ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 17, No. 11 2010

Tomasz CHOLEWA[1], Łukasz GUZ[1]
and Alicja SIUTA-OLCHA[1]

APPLICATION OF THE ALTERNATIVE ENERGY SOURCES IN HEATING AND AIR-CONDITIONING INSTALLATIONS

WYKORZYSTANIE ALTERNATYWNYCH ŹRÓDEŁ ENERGII W INSTALACJACH GRZEWCZO-KLIMATYZACYJNYCH

Abstract: One of the most important problems of last years is the development of society, which is not compatible with environment protection. Total consumption of energy does not reflect already the degree of economic development. The index of scientifical and technical progress is nowadays the minimization of the energy consumption and its ecological cleanness. Additionally growing prices of energy carriers, the environmental degradation and climate changes make alternative energy sources interesting. Alternative energy sources can be used not only for room heating but also for its cooling. The connection these both functions by means of 4 different ideas of the heating and air-conditioning installation for the existing auditorium is presented. In the first idea main devices are solar collectors, air-compressor heat pump, the underground heat magazine filled with stones and a water, and ground probes. The second solution introduces the connection into one system of solar collectors, the air-compressor heat pump, the triple hydraulical coupling and ground probes. Into the third solution entered ground probes, solar collectors, absorptive heat pump and the gas boiler. The main elements of the fourth solution are compact heating and cooling devices and solar collectors, which work with warm water tank. The technological schema with well-chosen devices are presented and the special attention on advantages and disadvantages of each solutions is paid. Besides for solution III and IV capital costs, the annual conventional fuel consumption on needs of the heatings, emissions of pollutions to the atmosphere and savings resulting from the use of alternative sources energy were calculated.

Keywords: alternative energy sources, solar collectors, absorptive heat pump, air-compressor heat pump, the ground probe

The renewable energy source are more frequently used in modern building, where the investor decides to join heating and air-conditioning installations into one single system, which may decrease the capital costs. The basic elements of such installations are the heat pumps which derive the energy from bottom source (usually air, ground, ground or surface water or even waste water) [1]. There are many solutions that enable heat derivation from above-mentioned bottom sources, however, it is necessary to take into consideration local conditions and temperature stability in annual and daily cycle. Many

[1] Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20–618 Lublin, Poland, phone: +48 81 538 44 24, email: T.Cholewa@wis.pol.lublin.pl; L.Guz@wis.pol.lublin.pl; A.Siuta-Olcha@wis.pol.lublin.pl

researches have been lead in the world [2–4], which purposes were to show the capability of alternative energy source used in HVAC installation.

Material and methods

The subject of the analysis are the four ideas of HVAC installations in the auditorium of the Faculty of Environment Engineering, which derive the energy from renewable sources. Heat demand for central heating ($Q_{c.o.}$ = 54 kW), hot water ($Q_{c.w.u.}$ = 10 kW) and ventilation ($Q_{c.t.}$ = 84 kW) for auditorium amounts 148 kW, however cold requirement is up to the level 62 kW. For the above-mentioned parameters with the consideration of a local conditions, series of analysis have been made, which were the basis for the elaboration of HVAC installation projects.
Details of individual solutions and their description are presented below.

I Conception

The installation (Fig. 1) consists of a heat pump with rated output 148 kW of heating power and 62 kW of cooling power and solar collectors with 102.5 m^2 of absorber area. Most of the energy acquired from the solar collectors in summer period is directed to underground heat magazine with dimensions 10 × 10 × 4 m filled with stones and water. This underground reservoir serves as a bottom energy source for heat pump in winter period, and after its depletion the bottom source becomes a ground probe. The chill in summer period is acquired from the ground probes [5] and is stored in a chilled water accumulator with capacity of 4 m^3, where from is derived by a chillers of handling units.

