IOP Conf. Series: Materials Science and Engineering **245** (2017) 052027 doi:10.1088/1757-899X/245/5/052027

Cooperation of Horizontal Ground Heat Exchanger with the Ventilation Unit During Summer – Case Study

Anna Romańska-Zapała [1], Marcin Furtak [1], Mirosław Dechnik [2]

[1] Cracow University of Technology, Warszawska 24 St., 31-155 Krakow, Poland
[2] AGH University of Science and Technology, al. Mickiewicza 30, 30,059 Kraków, Poland

a.romanska@pk.edu.pl

Abstract. Renewable energy sources are used in the modern energy-efficient buildings to improve their energy balance. One of them is used in the mechanical ventilation system ground air heat exchanger (earth-air heat exchanger - EAHX). This solution, right after heat recovery from exhaust air (recuperation), allows the reduction in the energy needed to obtain the desired temperature of supply air. The article presents the results of "in situ" measurements of pipe ground air heat exchanger cooperating with the air handling unit, supporting cooling the building in the summer season, in Polish climatic conditions. The laboratory consists of a ventilation unit intake - exhaust with rotor for which the source of fresh air is the air intake wall and two air intakes field cooperating with the tube with ground air heat exchangers. Selection of the source of fresh air is performed using sprocket with actuators. This system is part of the ventilation system of the Malopolska Laboratory of Energy-Efficient Building (MLBE) building of Cracow University of Technology. The measuring system are, among others, the sensors of parameters of air inlets and outlets of the heat exchanger channels EAHX and weather station that senses the local weather conditions. The measurement data are recorded and archived by the integrated process control system in the building of MLBE. During the study measurements of operating parameters of the ventilation unit cooperating with the selected source of fresh air were performed. Two cases of operation of the system: using EAHX heat exchanger and without it, were analyzed. Potentially the use of ground air heat exchanger in the mechanical ventilation system can reduce the energy demand for heating or cooling rooms by the pre-adjustment of the supply air temperature. Considering the results can be concluded that the continuous use of these exchangers is not optimal. This relationship is appropriate not only on an annual basis for the transitional periods (spring and autumn), but also in individual days in the potentially most favorable periods of work exchanger (summer and winter). Inappropriate operation of the heat exchanger, will lead to a temporary increase in energy consumption for the preparation of the desired air temperature, relative to the fresh air unit which is non-pretreated. For optimal energy system operation: exchanger EAHX - air handling unit, to preserve the most favourable parameters of inlet air to handling unit, there is a need to dynamically adjust the source of fresh air, depending on changing external conditions and the required outlet temperature of central unit (temperature of air forced to the rooms).

1. Introduction

Energy saving is the key challenge for the construction today. It is estimated that worldwide [1] 30 to 40% of total energy is used in residential buildings. In EU it is 40% for buildings and 63% for residential

IOP Conf. Series: Materials Science and Engineering **245** (2017) 052027 doi:10.1088/1757-899X/245/5/052027

buildings. For comparison transport uses 32% and industry 25% [2, 3, 4]. It is evident that there is a need to reduce energy consumption on all stages of creation and use of the building.

Renewable energy sources are used in the modern energy-efficient buildings to improve their energy balance. One of them is used in the mechanical ventilation system ground air heat exchanger (earth-air heat exchanger – EAHX, EAHE, ETAHE, ATEHE) [5, 6, 7, 8, 9]. This solution, right after heat recovery from exhaust air (recuperation), allows the reduction in the energy needed to obtain the desired temperature of supply air [8]. The concept of ground pre-heat has already been used in the times of ancient Greece and Persia [5, 6, 10]. Today the first application of pre-heat were glass-buildings. In recent years, these systems have been used in many types of buildings located in different climatic zones [5, 6].

