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ENERGETIC AND ECOLOGICAL BALANCING HYBRID HEATING SYSTEM WITH RENEWABLE ENERGY SOURCES

BILANSOWANIE ENERGETYCZNE I EKOLOGICZNE HYBRYDOWEGO SYSTEMU GRZEWCZEGO Z ODNAWIALNYMI ŹRÓDŁAMI ENERGII

A b s t r a c t

This paper deals with hybrid heating installation for house heating and domestic warm water production used in private house in Batowice (near Kraków). The system consist of four heat sources, including three renewable energy sources: brine-water heat pump with three vertical boreholes, a fireplace with a water jacket and heat exchanger, heat pipe vacuum-tube solar collectors and gas condensing boiler. The integration of all heat sources takes place through a novel, advanced cascade combination of two DigiENERGY control systems, which by registration large number of system parameters and compilation of statistics plays important role in energetic and ecological installation balancing. The operational installation results from September 2011 were presented and analyzed.

Keywords: heat pump, tube solar collectors, fireplace, control system, RES, condensing boiler

S t r e s z c z e n i e

Artykuł niniejszy dotyczy hybrydowej instalacji służącej do ogrzewania pomieszczeń oraz wytwarzania ciepłej wody użytkowej zastosowanej w prywatnym domu w Batowicach (Kraków). System ten składa się z czterech źródeł ciepła, w tym trzech odnawialnych źródeł energii: solankowej pompy ciepła z trzema odwiertami pionowymi, kominka z płaszczem wodnym i wymiennikiem ciepła, próżniowych kolektorów słonecznych oraz kotła kondensującego gaz. Integracja wszystkich źródeł ciepła odbywa się poprzez nowatorską, zaawansowaną kaskadową kombinację dwóch systemów kontroli DigiENERGY, co odgrywa istotną rolę w energetycznym i ekologicznym bilansowaniu instalacji poprzez zapis dużej liczby parametrów systemowych oraz zestawienie danych statystycznych. Zaprezentowano i zanalizowano wyniki działania instalacji z września 2011 roku.

Słowa kluczowe: pompa ciepła, rurowe kolektory słoneczne, kominek, system kontroli, RES, kocioł kondensujący

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1. Introduction

A systematic price increases of traditional energy sources causes the development of technologies aimed toward the largest energy self-sufficiency and smallest energy consumption in residential buildings. A number of negative effects associated with the conventional sources exploitation, such as ozone depletion, soil and air pollution or greenhouse effect intensifies searching solutions which will increase the share of renewable energy sources (RES) in the total balance of energy consumption [1]. Implementation of modern technical solutions based on RES may improve energy security and also positively impact on the country diversity of energy supply. The technological race in the area of renewable energy sources has become a development priority in many countries of the world causing a wider availability of these technologies to the average energy buyer [2].

Particularly in the newly constructed households with a higher standard and low energy intensity are used cooperating thermal energy sources including renewable sources [1]. Solar collectors biomass boilers, gas condensing boilers or heat pumps are usually used as a heating devices in hybrid systems. Different configurations of hybrid systems were subject of many projects since 1970 [3].

The study results showed that heating energy needs of the considered building was satisfactorily fulfilled by heat pump supported by solar collectors [3]. In another installation, during summer solar collectors obtained thermal energy were charging the bottom heat

Fig. 1. Photo of the part presented hybrid installation

Rys. 1. Zdjęcie przedstawiające fragment omawianej instalacji hybrydowej source of heat pump in the form of vertical ground borehole [4]. Such solution helped to achieve at the beginning of the next heating season heat pump coefficient of performance (COP) at a level corresponding to the value reached during the first start of the system [4]. Hybrid installation consisting of a biomass boiler and solar collectors located in Pikermi, in central Greece, allowed to get 100% energy from RES for coverage heat demand for heating an office building [5].

