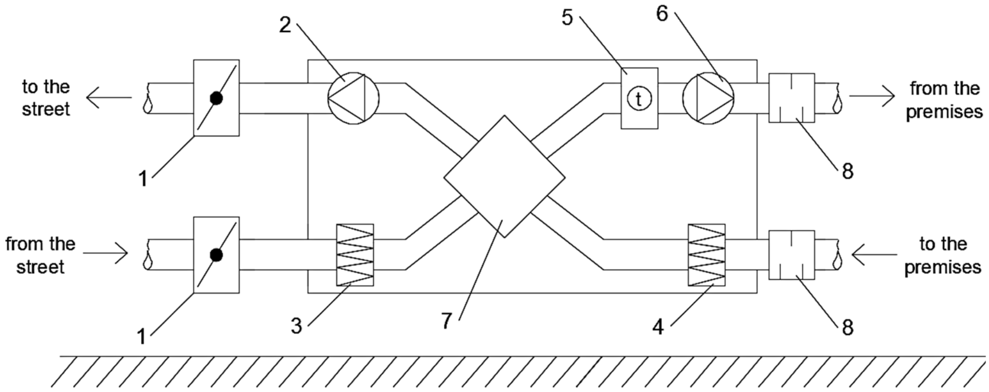


Fig. 2. Schematic diagram of a supply and exhaust ventilation system with heat recovery: 1 – air valve, 2 – exhaust fan, 3 – supply air filter, 4 – exhaust air filter, 5 – electric heater, 6 – supply fan, 7 – recuperator, 8 – silencer (*own research*)

In this system, air was supplied through the air valve 1 to the supply and exhaust system with a recuperator. After passing through the supply air filter 3, the air entered the recuperator 7, where the exhaust air gave off some of its heat to the supplied air. The electric heater 5 heated the air to the desired temperature and supplied it to the rooms through a branched supply ventilation system via a supply fan 6 and a silencer 8. The exhaust air was taken from the rooms, passed through the silencer 3 and entered the supply and exhaust system with a recuperator, where it passed through the exhaust air filter 4 and, entering the recuperator 7, gave off part of its heat to the supplied air and was removed from the house by the exhaust fan 2.

We calculated the heat output for a house with a supply and exhaust ventilation system with heat recovery efficiency of 86%. The amount of electricity required by the electric heater to preheat the supplied air was as follows:

$$N_{el.h} = N_{h.per.} - N_{rec} = 8399.52 - 0.86 \cdot 8399.52 = 1175{,}93\ \text{kW}. \quad (4)$$

Provided that the installation operates during the entire heating period, the cost of electricity equaled:

$$B_2 = N_{h.per.} \cdot E = 1175.93 \cdot 1.68 = 1975.56\ \text{UAH/h.per.}$$

The third option considered a supply and exhaust ventilation system with heat recovery and a geothermal air collector that uses heat from the ground to preheat the air supplied to the house. The ground collector is laid below the ground freezing level. The difference between this system and the previous is that the supply air is drawn by a fan 8 before passing through a coarse filter 9, and is then preheated in the pipes of the geothermal collector 10 before entering the supply and exhaust system with a recuperator. The movement of the supplied and exhausted air shown in Figure 3.

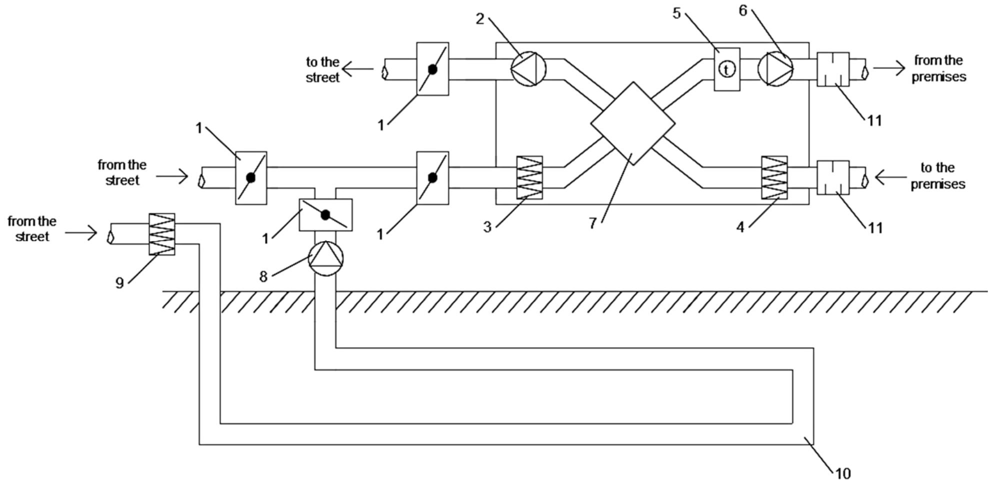


Fig. 3. Schematic diagram of a supply and exhaust ventilation system with heat recovery and a geothermal air collector: 1 – air valve, 2 – exhaust fan, 3 – supply air filter, 4 – exhaust air filter, 5 – electric heater, 6 – supply fan, 7 – heat recovery unit, 8 – collector fan, 9 – coarse filter, 10 – geothermal collector pipes, 11 – silencer (*own research*)

At a given average daily temperature of the heating period of –3.5°C and with a length of the air collector at 60 m, it is possible to obtain an air temperature at the outlet of the collector of +4.5°C. After the calculations performed by formulas (1)-(4), we obtained: N_h = 2.11 kW; $N_{h.per.}$ = 5772.96 kW; $N_{el.h.}$ = 808.21 kW; B_3 = 1357.8 UAH/h.per.

