Optimising the operation of the HVAC system with a ground source heat pump in a school building

Optymalizacja pracy systemu HVAC z gruntową pompą ciepła w budynku szkolnym

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A properly designed and assembled HVAC (Heating, Ventilation and Air Conditioning) system in an educational building is crucial for ensuring thermal comfort, improving indoor air quality, and positively impacting health and learning efficiency. Utilising renewable energy sources, such as a ground source heat pump, contributes to energy savings, reducing operating costs and CO_2 emissions. However, a faulty installation can lead to incorrect operation, necessitating a comprehensive HVAC system modernisation for proper functioning. The paper presents examples of design and operational errors in such installations, based on the actual HVAC system with a ground source heat pump and a vertical ground heat exchanger in the building of the Primary School in Ożarowice, Poland. The building inventory and analysis of the existing HVAC system revealed issues related to the improper functioning of the heat pump installation and ventilation system, as well as irregularities in their design and the selection of devices in respective installations. The possibility of optimising the operation of the existing system was indicated by, among others, expanding the ground heat exchanger installation and replacing current heat pump units with ones that are better suited to cover the building's heat demand. Also, upgrading air handling units with ones equipped with heat exchangers of higher efficiency was recommended.
Keywords: school building, HVAC system, ground source heat pump, ground heat exchanger, optimisation, modernisation, renewable energy sources

Prawidłowo zaprojektowana i wykonana instalacja HVAC (Heating, Ventilation and Air Conditioning) w budynkach edukacyjnych jest niezbędna dla zapewnienia komfortu cieplnego, poprawy jakości powietrza oraz pozytywnego wpływu na zdrowie i efektywność nauki. Wykorzystanie odnawialnych źródeł energii, na przykład gruntowej pompy ciepła, przyczynia się do oszczędności energii, obniżając koszty eksploatacji budynku oraz emisję CO_2. Wadliwie wykonany system HVAC może prowadzić do jego nieprawidłowego funkcjonowania i ostatecznie wymagać kompleksowej modernizacji. W publikacji przedstawiono przykładowe błędy projektowe i eksploatacyjne w tego typu instalacjach, na podstawie rzeczywistego systemu HVAC z gruntową pompą ciepła i pionowym wymiennikiem ciepła w budynku Szkoły Podstawowej w Ożarowicach w Polsce. Inwentaryzacja budynku i analiza istniejącego systemu HVAC ujawniły problemy związane z niewłaściwym funkcjonowaniem instalacji pompy ciepła oraz systemu wentylacyjnego, a także nieprawidłowości w ich projektach oraz doborze urządzeń w poszczególnych instalacjach. Możliwość optymalizacji działania istniejącego systemu wskazano między innymi poprzez rozbudowę instalacji gruntowego wymiennika ciepła oraz wymianę obecnych jednostek pomp ciepła na takie, które są lepiej dopasowane do pokrycia zapotrzebowania budynku na ciepło. Zalecono także wymianę central wentylacyjnych na wyposażone w wymienniki ciepła o wyższej efektywności.
Słowa kluczowe: budynek szkolny, system HVAC, gruntowa pompa ciepła, gruntowy wymiennik ciepła, optymalizacja, modernizacja, odnawialne źródła energii

Introduction

In Poland, in the school year 2022/23, there were 7.9 million children, adolescents and adults enrolled across all education levels, which accounted for 20.8% of the country's population [1]. In the European Union there were 93.3 million pupils and students enrolled, accounting for 21% of the total EU population [2].

For this reason, a properly designed and constructed HVAC (Heating, Ventilation, and Air Conditioning) system in educational buildings is crucial. Optimal indoor air temperature and humidity help students and teachers concentrate on learning, which affects the effectiveness of the educational process [3]. A well-functioning ventilation system ensures the supply of fresh air to the building and leads to the reduction of CO_2 levels and the removal of air pollutants such as pollen and bacteria in school rooms [4]. This is important for the health of students and staff and

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reduces the risk of spreading infectious diseases. An effective HVAC system based on renewable energy sources in an educational building helps minimize energy consumption [5] and reduce the costs associated with heating and cooling, saving money that can be used for other educational purposes. A properly functioning HVAC system can extend the life of a building by preventing problems with moisture, mould, and other structural issues [6]. Implementation of renewable energy sources can help educational buildings meet the criteria of sustainable construction, which is increasingly important in the context of environmental protection.