Literature shows several cases of ground – air exchangers for ventilation. Mostly these case deal with calculations [6, 11] e.g., article [5] that addresses efficiency of the heat exchanger where interaction between the heat exchanger and surroundings is discussed. Article [12] uses CFD to calculate summer and winter in the Mediterranean climate. Articles [7, 8, 9] discuss potential for ground heat exchangers, cost and benefit and drawbacks when they are incorrectly selected. Less popular are field evaluations. Article [13] reports one-year experience from 3 ground heat exchangers in office building in Germany, while [14] does the same in Bangladesh. Articles [15, 16] report evaluation in winter conditions in Poland.

The above reported cases permit us drawing conclusion that using ground located heat exchangers, one can reduce the loads of energy as pre-heated air is used for the ventilation system. In this manner, we reduce heating and cooling loads in ventilation air as well as in the rooms of the building.

2. Purpose and methodology of research

The goal of this work was in-situ assessment of interaction between ground heat exchanger and mechanical ventilation in the Malopolska Laboratory of Energy-Efficient Building (MLBE) building. The building is located at Cracow University of Technology in the centre of Cracow, in south part of Poland. On basis of this work, one will optimize control and operation of BMS system. Effectively, when such an interaction is economically beneficial, the ventilation system will be supported by ground heat exchangers.

The in-situ measurements were performed during the second half of the summer. The measuring set-up has been extracted within the mechanical ventilation system intake and exhaust, which supports the ground, first and second floor (without toilets and communication rooms) of the MLBE building.

The measuring set-up enables the assessment of the cooperation of EAHX – ventilation unit in real conditions. It consists of:

- Ventilation unit intake and exhaust (CW 1),
- Ground heat exchangers (EAHX),
- Fresh air inlet on the wall
- Sensors, with information collected every 15 minutes,
- Integrated building automation and control system

Ventilation unit intake and exhaust (CW 1) is located on the main floor. It is equipped with a rotary heat exchanger with 80% efficiency of heating and cooling, heating coil or water cooling device with powers 3,25 kW and 4,22 kW respectively. The ventilation unit can deliver 1850 m3/h and is equipped with its own built automation controller monitored by the integrated control system.

Fresh air can be delivered either from the fresh air inlet on the wall or from two other inlets that are integrated with the ground heat exchangers (photo 1). One of these ground heat exchangers is located under the building and the other outside the building. The heat exchangers are made out of 200 mm diameter PVC pipe with 59 or 60 m length on 1.5 to 2.5 m depth and have 2% slope as well as water collecting wells. Inlets are on the north side of the building [17]. Selection of the source of fresh air is

IOP Conf. Series: Materials Science and Engineering **245** (2017) 052027 doi:10.1088/1757-899X/245/5/052027

performed using sprocket with actuators controlled by the algorithm supplied to the computerized control system. The exhaust is organized through the roof exhaust.

The measuring system are the sensors used with the integrated process control system in the MLBE building, which is responsible for the acquisition and archiving of measurement data and the control of the mechanical ventilation system. Information collected for this project include: temperature and RH on entry and exit of the air pipes of the EAHX (thermal sensors sensitivity 0.1°C over the range 0 to 40°C; relative humidity sensitivity 2% over the range 10 to 90%). Measurement data were collected every 15 min. Figure 1 shows the control panel of ventilation unit CW 1 under the BMS system with adjustable sources of fresh air in the form of three examined intakes.

Figure 1. Mechanical room of the MBLE - ventilation unit (CW 1), channels from inlet and ground heat exchangers