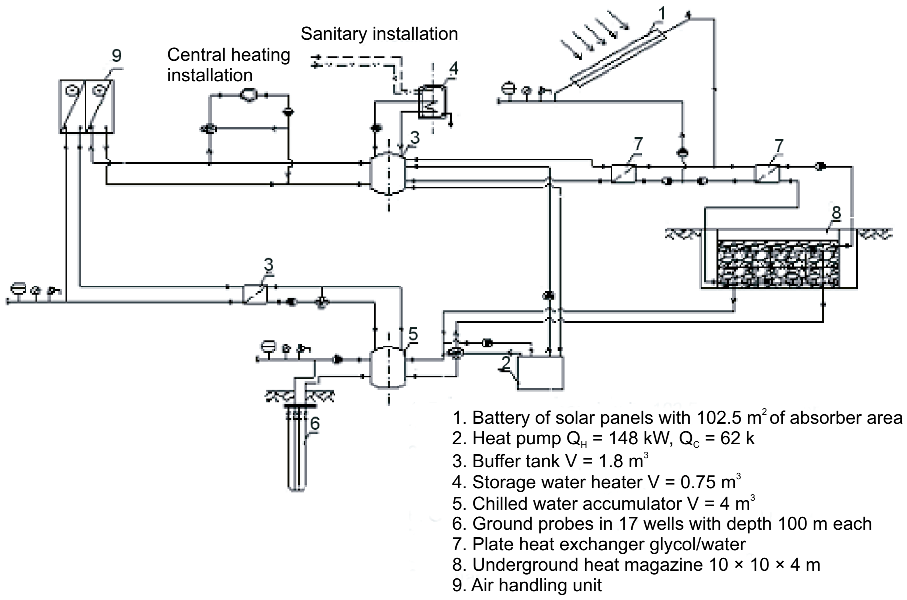

Fig. 1. The flow sheet of the I concept for heating and air-conditioning installation in auditorium of FEE

During chill acquisition from the ground probe, the heat simultaneously accumulates in ground. The advantage of this solution is a high temperature of the bottom heat source, which automatically increases COP (coefficient of performance) of heat pump and decreases the energy consumption in winter. Besides, there are high capabilities to store of solar energy surpluses in the underground heat magazine of 400 m^3 capacity. Disadvantages of this solution are a high costs of underground heat magazine structures and extensive area of solar panels which is the effect of forced finance conditions. Additionally in summer period heat regeneration of the ground takes place, which causes the increase of chill temperature from 7 to 14 ^{o}C at the end of the summer period [6].

II Conception

The basic elements of this solution are: heat pump Hibernatus type W29G3x2 with total heating power of 156 kW and chilling power 116 kW [7] and solar panels Viessmann Vitosol 200 with 10 m^2 of absorber area. In the installation a triple hydraulical coupling is employed, which serves as a tank for hot water with two perforated membranes [8]. These membranes together with two condensers implemented in the heat pump allow to maintain a 3 different temperature zones of upper heat source: $t > 55$ ^{o}C, 35 ^{o}C $< t < 55$ ^{o}C and $t < 35$ ^{o}C. In summer period there is a possibility to change the chill source from ground probes to chilled water accumulator and obtain a chilled water with 6 ^{o}C temperature. The redundant heat from the upper heat source through hydraulical coupling, heat exchanger and 3-way valve is directed to the ground probes. Then takes place the energy accumulation in the ground, which increases the COP coefficient of the heat pump [9]. In summer season the energy for heating purposes is derived by the heat pump, which discharges then ground heat accumulator, which consists of 26 ground probes with length about 90 m each.