In the light of the European Union's decarbonisation and CO_2 reduction policy [7], newly designed and modernised HVAC installations are usually based on renewable energy sources. In this respect, ground source heat pumps are becoming more and more popular. A system based on such a heat source is able to use the ground temperature as a heat source via a ground heat exchanger. It is an effective heat source, especially compared to an air source heat pump, because the ground temperature does not fluctuate and is higher than the external air temperature during the heating period and lower during the cooling period. Therefore, a system based on a ground source heat pump is characterised by higher energy efficiency than the one with an air source heat pump. Moreover, it provides heat without negative impact on the environment, which means it can significantly reduce CO_2 emissions. Numerous descriptions of research on ground source heat pumps and ground heat exchangers are available in the literature [8-27], including examples of their implementation in school buildings [25-27].

Educational buildings have unique needs related to HVAC systems, so an individual approach to the design and maintenance of these installations is important to meet the requirements of students, staff and the learning environment. Educational buildings often contain different zones such as classrooms, corridors, gymnasiums, etc. Each of these zones may have different requirements regarding air temperature, humidity and ventilation air volume flow rate, requiring a flexible HVAC system that can adapt to different conditions. In schools and universities there are often large groups of people in one place. The HVAC system must therefore be able to ensure thermal comfort conditions both during periods of low and high occupancy. Educational buildings often operate at different times depending on class schedules, which can impact heating and cooling demands at different times of the day. The HVAC system must also be able to exchange and filter air effectively. Ensuring adequate indoor air quality is crucial for the health and concentration of students and staff.

Due to limited financial resources, educational buildings often seek ways to save energy. Therefore, HVAC systems should be designed to be energy-efficient and environmentally friendly. They often require advanced control and monitoring solutions that allow them to adapt to changing conditions and ensure optimal performance. These aspects of the HVAC system can only be achieved if the devices and installation are carefully designed, properly selected, reliably assembled and operated without hindrance. Errors that appear at every stage of the system's operation may affect its incorrect operation and potentially lead to its components damage. To achieve specific parameters in HVAC systems, their careful and professional design and assembly are essential. As technology advances and the variety of components in such systems increases, expertise and experience become increasingly important. Errors in the design and execution of the HVAC systems may result in a lack of thermal comfort experienced by building's occupants, higher operating costs, increased negative impact of the system on the natural environment, reduced system efficiency and shortened equipment life. Therefore, designers, contractors and building owners should ensure that each HVAC system is designed and implemented in accordance with best practices and industry standards.

Installations based on ground source heat pumps are particularly sensitive to errors and negligence by designers and contractors. When sizing a heat source for a ground source heat pump, it is important to know the characteristics of the soil in which the ground heat exchanger will be located. For this purpose, geological research such as thermal response test (TRT) [28] should be carried out. For a specific type of soil, there is a certain amount of energy that can be extracted from it. The essence of a properly designed ground heat exchanger is to determine its appropriate length, i.e. the number and depth of boreholes, while maintaining the minimum distance between individual boreholes. Too compact arrangement of boreholes for vertical probes or inappropriate determination of their depth may lead to excessive cooling of the ground, which may hinder its regeneration. As a result, the input temperature of the heat pump may drop, which can lead to the heat pump malfunction and short cycling during peak demand periods. The issue of improper operation of systems based on ground source heat pumps and the related need for their optimisation were discussed in [18, 20, 25, 26].

The aim of this paper is to draw attention to possible design and assembly mistakes of HVAC systems and their consequences, as well as the sensitivity of similar systems to low-quality workmanship on the example of the Primary School building in Ożarowice, Poland. The paper analyses the operation of the existing HVAC system based on a ground source heat pump with a vertical ground heat exchanger (VGHE) and determines the possibilities of its optimisation.

Description of the analysed school building and its HVAC system

Building description

The analysed building was the Primary School in Ożarowice, Poland. It is located in the 3rd climate zone [29]. The building with an area of 3,951 m^2 was built in 2005. It consists of two parts: the old one (northern part of the building) and the new one (southern part of the building). Fig. 1 shows a view of the analysed building.

Fig. 1.
The analysed building of the Primary School in Ożarowice, Poland [30]

The calculation values of the building's heat demand in the design conditions, i.e. for an external air temperature of – 20°C, were specified in the building technical documentation provided by the investor. Tab. 1 presents the values of heat demand for heating of both parts of the building, as well as heat demand for ventilation system. In both parts of the building, heat losses were related to penetration through the building envelope and ventilation air heating. The heat demand for ventilation was related to the power of water heaters (heating coils) in air handling units and took into account heat recovery in glycol heat exchangers of those units. The total heat demand of the building was 255 kW.

