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HEAT PUMP INSTALLATION (JOHN PAUL II CENTRE, KRAKOW)

INSTALACJA POMP CIEPŁA (BUDYNEK CENTRUM JANA PAWŁA II W KRAKOWIE)

Abstract

In the paper energy balances for heating and cooling of buildings are presented. Heat pump diagrams are discussed and original solutions are presented. There are related drawings, tables and photographs in the paper.

Keywords: heat pump, heating system

Streszczenie

W artykule przedstawiono krótką charakterystykę obiektu, w tym bilanse energii do celów ogrzewania i chłodzenia. Omówiono zastosowane schematy instalacji pompy ciepła, instalacji grzewczych oraz chłodniczych. Szczególną uwagę zwrócono na zastosowane oryginalne rozwiązania. Artykuł uzupełniono rysunkami, tabelami oraz zdjęciami.

Słowa kluczowe: pompa ciepła, instalacja ogrzewania

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1. Introduction

Heat pumps are part of the environmentally friendly technologies using renewable energy. They are quoted in the European Directives on the use of Renewable Energy (RES), on the Energy Performance of Buildings (EPBD) and on Energy related products (ErP). In addition, heat pumps are also referenced in the Directive on the promotion of the use of energy from renewable sources (2009/28/EC, RES Directive, §2). The Directive recognizes the technology as using renewable energy sources from air, water and ground. Heat pumps are seen as a great opportunity to reach the EU target for a reliable, affordable and sustainable energy supply.

2. Heat pump system description

The heat pump installation system consists of heat pump units and lower and upper heat sources. Heat pump installation is constructed with three circuits: lower and upper heat source and heat pump. Operation of heat pump begins with the acquisition of heat from heat source (land) by glycol solution. A simplified diagram of the heat pump system is presented in Fig. 1. In reality, four heat pump units of type Vatra GIGA 160B are installed; each is connected to the lower heat source independently. Node points numbered. Nos. 1–5 are related to the lower heat source, 7–13 to the heating system and 14–17 to the hot water system. Vertical ground heat exchangers are designed as the lower heat source for each of the four heat pumps. Each vertical ground heat exchanger has 14 holes with a depth of up to 170 m.

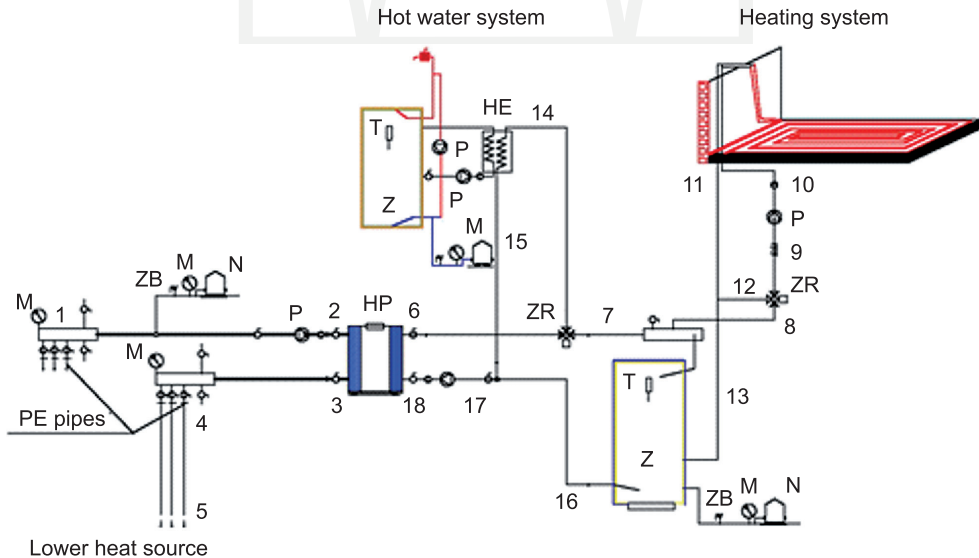


Fig. 1. Simplified diagram of the heat pump system: HP – heat pump, HE – heat exchanger, M – manometer, T – thermometer, N – expansion tank, ZR – regulating valve, ZB – security valve

The distance between the wells ranges from 12 m to 15 m. The wells are connected in series in the loop. Vertical ground collectors are made of polyethylene pipes placed in boreholes connected at the bottom with an u-shaped moulder.