This solution (Fig. 2) allows to accumulate waste heat from the air conditioning processes through ground probes and afterwards acquire this energy for heating

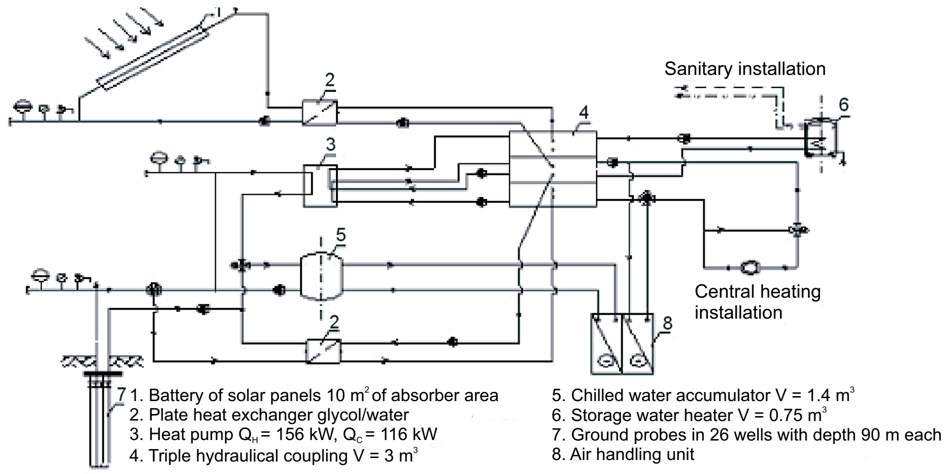

Fig. 2. The flow sheet othe the II concept for heating and air-conditioning installation in auditorium of FEE

purposes in winter season. The disadvantages of this conception are high costs of structures of ground probes and the consumption of useful area for buffer tank (hydraulical coupling) and chilled water accumulator.

III Conception

The installation described by Walaszek [10] consists of 4 absorptive heat pumps type GAHP-W Robur with heating power of 35.4 kW and cooling power 13.5 kW each. In the installation, there is also employed gas boiler Vitopend 200 with rated output 24 kW [11] as a conventional heat source. At the beginning of summer season the chilled water is derived directly from the ground probes until the preliminary charge of ground accumulator occurs which is revealed through the increasing temperature of chilled water. Subsequently the absorptive heat pumps are turned on and the heat source is shifted from ground probes to chilled water installation. Simultaneously the charging processes follow from the ground accumulator with a heat from generating process of chilled water in plate heater exchanger. The hot tap water is prepared in the solar panels with 6 m^2 of absorber area along with gas boiler. In winter season the energy for heating purposes is derived from 4 heat pomps and in case of higher heat requirement from gas boiler.

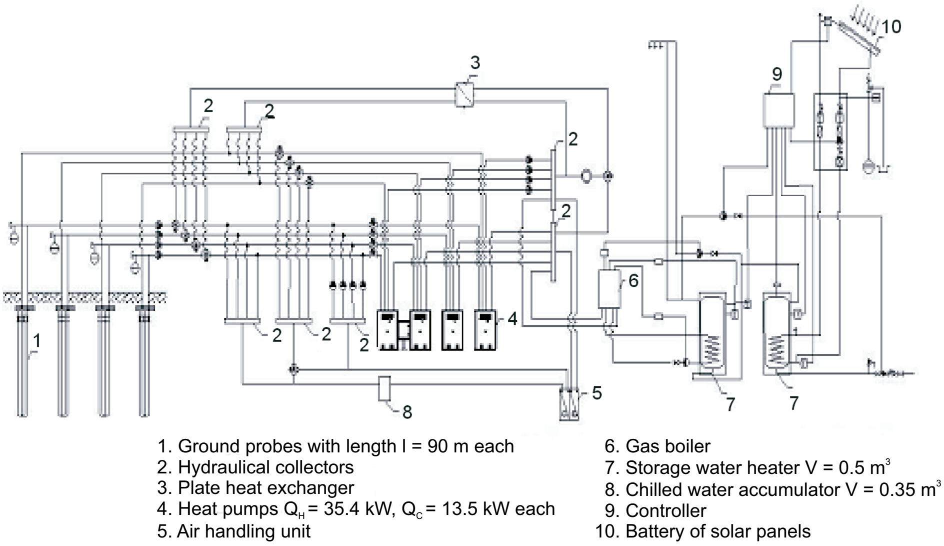

Fig. 3. The flow sheet of the III concept for heating and air-conditioning installation in auditorium of FEE

The main advantage of this solution is a fact, that energy carrier for heat pumps is a gas, which causes the decrease of exploitation costs in comparison with the unit with compressor and decreasing load of electrical energy network. In the installation are not employed buffer tanks and big chilled water containers. Due to lower chilling power in winter period, the amount of ground probes is smaller and this prolongs discharge of ground accumulator in winter. This installation is characterized by high cost of investment and lack of exploitation experience, because this is a rare and rater not typical.