Tab. 1. Heat demand of the analysed school building

Old part of the building	63 kW
New part of the building	83.3 kW
New part of the building – unadapted rooms under the gymnasium (thermal power reserve at the investor's request)	23 kW
Ventilation technological heat	80.3 kW

Heat source

Three ground source heat pumps with a total nominal power of 114 kW (3 x 38kW) and coefficient of performance COP = 4 were installed as the basic heat source in the existing heating system. The maximum supply temperature that could be achieved by them was 55°C. The whole system is bivalent and the additional heat source in the existing heating system were two gas boilers with a total power of 190 kW (2 x 95 kW). The bivalent temperature in the technical documentation was specified as – 4.1°C. Those devices supplied the central heating, domestic hot water and ventilation technological heat installations. Domestic hot water preparation had priority over heating and a constant supply temperature. Amount of energy used for heating domestic water was estimated as 30 000 kWh per year.

The heat source of the ground source heat pumps was a vertical ground heat exchanger (VGHE) consisting of 11 vertical boreholes and a network of horizontal pipes connecting the boreholes to the manifolds. The tubing was made of polyethylene pipes 40 x 2.4. The heat carrier fluid, with which the VGHE was filled, was a solution of water with ethylene glycol 30%. The increase of the fluid in the soil was estimated at Δ4°C. The total depth of the vertical boreholes was 974 m, and the total length of the horizontal pipes was 1968 m.

The possibility of using the recovered heat in heat exchangers of air handling units was designed in the ground heat source installation. The heat recovered in this way was intended to increase the parameters of the heat carrier fluid in the VGHE. Heat recovery would take place via glycol heat exchangers installed in the air handling units (fig. 2).

Heating elements

The old part of the building was equipped with steel radiators, while the new part was equipped with an underfloor heating system. The heat was also supplied to 4 water heaters (heating coils) in air handling units and 2 double-jacket domestic hot water tanks with a capacity of 700l and 500l. The 500l tank was equipped with a 9 kW electric heater as an additional heat source for domestic hot water preparation.

Total power of heating elements was equal to:

– Steel radiators 62.5 kW
– Underfloor heating 123 kW
– Water heaters in air handling units 80.3 kW

Air handling units

The mechanical ventilation system was designed and implemented in the new part of the building. Tab. 2 presents a description of the air handling units with the listed rooms they support. The other rooms in the building were not equipped with the mechanical ventilation system.

Tab. 2. Description of the air handling units

Air handling unit	Supported rooms	Ventilation air volume flow rate [m^3/h]		Heat recovery type	Recirculation	Supply air temperature [°C]
		Supply	Exhaust			
N1W1	gymnasium locker rooms and equipment storage hall and corridors by the gymnasium	4700	4900	glycol heat exchanger + heat recovery supporting the VGHE	yes	20
N2W2	classrooms 1st floor hall second equipment storage	1900	1700	glycol heat exchanger + heat recovery supporting the VGHE	yes	20
N3W3	kitchen scullery canteen extra rooms	2170	2480	glycol heat exchanger + heat recovery supporting the VGHE	no	20
N4W4	cellar storage rooms	1400	1400	glycol heat exchanger (no heat recovery supporting the VGHE)	no	20

Fig. 2 shows the structure of the existing N1W1, N2W2, N3W3 and N4W4 air handling units. The numbers indicate the individual elements relevant in the context of heat demand analysis: 1 – water heater (heating coil), 2 – glycol heat exchanger, 3 – heat exchanger supporting the VGHE of the ground source heat pump, 4 – mixing box.

Analysis of the existing HVAC system operation

Building stocktaking

During the operation of the heating system in the building, it was noticed that the heat pumps did not work. The entire building was heated only by gas boilers. Domestic hot water preparation was entirely carried out by the electric heater installed on a double-jacket 500l water tank. Furthermore, during the inspection of ventilation system it was noticed that the air handling units also did not work.

Building stocktaking showed that the heat source installation was not hermetic. This was evidenced by the inability to maintain the set pressure in the glycol installation of the VGHE and the necessity of its regular manual filling. Fig. 3 shows a photo of the glycol manifold in the analysed building.

Some of the control valves in the boiler room and air handling unit mechanical room were incorrectly installed. A few of the three-way valves had their dedicated