A 33% aqueous solution of propylene glycol is provided as the heat transfer medium. In the wells two pipes with a diameter of 40 mm are used. Heat pumps work with heat buffers, consolidating additional heat source and heat consumers. It is expected that excess heat will be discharged into the ground heat exchanger and atmosphere.

The installation enables production of cold chill, which is accumulated in the ground after the heating season. This is called passive cooling. After the initial regeneration of the lower source, a cold solution of propylene glycol will be produced using the heat pumps. This is so called active cooling. Further regeneration of the lower source is exploited by the refrigerant condensation heat. This heat pump system provides heat in the heating period and cooling during the summer. The designed and installed system allows for the simultaneous generation of heat and cold. A combustion engine OTTO – the CHP system produces electricity to drive heat pumps and heat to power the heating system. CHP is powered by a fuel gas GZ50.

3. Heat pump specifications

Technical details of the used heat pumps type Vatra GIGA 160B are presented in Table 1.

Table 1

Technical details of the heat pump type Vatra GIGA 160B [5]

Dimensions <i>W./H./D.</i> :	880/1310/1850 [mm]
Net weight:	965 [kg]
Lower heat source temperature:	-5 to +25 [°C]
Central heating maximum temperature:	55 [°C]
Preparation of hot water:	through an external water tank
Medium:	R 407c
Application:	for central heating for installation of hot water
Nominal output:	158.3 [kW]
Cooling power:	122.4 [kW]
Input power:	38.65 [kW]
COP:	4.15 assuming at 0/35 [°C]
Noise level:	66 [dB]
Country of production	Poland

4. Heat pump circuit

Thermodynamic cycle is carried out using R407C refrigerant. The evaporator and condenser are constructed of plate heat exchangers, brazed copper plates of stainless steel AISI 316. The parameters given in the characteristics (Fig. 2) are in accordance with the following data [5]:

– cooling side – medium: 33% aqueous solution of propylene glycol and:

$$\Delta T_E = t_2 - t_3 = 4K \quad (1)$$

– heating side – medium: water, and:

$$\Delta T_C = t_6 - t_{18} = 8K. \quad (2)$$

The thermal power P_c of the evaporator in steady state conditions is described by the following equation:

$$P_C = c_{pg} m_{lhs} (t_2 - t_3) = m_R \Delta i_E \quad (3)$$

where:

- c_{pg} – specific heat of the 33% solution of propylene glycol,
- m_{lhs}, m_R – mass flow rates, in lower heat source and refrigerant respectively,
- Δi_E – refrigerant enthalpy increase in the evaporator.

The electric power P_e of the compressor is described by the following equation:

$$P_e = m_R \Delta i_C \quad (4)$$

- Δi_C – refrigerant enthalpy increase in the compressor.

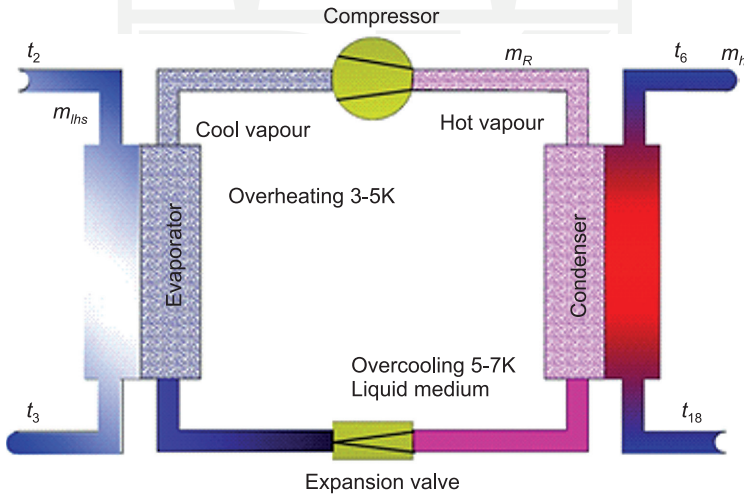


Fig. 2. Diagram of the heat pump with marked symbols

The thermal power P_h of the condenser in steady state conditions is described by the following equation:

$$P_h = c_w m_h (t_6 - t_{18}) = m_R \Delta i_h \quad (5)$$

where:

- c_w – specific heat of the water in heating system,
- m_h, m_R – mass flow rates, for operating medium in the upper heat source and refrigerant mass flow rate respectively,
- Δi_h – refrigerant enthalpy decrease in the condenser.