Figures 4 and 5 show a comparative characterization of energy consumption by supply and exhaust ventilation systems during the heating period and for the coldest months. The nomograms are constructed for three typical cases that were taken for analysis.

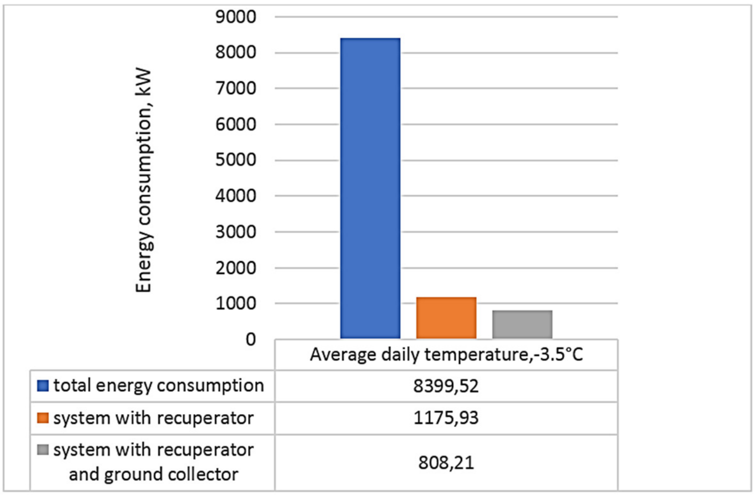
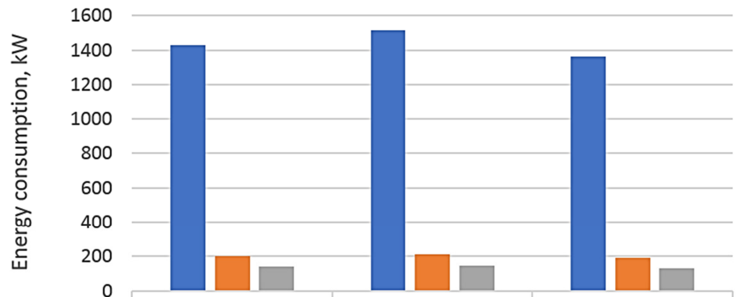


Fig. 4. Energy consumption for supply air heating during the heating period (*own research*)



	December, -2.0°C	January, -4.3°C	February, -3.3°C
total energy consumption	1428,48	1514,88	1360,13
system with recuperator	199,99	212,08	190,42
system with recuperator and ground collector	141,66	145,15	131,71

Fig. 5. Energy consumption for supply air heating in the coldest months (*own research*)

The above calculations show that the combined use of a supply and exhaust unit with heat recovery and a geothermal air collector is the most economical option. The savings amounted to UAH 617.76 per heating period compared to the second option (Figs. 4 and 5). In general, the results obtained provide valuable information on the efficiency of mechanical ventilation systems in residential buildings.

Conclusions

In today's environment of rising energy prices and increased attention to environmental issues, recuperators can be a key tool for providing efficient and environmentally friendly ventilation equipment in buildings. The results of analytical studies showed that the use of a recuperator in the ventilation system will reduce the consumption of electricity for heating the supplied air during the heating period by 86%, and the simultaneous use of a recuperator and a geothermal ground collector, which is especially effective for preheating the supplied air, will save 90.38% of electricity or 7591.31 kW during the heating period.

Bibliography

Cai, B. et al. (2017) Theoretical and experimental study of combined heat and power (CHP) system integrated with ground source heat pump (GSHP). *Appl. Therm. Eng*., 127, 16-27.

Chenari, B. et al. (2016) Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review. *Renewable and Sustainable Energy Reviews*, 59, 1426-1447.

Khatry, A. et al. (1978) Periodic variation of ground temperature with depth. *Solar Energy*, 20, 425-427.

Krarti, M. et al. (1995) Analytical model to predict annual soil surface temperature variation. *J. Sol. Energy Eng*., 117, 91-99.

Larwa, B. & Kupiec, K. (2020) Heat transfer in the ground with a horizontal heat exchanger installed – Long-term thermal effects. *Appl. Therm. Eng.*, 164, 114539.

Lis, A. & Savchenko, O. (2022) Possibilities of using the energy potential of geothermal waters in the case of Poland and Ukraine. *Construction of Optimized Energy Potential*, 11, 181-194.

Pan, A. et al. (2020) A new analytical model for short vertical ground heat exchangers with Neumann and Robin boundary conditions on ground surface. *Int. J. Therm. Sci.*, 152, 106326.

Pavlenko, V. & Tkachenko, D. (2018) Evaluation of efficiency of use of receiver in ventilation systems of office accommodation. *Technologies and Design*, 26, 1-7.

Peng Liu et al. (2023) Global sensitivity analysis and optimal design of heat recovery ventilation for zero emission buildings. *Applied Energy*, 329, 120237.

Pérez-Lombard, L. et al. (2008) A review on buildings energy consumption information. *Energy Build.*, 40, 394-398.

SSU-A C V.1.1-27:2010. *Building climatology*.

Zhang, L. et al. (2016) A transient quasi-3D entire time scale line source model for the fluid and ground temperature prediction of vertical ground heat exchangers (GHEs). *Appl. Energy*, 170, 65-75.

Zhelykh, V. (2021) The cooling capacity of geothermal ventilation under the conditions of a temperate climate. *Construction of Optimized Energy Potential*, 10, 69-76.