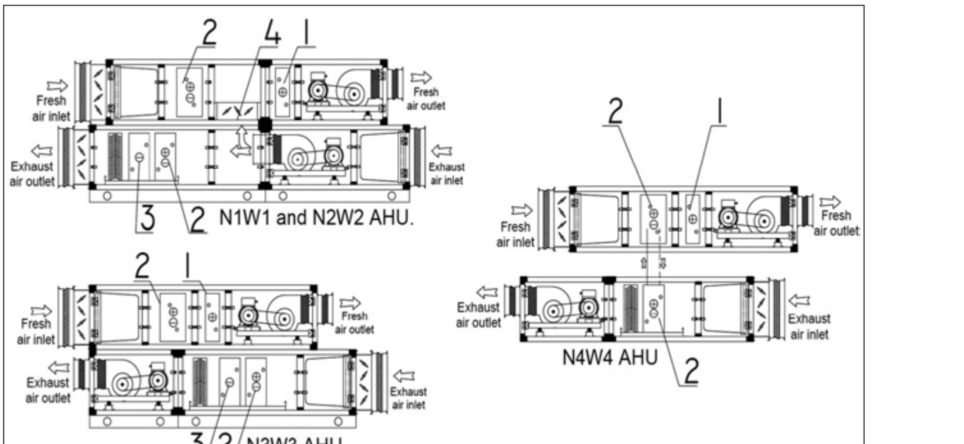

Fig. 2.
Scheme of particular air handling units; 1 – water heater (heating coil), 2 – glycol heat exchanger, 3 – heat exchanger supporting the VGHE of the ground source heat pump, 4 – mixing box

Fig. 3.
Glycol manifold in the VGHE installation – glycol return to the building

actuator removed and remained in a fixed position. The technical documentation of the facility did not contain information justifying the dismantling of the originally installed actuators. One of the three-way valves located on the heating pipes of the heat pump circuit had a regulating element stuck in the insulation of the pipes, which prevented its proper operation (fig. 4). Part of the measuring equipment, i.e. thermometers and manometers, was also found to be missing or malfunctioning (fig. 5).

Discrepancies between the technical documentation and the existing state were also identified, i.e. the way of connecting

Fig. 4.
The regulating element of the three-way valve immobilized by heating pipe insulation

Fig. 5.
Missing or malfunctioning thermometers and manometers

the radiators' installation in the old part of the building, as well as the location and connection of the N3W3 and N4W4 air handling units and thus the routing of some of the ventilation ducts. The air handling units had fan inverters damaged due to a short circuit. In the exhaust part of the N4W4 air handling unit a fan was found to be missing.

Analysis of the existing HVAC system design

In order to further identify problems with the operation of the HVAC system in the building, a computational analysis of the design of the VGHE and heat source installation, as well as the ventilation system was carried out.

Analysis of the technical documentation of the VGHE installation showed that the spacing between the boreholes was approximately 15 m while the horizontal pipes were located at the depth of 1.3 m and 1.7 m, respectively for the return and supply pipes. These values were consistent with the recommendations [31]. According to the available documentation, the horizontal pipes were laid in the ground in close proximity to each other, without maintaining the minimum recommended distance of 0.7 m [31]. Due to this, it is difficult to estimate the possible heat gain from the ground through the horizontal pipes of the VGHE. According to the guidelines [31], with a spacing of min. 0.7 m the heat gain from the ground can be assumed to be 20 W/m^2. When reducing the distance between horizontal pipes, a decrease in heat gain and possible thermal interaction between the pipes should be taken into account. Due to this, the influence of horizontal pipes of the VGHE on the amount of heat obtained by the HVAC system was omitted in further analysis.

In the case of the heating system powered by a ground heat pump the key value that should be defined at the design stage is the heat flow available to be extracted from the ground. The available technical documentation did not indicate that thermal reaction test was carried out to examine soil parameters. For this reason, it was decided to verify computationally the amount of heat that could be extracted from the ground. The technical documentation specified the material and thickness of soil layers on the school premises (tab. 3). The values of the heat conductivity coefficients for individual layers were determined on the basis of [31].

The average calculated value of thermal conductivity coefficient of the soil was λ = 1.77 W/(m*K), in accordance with

Tab. 3. Material and thickness of individual soil layers according to the technical documentation

Material	Thickness [m]	Thermal conductivity, λ [W/(m*K)]
sand, clay	4.4	0.7
medium-hard limestone	11.6	1.96
limestone very hard	15	1.96
medium-hard limestone	26	1.96
fissured limestone	21	1.96
red loam, plastic	23	0.9

[31]. On this basis, the specific thermal efficiency of the soil was assumed to be 38 W/m. With boreholes with a total depth of 974 m, the amount of heat that could be extracted from the ground was 37 kW. Meanwhile, heat pumps with a total power of 114 kW were installed in the building. These units were therefore oversized in relation to the capacity of the ground heat source. It can be assumed that for such a sized VGHE, one of the three heat pumps installed in the building could operate successfully. The heat pump efficiency was COP = 4 (for the nominal heat pump power of 38 kW). The heat gain from the operation of the compressor would thus be 9.5 kW, and the total heating power of a single heat pump would be 47.5 kW. However, this value would not cover the total heat demand of the building. The bivalent point would be established at a temperature of approximately 15.5°C (fig. 6).