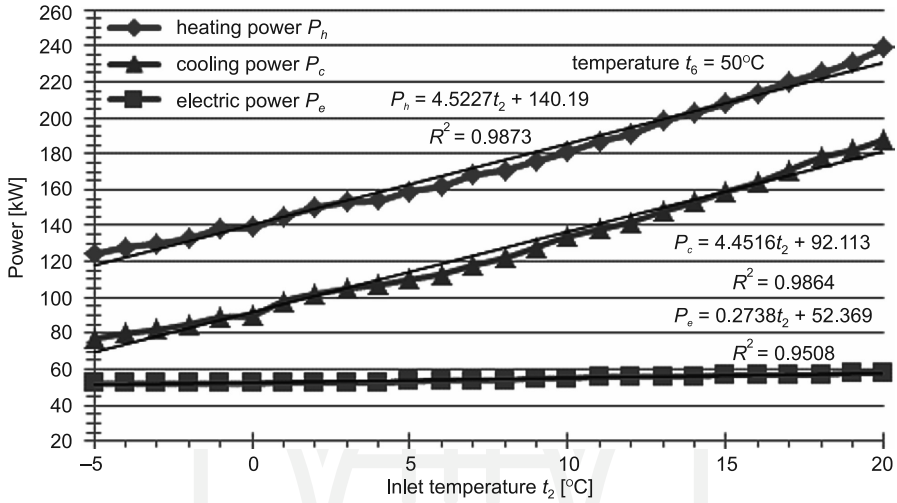


Fig. 3. Heating power P_h , cooling power P_c and electric power P_e versus inlet temperature t_2 to the evaporator, $t_6 = 50^\circ\text{C}$

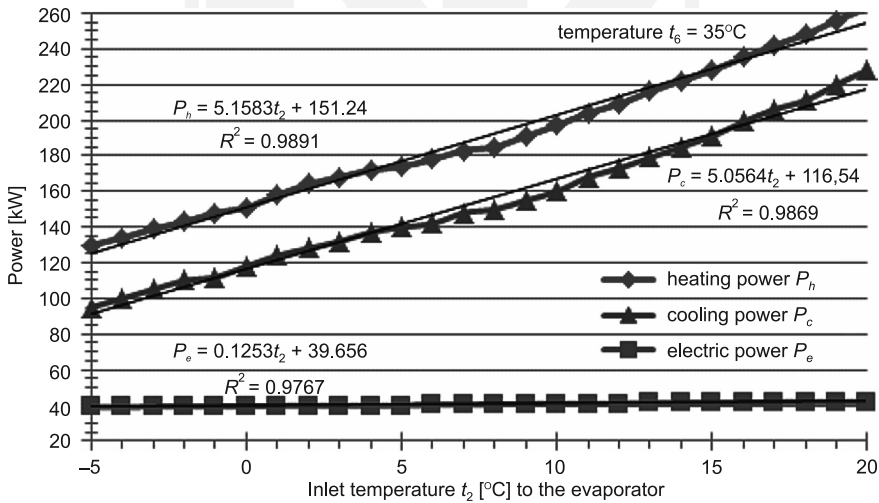


Fig. 4. Heating power P_h , cooling power P_c and electric power P_e versus inlet temperature t_2 to the evaporator, $t_6 = 35^\circ\text{C}$

In theoretical considerations, neglecting energy losses to the environment and assuming isentropic expansion process in valve, it is assumed that:

$$P_h = P_c + P_e, \quad (6)$$

This is equivalent to that:

$$\Delta i_h = \Delta i_c + \Delta i_e. \quad (7)$$

Approximations P_h , P_c and P_e versus inlet temperature t_2 to the evaporator are presented in Fig. 3, t_6 is assumed 50°C. Hence the COP installed heat pumps for heating could be calculated from formula:

$$\text{COP}_{\text{heating}} = \frac{P_h}{P_e} = \frac{4.5227t_2 + 140.19}{0.2738t_2 + 52.369}. \quad (8)$$

Approximations for $t_6 = 35^\circ\text{C}$ are given in Fig. 4. In this case, for temperature $t_6 = 35^\circ\text{C}$, COP for heating is represented by the equation:

$$\text{COP}_{\text{heating}} = \frac{P_h}{P_e} = \frac{5.1583t_2 + 151.24}{0.1253t_2 + 39.656}. \quad (9)$$

Obtained functions can be used to assessment of economic and energy efficiency heat pump installations in varying outside temperatures.