This paper focuses on hybrid heating system (Fig. 1) for heating and domestic hot water (DHW) preparation residential and service building of 460 m^2 usable floor area in Batowice (near Cracow). The system operating from September 2011 consists of four heat sources, including three renewable:

– brine-water heat pump, with bottom heat source in the form of three vertical ground boreholes, each with a depth of 70 m,
– biomass boiler as a fireplace with a water jacket and heat exchanger,
– vacuum-tube solar collectors, type Heat-Pipe,
– gas condensing boiler.

The presence in the installation of several energy sources requires a sophisticated control system, because most drivers offered on the market only works efficiency with a single heat source [6]. In the concerned installation optimal integration of all heat sources takes place through an innovative combination of cascade connection of two advanced DigiENERGY control systems. Intelligent controlling of hybrid installation enables the production of thermal energy primarily from renewable energy sources. Conventional energy source which is in this case condensing boiler is launching only in necessary situations.

2. The hybrid heating system

Figure 2 shows the schematic diagram of the concerned hybrid installation. A single function, wall mounted condensing boiler in the system is only one conventional source of thermal energy with adjustable heat output of 7–18 kW. Generated heat is transmitted directly to the buffer tank or by top coil to the internal tank of combined tank. Such solution was achieved by mounting regulated by DigiENERGY three-way valve. Because of the difficulties with controlling inside boiler build-in three-way valve this fitting haven't been used.

In the installation bottom heat source for heat pump type brine-water and heat output 10.4 kW is vertical ground collector in the form of three boreholes, which each has a depth of 70 m. Boreholes was performed at a distance of about 6 meters from the northern wall of the building in one line and a seven-meter intervals. The main heat pump function in the installation is production thermal energy for heating the building.

The appropriate combination of settings two three-way valves mounted in the flow of heat pump heating circuit allows to:

– storage generated thermal energy in the buffer tank,
– pass thermal energy in the air handling unit to the air supplying building rooms (HC 7 in Fig. 2),
– storage generated thermal energy in the buffer tank and then passing heat energy to the air heater by heat pump heating circuit back flow in the air handling unit.