In the case of the ventilation system, the technical documentation did not include a description of the operation of heat exchangers in the existing air handling units. Therefore, the most favourable scenario from the energy efficiency perspective was considered in the calculation, assuming the simultaneous use of both heat exchangers at their full capacity. Before carrying out the analyses, other variants were also considered, i.e. the independent operation of one of the heat exchangers:

- the individual operation of only the glycol heat exchanger (fig. 2, element 2) was a less advantageous solution

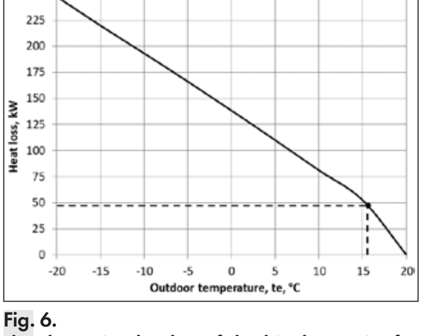

Fig. 6.
The determined value of the bivalent point for the analysed operation of one heat pump in the building

from the point of view of the system's energy efficiency due to the smaller amount of heat recovered from the exhaust air. For this reason, it was not taken into account in further analyses regarding the validity of replacing air handling units,

- the individual operation of only the heat exchanger recovering heat from the exhaust air to support the operation of the VGHE (fig. 2, element 3) meant that the air would have to be heated by the water heater (heating coil) under design conditions from – 20°C to +20°C. In none of the existing air handling units, the water heating coil had sufficient power to increase the temperature of the designed air volume flow rate by 40°C, so the operation of the glycol heat exchanger (fig. 2, element 2) was necessary.

Tab. 4 shows the power of the water heating coils, as well as the amount of heat recovered from the exhaust air by the glycol heat exchangers and the heat exchangers supporting the operation of the VGHE in all air handling units. The value of heat to be transferred for technological heat purposes, including heat extracted from the ground and waste heat from the operation of the heat pump compressor, is also presented.

Tab. 4. The values of heat recovered in both heat exchangers and power of water heating coils in all air handling units

Air handling unit	Heat recovered from the exhaust air in the glycol heat exchanger [kW], (heat recovery efficiency [%])		Heat recovered from the exhaust air to support the operation of the VGHE [kW]	Power of water heating coils in air handling units [kW]	Heat to be transferred for technological heat purposes [kW]
N1W1	24	(37.6)	14.6	36.58	21.98
N2W2	9.26	(36.1)	2.2	15.04	12.84
N3W3	11.84	(40.4)	3.53	17.31	13.78
N4W4	8.7	(43.5)	-	11.36	11.36
Total =	53.8		20.33	80.29	59.96

The values of heat recovered in the heat exchanger supporting the VGHE operation (fig. 2, element 3) were determined on the assumption that all the heat transferred to the VGHE from the exhaust air increased the temperature of the heat carrier fluid and was not dispersed in the ground. In fact, part of the heat transferred may be dissipated in the ground if the ground temperature is higher than the temperature of the heat carrier fluid. Due to the lack of ground temperature data in further analysis on determining the validity of modernising the existing HVAC system, the most favourable variant in terms of energy efficiency of the existing system was adopted, assuming full use of the recovered heat for the support of the VGHE. Heat recovery in the glycol heat exchanger (fig. 2, element 2) was characterised by relatively low efficiency compared to currently available on the market rotary or crossflow heat exchangers. In the next section of the paper, the parameters of newly designed and existing air handling units are compared in order to determine the degree of ventilation system optimisation (tab. 5 and 6).

Indications for HVAC system optimisation

To improve the heating system operation optimisation of the ground source heat pumps installation was proposed. In place of the existing heat pumps, a cascade of new units was designed. Their bivalent temperature would be – 10°C, below which the additional heat source in the form of existing gas boilers would start operating. The power of the new heat pumps would be 195 kW, and the power of the existing additional heat source would be 190 kW. In accordance with the investor's request, a reserve of thermal power was provided for previously unadapted rooms located under the gymnasium. To minimise the effect of sudden on-off switching of heat pumps (short cycling) and thus the wear rate of heat pump compressors, each of the selected devices would have 4 compressors, to allow for cascading switching of heat pumps depending on the building's current heat demand. To reduce the wear of compressors in heat pumps and to use heat more effectively in the system, a heat buffer with a capacity of 1,500 litres would be installed. The pipes and all fittings connecting the heat pumps with the existing additional heat source should be completely replaced with new ones due to the increase in the flow of the heat carrier fluid in the installation. Three-way mixing valves located at the manifolds of individual heating elements should also be equipped with new actuators. The master controller of the entire system would be the heat pump controller HP-01. The gas boilers would be switched on after receiving a signal from this controller. Domestic hot water preparation in hot water tanks would be carried out by HP-02 and HP-03 heat pumps. The heat would be transferred to the hot water tanks via a 3-way switching valve. Fig. 7 shows a scheme of the optimised boiler room.