5. Economical considerations

Price c_h per unit of heat energy gained from the heat pump is calculated from equation:

$$c_h = \frac{1 + \psi}{\text{COP}_{\text{heating}}} c_e. \quad (10)$$

where:

- c_h – electrical energy price,
- ψ – factor related to the energy dissipation.

Table 2

The prices of energy carriers

Energy carriers	Cost of energy (in Poland, May 2014) [€/kWh]*
Electrical energy, rate I	0.133
Propane	0.111
Fuel oil	0.089
Electrical energy, rate II	0.081
Natural gas	0.074
Thermal network	0.051
Hard coal mill	0.033
Wood, biomass (pellets)	0.019

* It was taken 1€ = 4,2 zł

The prices of energy carriers are shown in Table 2. The value of the parameter ψ is assumed 0.1. Calculated values of the heat energy prices are presented in Figs 5 and 6.

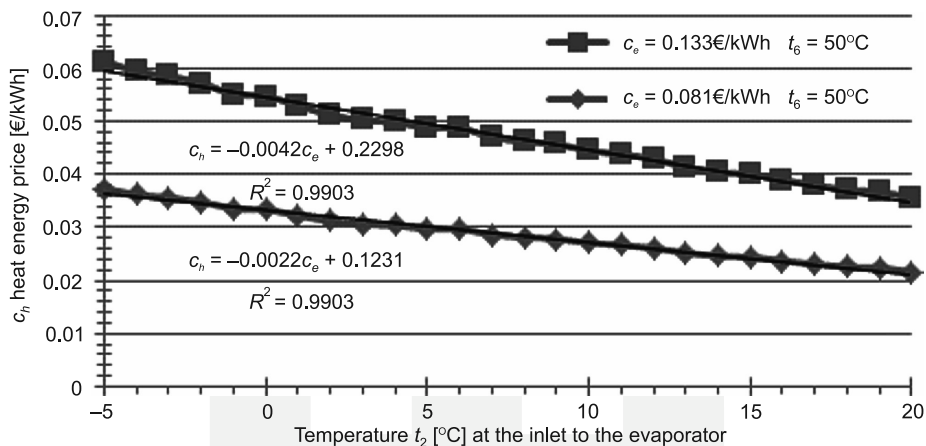


Fig. 5. Heat energy price c_h for heating ($t_6 = 50^\circ\text{C}$) versus inlet temperature t_2 to the evaporator

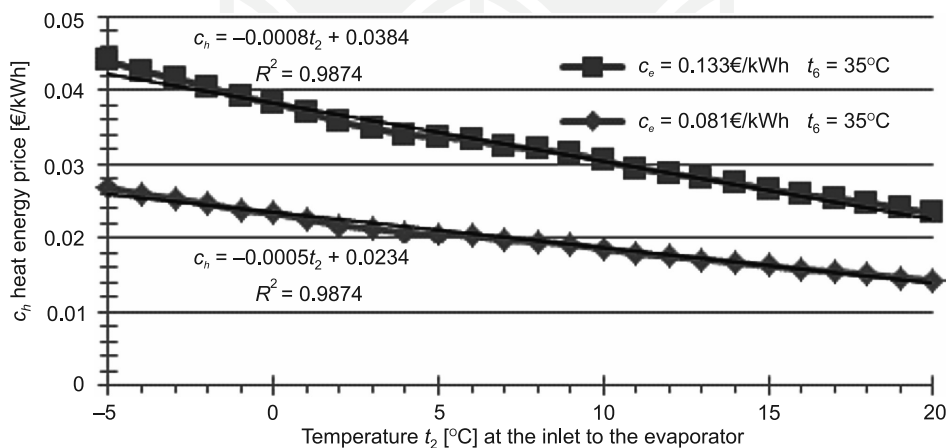


Fig. 6. Heat energy price c_h for heating ($t_6 = 35^\circ\text{C}$) versus inlet temperature t_2 to the evaporator

6. Conclusions

This paper presents heat pumps installation in John Paul II Centre in Krakow. The new installation presented here is an important element in the development of heat pump installations. Start-up phase was successful and the installation is working properly.

If the second electricity tariff is used properly then the operating costs of heating are less than the heat from the thermal network.

The experience in the installation and startup of the heat pumps are important in the subsequent heat pump systems with significant capacities.

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