IV Conception

Installation consists of 4 heating-cooling units Robur [12] type RTYF 240-476/2. Each of them consist of gas boiler rated output 32.5 kW of heating power and from chiller with 17.5 kW of cooling power. In summer period the hot tap water is prepared in solar panels with 6 m^2 of absorber area and in gas boilers.

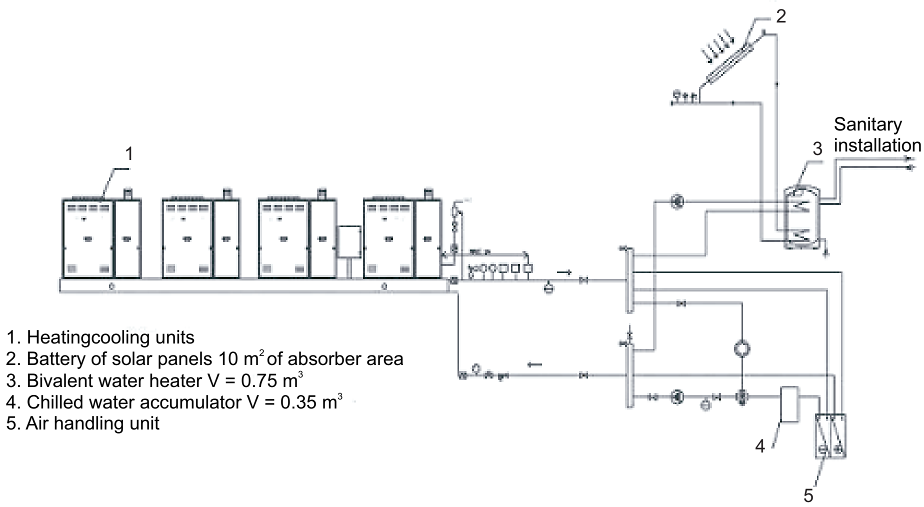

Fig. 4. The flow sheet of the IV concept for heating and air-conditioning installation in auditorium of FEE

The advantage of this solution is lack of necessity of expensive ground collectors and buffer tanks application. Besides, there is a possibility of placing the heat and chill source outside the building onto a common frame, which safes the room useful area. In case of outdoor air temperature decrease below – 20 ^{o}C, the problems with rooms heating may occur.

Results and discussion

In consideration of 4 specifications of heating-cooling system it can be noticed that technical possibilities of the application of renewable energy sources in heating and air-conditionig installations can exist. This contributes to the environment protection. However for the purpose of the detailed estimation its influence on the environment, solutions III and IV, were chosen. For this solutions capital costs were put together. The diminution of the unrenewable annual fuel consumption on each aim and the diminution of gaseous and dust emission, which are introduced to the atmosphere from the energy-combustion of fossil fuels, is defined. If depends on capital costs, in which one seized prices of basic devices, then they are put together it in Table 1 and Table 2.

Table 1

Capital costs of installation number III

Item	Type	Quantity	Price [PLN]
Absorptive heat pump	GAHP-W Robur	4	160000
Gas boiler	Viessmann Vitopend 200, Q = 24 kW	1	65000
Capacitive water heater	Viessmann Vitocell 300-B Vn = 500 m^3	2	27000
Solar Divicon set	Viessmann	1	2600
Pump of bottom source	WILO VeroLine-IP-E 80/140-4/2R1	4	11200
Pump of upper source	WILO VeroLine-IP-E 80/140-4/2R1	4	11200
Pump of iced water	WILO VeroLine-IP-E 80/140-4/2R1	4	11200
Solar collector	Viessmann Vitosol 200-T 6m^2	1	18000
Ground collector	U-pipe l = 90 m	16	100800
		Sum	348500