The rate of wear of the extension vessels and hydraulic separator should be verified. The technical condition of hot water tanks should be checked for their efficiency, due to their age. If the condition of these elements were unsatisfactory or if

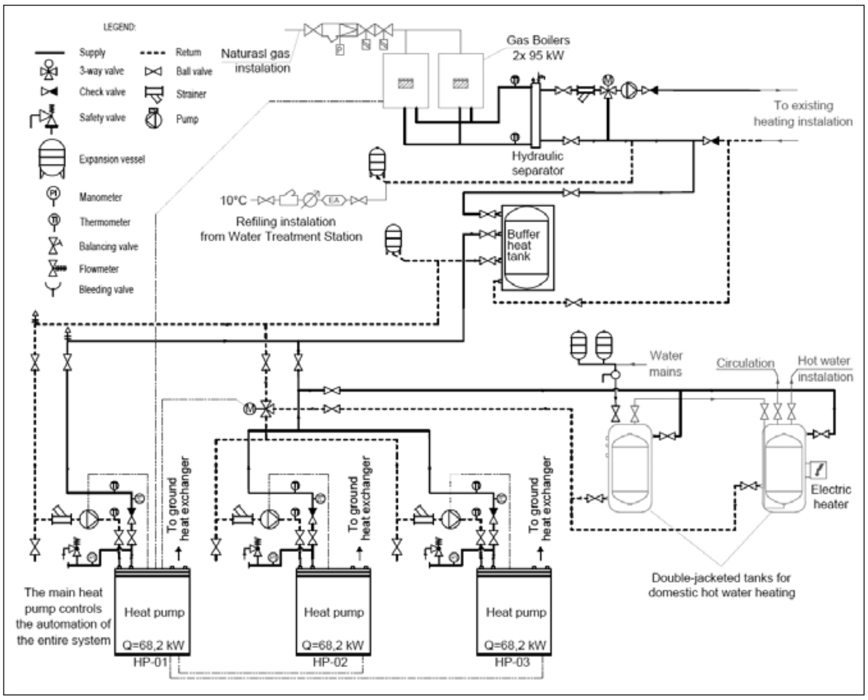

Fig. 7.
Scheme of the optimised boiler room. Existing devices and installations are marked in grey; new devices and installations are marked in black

there were discrepancies between the modified parameters of the heating system after modernisation and the technical parameters of the existing devices, they should be replaced with new ones.

The optimisation of the ground source heat pumps installation would require the VGHE extension and should be preceded by carrying out:

- the ground thermal response test (TRT) to precisely determine its thermal conductivity coefficient, i.e. the heat transfer capacity of the soil,
- the verification of the existing VGHE tightness by filling each collector loop separately and maintaining the set pressure for a specified time. The purpose of the tightness check would be to locate a possible leaking section.

To cover the building's heat demand at an external temperature of – 10°C, additional 34 boreholes with a depth of 100 m should be drilled, so that the total number of boreholes would be 45. The distances between individual boreholes would be a minimum of 7 m. The depth of horizontal pipes would be approx. 1.2 m. The design heat flow extracted from the ground would be 153 kW. It was assumed that the temperature difference of the heat carrier fluid in inlet and outlet would be 3K and the VGHE was dimensioned for such a value (and ultimately a volume flow of 48.6 m^3/h). The glycol manifold would also require to be adapted to the newly extended VGHE. Due to lack of space in the building three distribution wells would be designed outside. Each well would have supply and return distribution beams and fittings in the form of a rotameter, a control element and a shut-off valve. In the boiler room, only manifolds connected to the wells, equipped with rotameters and control valves to balance the flow, would be located. Fig. 8 shows a situational plan for the extension of the VGHE, while fig. 9 presents a scheme of the optimised ground source heat pumps installation supplied from the three distribution wells of the VGHE.