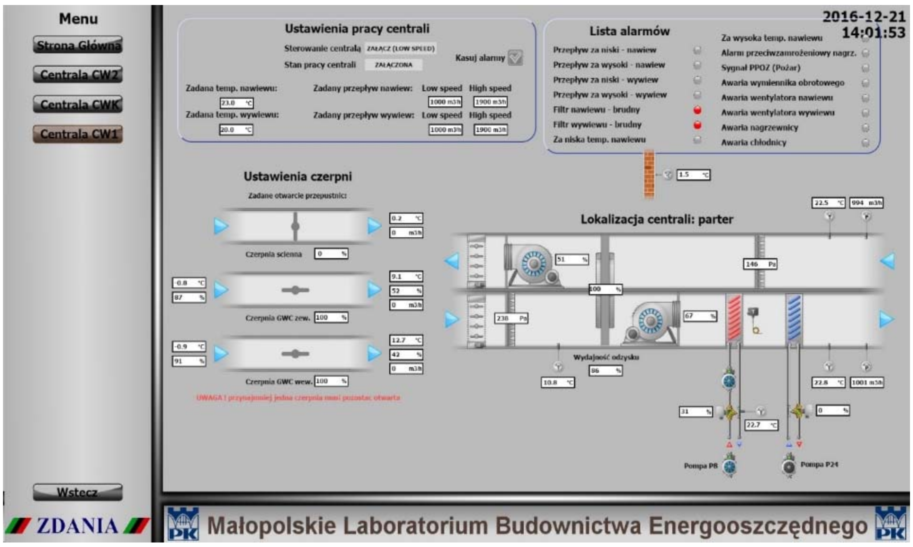

Figure 2. Control panel for mechanical ventilation and fresh air inlets within the integrated control system for the building MLBE

3. Results and discussions

Duration of these tests was 3 weeks. Measurements were collected in September 2016 in three periods (a) 1-6 Sept, (b) 8-12 Sept, (c) 16-20 Sept. In this time, balanced system (1000 m3/h supply and exhaust) and required air temperature were continually maintained.
The figures 3 through 5 show the temperatures registered at the inlet and outlet air of ground heat exchangers. These figures allow to consider two cases of operation of the system: using EAHX heat exchanger and without it (using fresh air intake on the wall). In the first case, ventilation unit inlet air temperature is the same as output EAHX air temperature. In the second case, input EAHX air temperature is the same as temperature of external air. Air at the same temperature would be collected by the air intake on the wall in the case of the system without EAHX.
Temporary increase of temperature on exit from ground heat exchanger at time 0:00 is caused by a restart of the ventilation unit or, on Sept 1, by the temporary closure of the ventilation unit. Closing the air flow caused an increase of temperature in the room in which the end of the ventilation was located.
One may observe, comparing figures 3 through 5, that EAHX provides stabilization of air temperature on entry to the ventilation unit in comparison to the outdoor temperature. This is seen in all Figures.
In summer, it is necessary to cool the building. Figures 6 through 8 show the impact of the EAHX system on the ventilation unit inlet air temperature in 3 periods of experiment. During the day, operation of the EAHX system had a positive effect on the ventilation unit inlet air temperature. The air was cooled. While in the case of night work, operation of the EAHX system had a negative effect on the ventilation unit inlet air temperature. All this time, the building should be cooling, and the air was unnecessarily heated. In addition, energy requirement for the air flow through the EAHX are higher than air inlet on the wall. This causes unnecessary loading of fan drives and undesirable increase in electricity consumption.
Potentially, the use of ground air heat exchanger in the mechanical ventilation system can reduce the energy demand for heating or cooling rooms by the pre-adjustment of the supply air temperature.
Considering the results, it can be concluded that the continuous use of these exchangers is not optimal. This relationship is appropriate not only on an annual basis for the transitional periods (spring and autumn), but also on individual days in the potentially most favourable periods of work exchanger (summer and winter). Inappropriate operation of the heat exchanger, will lead to a temporary increase in energy consumption for the preparation of the desired air temperature, relative to the fresh air unit which is non-pretreated. For optimal energy system operation: exchanger EAHX - air handling unit, to preserve the most favourable parameters of inlet air to handling unit there is a need to dynamically adjust of source of fresh air, depending on changing external conditions and the required outlet temperature of ventilation unit (temperature of air forced to the rooms). This relation is not only valid for condition of constant flow but also for the condition of variable air flow as needed to maintain a constant pressure in different parts of the building.
In summary, to optimize interaction of ground heat exchanger with the mechanical ventilation, unit one must have a selection of the fresh air delivery. In the control algorithm, one must include:

- outdoor air temperature,
- air temperature on exit from ground heat exchanger,
- air temperature on exit from ventilation unit,
- electric energy for moving air,
- air temperature on exhaust for the building and the necessity of working ventilation unit's rotary heat exchanger (recuperator),
- additional energy to heat or cool the ventilation air,
- the necessary air flow.