Table 2

Capital costs of installation number IV

Item	Type	Quantity	Price [PLN]
Heating-colling devices	RTYF-240-476/2	4	183920
Solar collector	Viessmann Vitosol 200-T 6 m^2	1	18000
Capacitive water heater	Viessmann Vitocell 360-M Vn = 750 m^3	1	15300
Solar Divicon set	Viessmann	1	2600
		Sum	219 820

Assuming that the energy source for this building is individual gas boiler, annual consumption of natural gas (GZ-50) for each purpose, can be calculate by means of formulas (1)–(3) [13, 14].

– annual consumption of fuel for central heating:

$$B_a^{c.o} = (24 \cdot 3600 \cdot Q_{c.o.} \cdot SD_{20}) \cdot (Q_i^r \cdot \eta_k \cdot \eta_{inst.c.o.} \cdot (t_i - t_e))^{-1},\ [m^3 \cdot a^{-1}] \quad (1)$$

– annual consumption of fuel for hot water preparation:

$$B_a^{c.w.u.} = (24 \cdot 3600 \cdot Q_{c.w.u.} \cdot 36) \cdot (Q_i^r \cdot \eta_k \cdot \eta_{inst.c.w.u.})^{-1},\ [m^3 \cdot a^{-1}] \quad (2)$$

– annual consumption of fuel for ventilation (technological heat):

$$B_a^{c.t.} = (24 \cdot 3600 \cdot Q_{c.t.} \cdot 180\ ) \cdot (Q_i^r \cdot \eta_k \cdot \eta_{inst.c.t.})^{-1},\ [m^3 \cdot a^{-1}] \quad (3)$$

where: $Q_{c.o.}$ is computational heat demand on central heating ($Q_{c.o.}$ = 54 kW); SD_{20} is numer of degree-day and for the city Lublin amounts SD_{20}= 3957.4 K · d · a^{-1}; Q_i^r is calorific value of natura gas GZ-50 and amounts Q_i^r = 36000 kJ · $(m^3)^{-1}$; η_k is the efficiency of gas boiler, assumed η_k = 0.9; $\eta_{inst.c.o.}$ is the efficiency of central heating installation running, assumed $\eta_{inst.c.o.}$ = 0.85; t_i is computational temperature of internal air, assumed t_i = 20 ^oC; t_e is computational temperature of external air, assumed for Lublin city t_e = –20 ^oC; $Q_{c.w.u.}$ is computational heat demand on hot water preparation ($Q_{c.w.u}$ = 10 kW); $\eta_{inst.c.w.u.}$ is the efficiency of hot water installation running, assumed $\eta_{inst.c.w.u.}$ = 0.7; $Q_{c.t.}$ is computational heat demand on ventilation ($Q_{c.t.}$ = 84 kW); $\eta_{inst.c.t.}$ is the efficiency of technological heat installation running, assumed $\eta_{inst.c.t.}$ = 0.7.

However the consumption of unrenewable fuels on each aims for the installation number III and number IV was calculated. These calculations were made on the basis of burners characteristics of components devices of investigated installations and also on the basis of the fuel consumptions for the gas boiler. The results of these calculations are presented in Table 3.

Table 3

Fuel consumptions on each aims

Heat source	$B_a^{c.o.}$	$B_a^{c.w.u.}$	$B_a^{c.t.}$	B_a
Gas boiler	16761	13905	57600	88266
Conception III	6185	5131	21254	32570
Conception IV	13325	11054	45792	70171

On the basis of Table 3 one can, ascertain that the installation number IV uses up about 20.5 % less fuels in comparison with the individual gas boiler, and the installation number III till 63.1 % less. By use of the formula No. 4 [15] average yearly emissions of individual pollutions from individual gas boiler, installation No. III and No. IV, were evaluated. Results of these investigations are placed in Table 4.