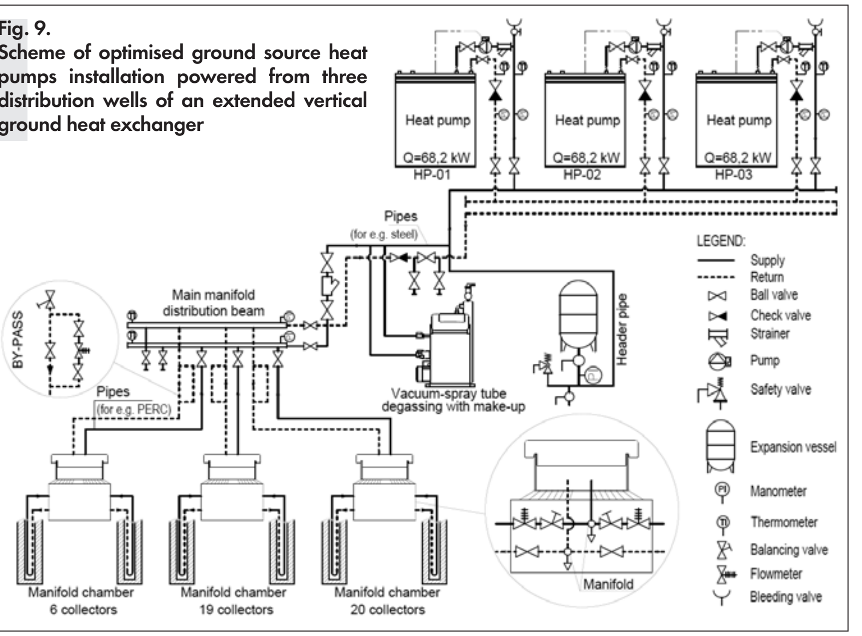

Fig. 9.
Scheme of optimised ground source heat pumps installation powered from three distribution wells of an extended vertical ground heat exchanger

The ventilation system would also require optimisation because of:

- low heat recovery efficiency in glycol heat exchangers of existing air handling units compared to the efficiency of counterflow heat exchangers currently available on the market,
- faulty devices included in the air handling units (damaged fan inverters, missing exhaust fan in the N4W4 unit),
- the desire to simplify the system by eliminating heat recovery from the exhaust air for the VGHE operation support.

Due to these reasons, it was decided to replace all existing air handling units with

Tab. 5. Parameters of newly designed air handling units

Air handling unit	Air volume flow rate [m^3/h]		Heat recovered from counterflow heat exchanger [kW], (heat recovery efficiency [%])		Designed water heating coils power [kW]
	Supply	Exhaust			
N1W1	4700	4900	57.03	(90.4)	15.3
N2W2	1900	1700	22.07	(86.6)	8.1
N3W3	2170	2480	24.02	(82.5)	9.8
N4W4	1400	1400	15.83	(73.4)	6
		Total =	118.95		39.2

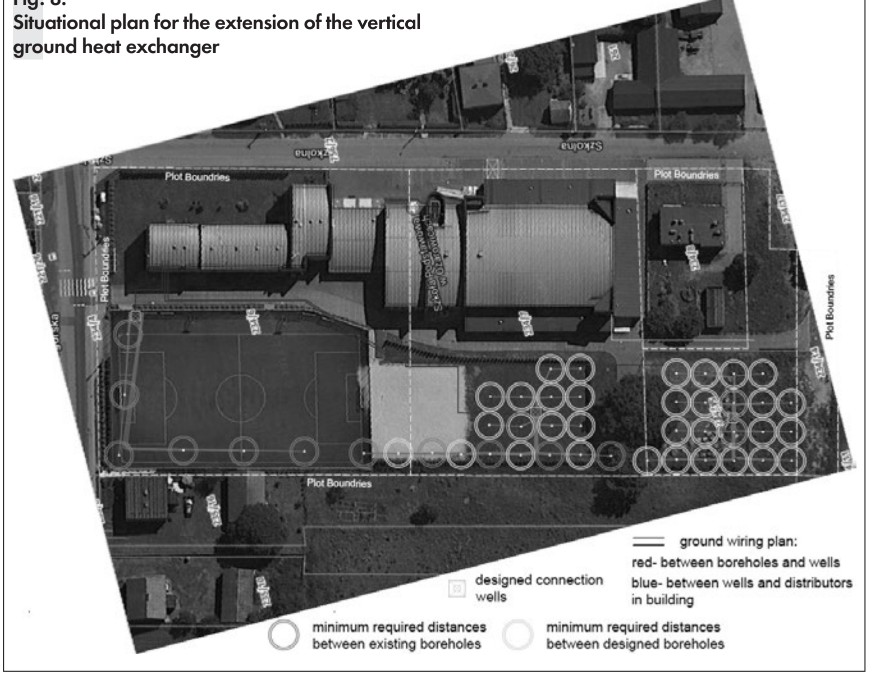

Fig. 8.
Situational plan for the extension of the vertical ground heat exchanger

Tab. 6. Comparison of the heat value required to be supplied to water heating coils in existing and newly designed air handling units

	Heat to be transferred for technological heat purposes [kW]	
Air handling unit	Existing units	Newly designed units
N1W1	21.98	15.3
N2W2	12.84	8.1
N3W3	13.78	9.8
N4W4	11.36	6
Total =	59.96	39.2

new ones. They would be located in the same place as the previous devices and would be connected to the existing ventilation ducts. The parameters of the new air handling units were determined and listed in tab. 5. A comparison of water heating coils power and the amount of heat to be transferred for purposes of ventilation technological heat of new and existing air handling units is listed in tab. 6.