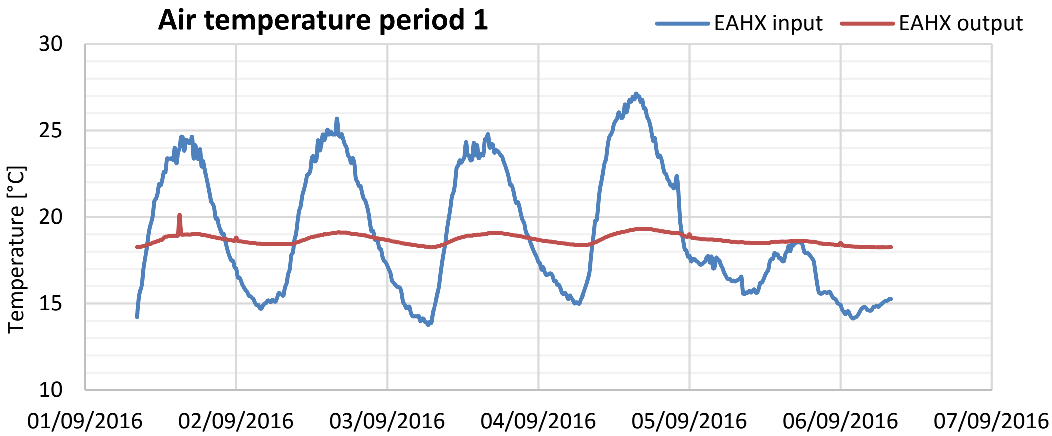

Figure 3. Air temperature on entry and exit from ground heat exchanger in period of September 1 – 6, 2016

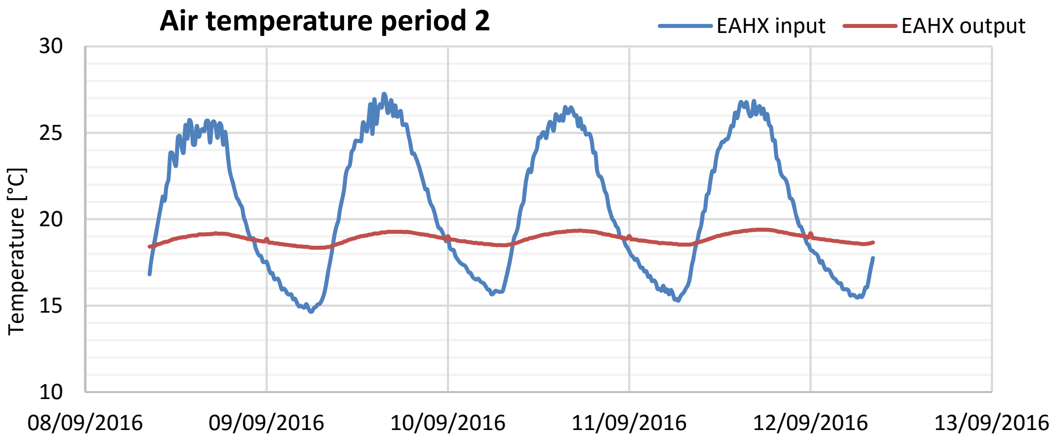

Figure 4. Air temperature on entry and exit from ground heat exchanger in period of September 8 – 13,2016