$$E_{zan} = B_a \cdot u_{zan}^j \text{ [kg/a]} \tag{4}$$

where: B_a is yearly consumption of natural gas GZ-50, $m^3 \cdot a^{-1}$; u_{zan}^j is index of unit sling of polluting substances from the emission source, for NO_2: $u_{NO_2}^j$ = 1280 · 10^{-6} kg · $(m^3)^{-1}$, for CO: u_{CO}^j = 360 · 10^{-6} kg · $(m^3)^{-1}$, for CO_2: $u_{CO_2}^j$ = 1964000 · 10^{-6} kg · $(m^3)^{-1}$, for dust: u_D^j = 15 · 10^{-6} kg · $(m^3)^{-1}$.

Table 4

Average yearly emissions

Heat source	E_{NO_2}	E_{CO}	E_{CO_2}	E_D
Gas boiler	113.0	31.8	173354.4	1.32
Conception III	41.7	11.7	63967.8	0.49
Conception IV	89.8	25.3	137815.8	1.05

Then by utilization of the formula No. 5, yearly savings [in PLN], received thanks use of alternative energy sources in installations No. III and IV in comparison with the individual gas boiler, were calculeted.

$$\Delta O = \Delta B \cdot K^j \ [PLN \cdot a^{-1}] \tag{5}$$

where: ΔB are yearly savings of the fuel consumption in comparison with the individual gas boiler [kg/a]; K^j is unit cost of fuel, for natural gas GZ-50 assumed $K^j = 1.31$ PLN × × $(m^3)^{-1}$.

One received yearly savings thank utilization of the installation No. III on the level 72962 PLN · a^{-1}, and through the utilization of the installation No. IV up to the level of 23704 PLN · a^{-1}. Besides one should remember that the additional savings are geting out of the diminutions of charges for the use of environment and costs on forests revitalisations or on the purchase of medicines for allergy.

Conclusions

1. The utilization of renewable energy sources in heating and air-conditioning installations, in the form of gas absorptive heat pumps, allows the diminution of the unrenewable fuels consumption even about 63 % in comparison with conventional parley.

2. Use of heating devices using alternative sources of energy allows CO_2 emission reduction to the atmosphere, minimally about 20 % in the scale of the year.

3. In consideration of the existing possibilities to use renewable energy sources in heating and air-conditioning installations which contribute to the environment protection across the diminution of loads of pollutions emitted to the atmosphere. Every one should promote their utilization in new, as and modernized objects especially in the face of obligatory for Europe regulations "3×20".

References

[1] Rubik M., Nowicki J., Chmielowski A., Pykacz S. and Furtak L.: Centralne ogrzewanie, wentylacja, ciepła i zimna woda oraz instalacje gazowe w budynkach jednorodzinnych. Poradnik. Ośrodek Informacji „Technika instalacyjna w budownictwie", Warszawa 2000.

[2] Omer A.M.: *Ground-source heat pumps systems and applications*. Renew. Sustain. Ener. Rev. 2008, **12**, 344–371.

[3] Sanner B., Karytsas C., Mendrinos D. and Rybach L.: *Current status of ground source heat pumps and underground thermal energy storage in Europe*. Geothermics 2003, **32**, 579–588.

[4] Yiping W., Yong C., Li Z. and Lijun H.: *Experiments on novel solar heating and cooling system*. Ener. Convers. Manage. 2008, **49**, 2083–2089.

[5] Wytyczne projektowe firmy Viessmann: Vitocal 300/350 Systemy pomp ciepła, kwiecień 2007.

[6] Wita A., Balcerzak A. and Świątek D.: Określenie efektywności ekologicznej systemu ogrzewania wykorzystującego magazynowanie energii cieplnej w gruncie. Materiały badawcze IMGW, Ser. Inżynieria Wodna, 2000.

[7] www.hibernatus.com (06.05.2008).

[8] Mirowski A., Lange G. and Jeleń J.: Materiały do projektowania kotłowni i nowoczesnych systemów grzewczych, wyd. 1, Dział Wsparcia Technicznego Viessmann, Viessmann, kwiecień 2004.