Comparing the values of the design power of water heating coils of newly designed and existing air handling units a decrease in heat demand equals to 20.76 kW. This difference results from significantly higher efficiency of the counterflow heat exchangers of newly designed air handling units compared to glycol exchangers in existing devices. Fig. 10 shows a scheme of an optimised technical heat installation for water heaters of new air handling units.

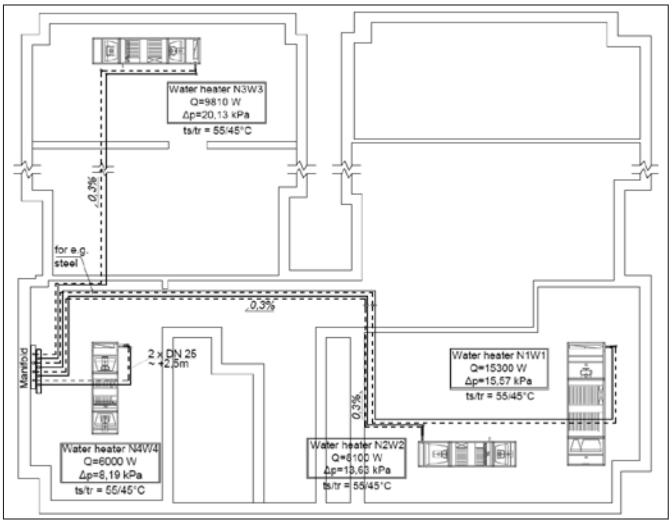

Fig. 10. Scheme of optimised technological heat installation for water heaters of air handling units

Conclusions

The proper execution of HVAC systems is crucial as potential errors in its design and assembly may lead to a diminished sense of thermal comfort for the occupants, elevated operational expenses, heightened adverse effects on the environment, decreased system efficiency, and a shortened lifespan of the equipment. The paper analysed the design and assembly mistakes related to the implementation of an HVAC system based on a ground source heat pump with a vertical ground heat exchanger in the actual school building in Poland. The sensitivity of such a system to low-quality workmanship was indicated.

Based on the stocktaking of the building and the analysis of the design and operation of the existing HVAC system, the following problems were identified:

- in the ground source heat pump installation:
  - non-functioning heat pumps resulting in the total heat demand of the building being covered by an additional source in the form of conventional gas boilers,
  - the VGHE installation not being hermetic,
  - improperly installed control fittings,
  - missing or malfunctioning control and measurement fittings,
  - no verification of the thermal conductivity of the soil at the VGHE design stage,
  - too small distance between horizontal sections of the VGHE,
  - oversizing of heat pump power in the existing system,
- in the ventilation system:
  - low heat recovery efficiency in heat exchangers of existing air handling units,
  - overcomplicated installation due to an additional heat exchanger intended for the support of the VGHE,
  - damaged fan inverters due to a short circuit,
  - missing exhaust fan in one of the air handling units,
  - lack of compliance with the technical documentation regarding the connection and location of air handling units.

After carrying out computational analyses regarding the possibility of improving the functioning of the HVAC system, the following optimisation possibilities were indicated:

- in the ground source heat pump installation:
  - replacement of existing heat pumps with units of higher power selected for lower bivalent temperature and installed in a cascade to reduce the wear of compressors,
  - installing a heat buffer with a capacity of 1,500l to increase the service life of heat pumps and the efficiency of the heating system,
  - replacement of the pipes and fittings connecting the heat pumps with the existing additional heat source because of the increase in heat carrier fluid flow in the installation,
  - carrying out an inspection of the technical condition of the extension vessels, hydraulic separator and domestic hot water tanks to ensure their highest possible efficiency,
  - carrying out the ground thermal response test (TRT),
  - increasing the number of boreholes of the VGHE to cover the building's heat demand and adapting the glycol manifold to the newly extended VGHE,
  - carrying out the verification of the tightness of the VGHE.
- in the ventilation system:
  - replacement of existing air handling units with the new ones equipped with modern counterflow heat exchangers with an average efficiency higher by 43.8% compared to the current ones and thus equipped with water heaters requiring 20.8 kW less technological heat,
  - simplifying the installation by eliminating the additional heat recovery from the exhaust air for the VGHE operation support.

To validate the optimisation solutions of the HVAC system in the analysed school building, it would be necessary to carry out numerical energy analyses using dedicated software to determine the impact of the indicated proposals on the improvement of building's energy efficiency and reduction of its operating costs.

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