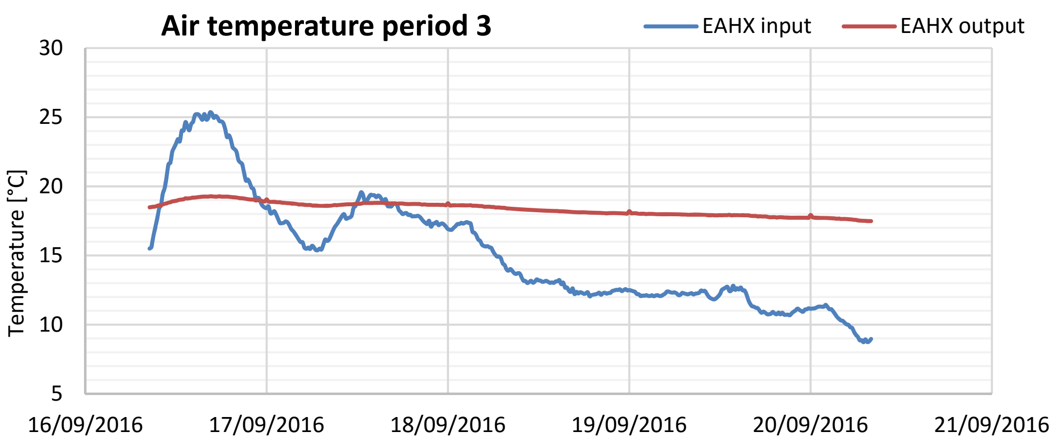

Figure 5. Air temperature on entry and exit from ground heat exchanger in period of September 16 – 21, 2016

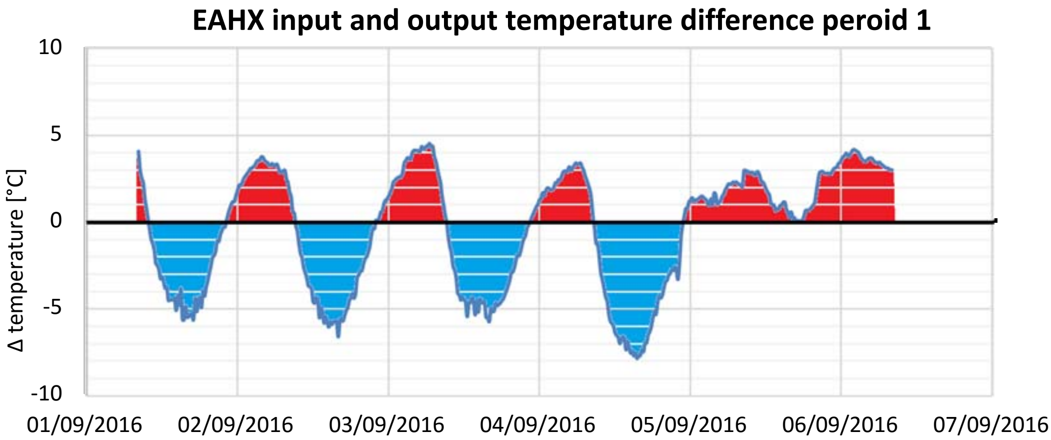

Figure 6. EAHX system input and output temperature difference in period of September 1 – 6, 2016. Red mark – air heating. Blue mark – air cooling

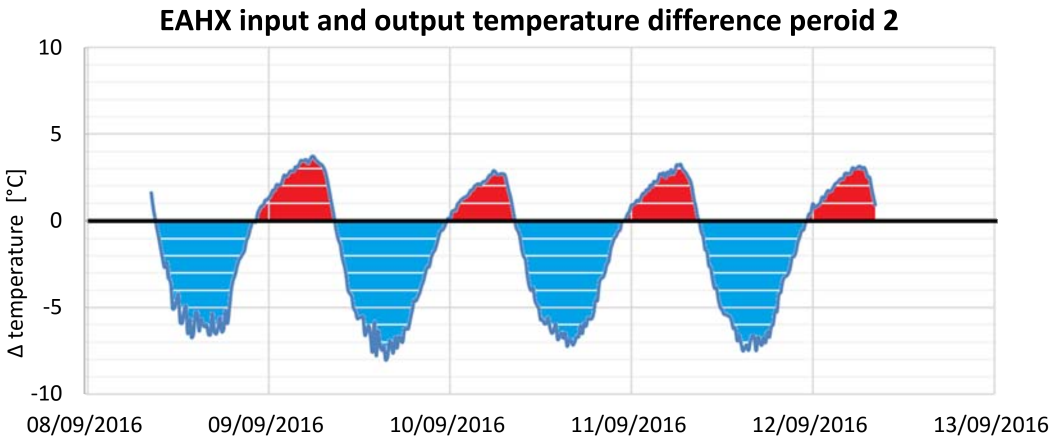

Figure 7. EAHX system input and output temperature difference in period of September 8 – 13, 2016. Red mark – air heating. Blue mark – air cooling