[9] Hiroshi O.: *Energy performance of borehole thermal energy storage systems*, J. Architect. Plann. Environ. Eng. 2002, **555**, 77–84.
[10] Walaszek S.: Systemy grzewczo-klimatyzacyjne oparte na odnawialnych źródłach energii. Praca dyplomowa magisterska. Wydział Inżynierii Środowiska Politechnika Lubelska, Lublin 2006.
[11] www.viessmann.pl (10.05.2008).
[12] www.robur-polska.pl (07.05.2008).
[13] Recknagel-Sprenger: Ogrzewanie i klimatyzacja. Wyd. Arkady, Warszawa 1976.
[14] Kwiatkowski J. and Cholewa L.: Centralne ogrzewanie – pomoce projektanta. Wyd. Arkady, Warszawa 1980.
[15] Cholewa L.: *Zanieczyszczenie powietrza atmosferycznego przez kotłownie opalane paliwem płynnym*, X Int. Conf. "Air Conditioning and District Heating", Wrocław-Szklarska Poręba 2002, 687–695.
[16] Danielewicz J. and Gołecki K.: Projektowanie kotłowni wodnych, niskotemperaturowych. Materiały pomocnicze firmy DeDietrich. Ofic. Wyd. Polit. Wrocław., Wrocław 2002.

WYKORZYSTANIE ALTERNATYWNYCH ŹRÓDEŁ ENERGII W INSTALACJACH GRZEWCZO-KLIMATYZACYJNYCH

Instytut Inżynierii Ochrony Środowiska, Wydział Inżynierii Środowiska
Politechnika Lubelska

Abstrakt: Jednym z ważniejszych problemów ostatnich lat jest pogodzenie rozwoju cywilizacyjnego społeczeństwa ze środowiskiem naturalnym. Globalne zużycie energii nie odzwierciedla już dziś stopnia rozwoju gospodarczego, a wręcz odwrotnie. Wyznacznikiem postępu naukowo-technicznego danego kraju jest obecnie minimalizacja zużycia energii i jej ekologiczna czystość. Dodatkowo ciągle rosnące ceny nośników energii, degradacja środowiska naturalnego oraz zmiany globalne klimatu doprowadziły do wzrostu zainteresowania alternatywnymi źródłami energii. Alternatywne źródła energii można wykorzystywać zarówno do ogrzewania, jak i chłodzenia pomieszczeń. Połączenie tych obu funkcji zaprezentowano za pomocą 4 różnych koncepcji instalacji grzewczo-klimatyzacyjnych dla sali wykładowej. W pierwszej koncepcji głównymi urządzeniami są kolektory słoneczne, sprężarkowa pompa ciepła, podziemny magazyn ciepła wypełniony kamieniami i wodą oraz sondy gruntowe. Drugie rozwiązanie przedstawia połączenie w jeden układ kolektorów słonecznych, sprężarkowej pompy ciepła, trójdzielnego sprzęgła hydraulicznego oraz sond gruntowych. W skład trzeciego rozwiązania weszły sondy gruntowe, kolektory słoneczne, absorpcyjna pompa ciepła oraz kocioł gazowy. Natomiast głównymi elementami czwartego rozwiązania są kompaktowe urządzenia grzewczo-chłodzące, kolektory słoneczne współpracujące z biwalentnym podgrzewaczem wody. Zaprezentowano schematy technologiczne z dobranymi urządzeniami oraz zwrócono uwagę na wady i zalety poszczególnych rozwiązań. Ponadto dla rozwiązania III oraz IV obliczono koszty inwestycyjne, roczne zużycie paliwa konwencjonalnego, emisje zanieczyszczeń do atmosfery oraz oszczędności, które wynikają z wykorzystania odnawialnych źródeł energii.

Słowa kluczowe: alternatywne źródła energii, kolektory słoneczne, absorpcyjna pompa ciepła, sprężarkowa pompa ciepła, sonda gruntowa