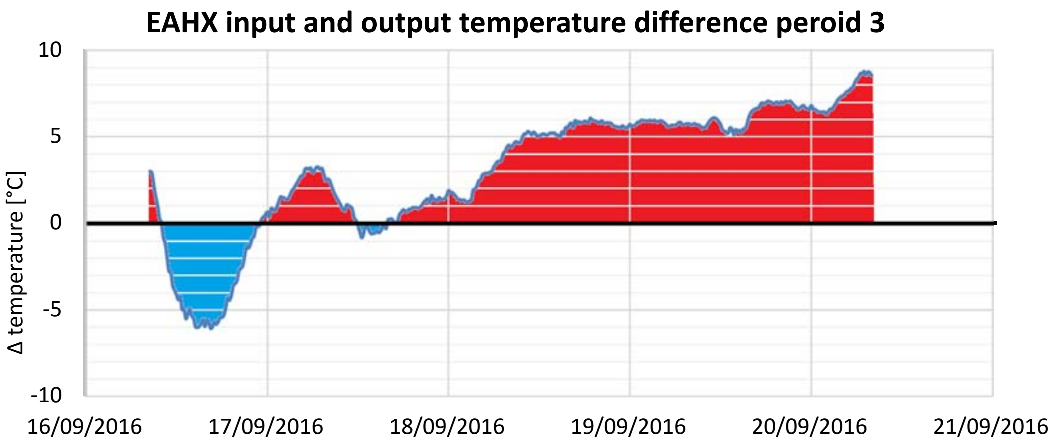

Figure 8. EAHX system input and output temperature difference in period of September 16 – 21, 2016. Red mark – air heating. Blue mark – air cooling

4. Conclusions

Increasing requirements of energy conservation forces us to use alternative energy sources and integrated automation and control systems.

The use of ground air heat exchanger, depending on the relationship of outdoor air temperature and air temperature on exit from ground heat exchanger, allows pre-adjustment of the supply air temperature by pre-heating or pre-cooling. Such prepared air supplied to the mechanical ventilation system should reduce the energy inputs necessary to achieve the desired temperature in each room of the building.

The maximum energy efficiency of system EAHX-ventilation unit is possible if we use integrated control system that will select the source of the fresh air in relation to the existing conditions and requirements that may vary for different occupancy or use of different rooms. Such a system will provide comfort with a minimum energy needed to achieve it.

This research indicates the significance of interaction and integration of different elements such as ground heat exchanger, direct fresh air inlets with mechanical ventilation unit in low energy building.

The above results form a foundation for further work on control algorithms on delivery of the fresh air and recirculation of air in the building. Using a dynamic selection of the fresh air source, already before applying other methods of air conditioning, we can optimize system EAHX- ventilation unit. Such algorithm will be universally applicable to all buildings with mechanical ventilation and ground heat exchangers.

References

[1] S. Eleni Vergini, P.P. Groumpos, "A review on Zero Energy Buildings and Intelligent Systems", *Information, Intelligence, Systems and Applications (IISA), 2015 6th International Conference on*, 6 – 8 July 2015

[2] H. Wicaksono, S. Rogalski, E.Kusnady, "Knowledge-based intelligent energy management using building automation system", *IPEC, 2010 Conference Proceedings*, 27 – 29 Oct. 2010.

[3] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, http://eur-lex.europa.eu/

[4] S. Firląg, "Investor's Guide: I build wisely, I build energy-saving" (Poradnik inwestora: buduję z głową buduję energooszczędnie), *Fundacja Ziemia i Ludzie*, Warszawa, 2014.

[5] G. Gan, "Dynamic interactions between the ground heat exchanger and environments in earth–air tunnel ventilation of buildings", *Energy and Buildings*, vol. 85, pp. 12–22, 2014.

[6] C. Peretti, A. Zarrella, M. De Carli, R. Zecchin, "The design and environmental evaluation of earth-to-air heat exchangers (EAHE). A literature review", *Renewable and Sustainable Energy Reviews*, vol. 28, pp. 107–116, 2013.

[7] Ż. Mirosław, "Assessment of Potential Applicability of Ground Air Heat Exchanger (GAHE) in Białystok" (Ocena potencjalnych możliwości zastosowania GPWC na terenie Politechniki Białostockiej), *Ciepłownictwo, ogrzewnictwo, wentylacja*, vol. 8/2012, pp. 323–346.

[8] M. Szymański, J. Wojtkowiak, "Analysis of Year-Long Operation of RGWC Ground Pipe Heat Exchanger in Mechanical Ventilation System of Apartment Building" (Analiza całorocznej pracy rurowego gruntowego wymiennika ciepła RGWC w układzie wentylacji mechanicznej budynku mieszkalnego), *Ciepłownictwo, ogrzewnictwo, wentylacja*, vol. 11/2008, pp. 36–38.

[9] M. Szymański, J. Wojtkowiak, "Simplified method of dimensioning and cost-effectiveness evaluation of earth-to-air heat exchanger in building ventilation system" (Uproszczona metoda wymiarowania i oceny opłacalności gruntowego wymiennika ciepła w układzie wentylacji budynku), *Ciepłownictwo, ogrzewnictwo, wentylacja*, vol. 7-8/2007, pp. 55–63.

[10] C. Ionescu, T. Baracu , G-Elena Vlad , H. Necula , A. Badea, "The historical evolution of the energy efficient buildings", *Renewable and Sustainable Energy Reviews*, vol. 49, pp. 243–253, 2015.

[11] Maneesh Kaushal, "Geothermal cooling/heating using ground heat exchanger for various experimental and analytical studies: Comprehensive review", *Energy and Buildings*, vol. 139, pp. 634–652, 2017.

[12] P. M. Congedo, C. Lorusso, M. Grazia De Giorgi, R. Marti, D. D'Agostino, "Horizontal Air-Ground Heat Exchanger Performance and Humidity Simulation by Computational Fluid Dynamic Analysis", *Energies*, vol. 9, iss. 11, 2016.
[13] J. Pfafferott, "Evaluation of earth-to-air heat exchangers with a standardised method to calculate energy efficiency", *Energy and Buildings*, vol. 35, iss. 10, pp. 971–983, 2003.
[14] Md. Shazib Uddin, A. Raju, R. Masudur, "Performance evaluation and life cycle analysis of earth to air heat exchanger in a developing country", *Energy and Buildings*, vol. 128, pp. 254–261, 2016.
[15] A. Skotnicka Siepsiak, M. Wesołowski, "Efficiency of Tubular Ground-Air Heat Exchanger in Winter Season in the Light of Laboratory Empirical Measurement Data" (Wydajność rurowego gruntowego powietrznego wymiennika ciepła w świetle laboratoryjnych danych pomiarowych w okresie zimowym), *Ciepłownictwo, ogrzewnictwo, wentylacja*, vol. 2/2016, pp. 71–75.
[16] A. Flaga-Maryanczyk, J. Schnotale, J. Radon, K. Was, "Experimental measurements and CFD simulation of a ground source heat exchanger operating at a cold climate for a passive house ventilation system", *Energy and Buildings*, vol. 68, Part A, pp. 562–570, 2014.
[17] J. Rudolf, M. Dechnik, "Małopolska Laboratory of Energy Efficient Building: innovative and energy efficient ventilation technologies" (Małopolskie Laboratorium Budownictwa Energooszczędnego: innowacyjne i energooszczędne technologie wentylacyjne), *Cyrkulacje: powietrze, wentylacja, klimatyzacja*, vol. 32, pp. 30–34, 2016.