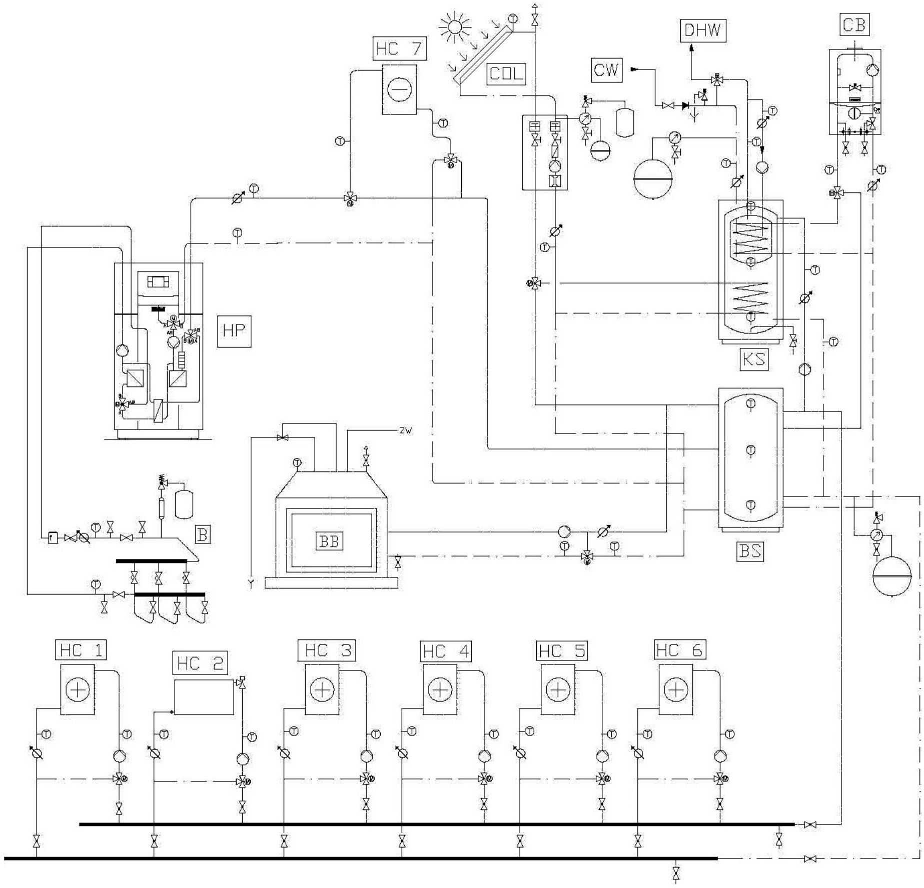

Fig. 2. Schematic diagram of the installation: B – ground boreholes, BB – biomass boiler, BT – buffer tank, CB – condensing boiler, COL – solar collectors, CS – combination-tank, CW – cold water, DHW – domestic hot water, HC – heating circuit, HP – heat pump (Source: AMT-Project)

Rys. 2. Schemat ideowy instalacji: B – odwierty gruntowe, BB – kocioł na biomasę, BT – zbiornik buforowy, CB – kocioł kondensacyjny, COL – kolektory słoneczne, CS – zasobnik kombinowany, CW – zimna woda, DHW – ciepła woda użytkowa, HC – obieg grzewczy, HP – pompa ciepła (Źródło: AMT-Project)

The heat pump is also equipped with an electric heater with a power of 6 kW and has an integrated passive cooling function which in summer time can be used for cooling the building.

Vacuum-tube solar collectors type heat-pipe are another renewable energy source in the installation. Five collectors, each composed of 20 solar tubes and one collector composed of 12 solar tubes are part of two parallel connected groups of collectors (3 collectors in each group). The heat generated in the first instance is passed through the lower coil to combined tank. If the tank adjusted temperature is reached control system by three-way valve directs energy to the buffer tank.

The intermediate fluid which passes energy from the collectors to tanks is demineralized water. Using of such fluid allows charging the buffer tank with solar energy, without need of heat exchanger. Also solar collectors achieve better working performance. For outdoor temperatures below 0°C the risk of water freezing in the collectors is avoiding by proper adjusting switching on/off circulating pump.

Biomass boiler is in the form of a fireplace with a water jacket and heat exchanger with thermal power of water circuit equal to 21 kW and the total heating power of 24 kW. Thermal energy produced from combustion wood logs is transported to the buffer storage. By controlling the operation of three-way mixing valve mounted in the return flow circuit and using a variable pump flow DigiENERGY keeps the temperature of water supplying fireplace above 50°C. This approach reduces the risk of condensation of water vapor on the walls of the fireplace thereby prolonging its life.

Thermal energy produced by heating devices is stored by:
- storage tank with a capacity of 1500 l without coils loaded directly,
- combined tank with a total capacity of 800 liters, of which 200 l attributable to inner tank for domestic hot water preparation; combined tank can be loaded directly and also by two coils integrated in it.

Through a large number of stub connection various streams of energy produced by heat sources in efficiency way are charging the buffer tank. In addition, excess heat from buffer tank may be discharged to the combined tank through the additionally installed circulating pump.

The energy from the system is received by six heating circuits (see Fig. 2):
- HC 1 is the heating circuit of industrial air heater installed in the garage of the building, not cooperating with the air handling unit,
- HC 2 is a radiator heating circuit, convection heaters are installed in a basement rooms, two bathrooms and two other rooms of the building,
- HC 3-6 are 4 heating circuits of water heaters cooperating with the air handling unit and providing warm air into four separate heating zones of the building.

3. Control system

Because concerned installation consists of several heat sources and seven heating circuits it were necessary to connect in a cascade two advanced DigiENERGY control systems. Master DigiENERGY, which the main window is presented in Fig. 3 shows a schematic diagram of the controlled system, regulates the work of condensing boiler, solar collectors, two heating circuits and system of DHW preparation. Heat pump operation are being controlled by an internal driver, DigiEnergy serves only as a measurement device. Secondary-slave DigiENERGY is responsible for the operation of the biomass boiler and 4 heating circuits.

Intelligent control system maximizes energy yields from the system. The number of system parameters are recorded and then presented in real time by built-in internet module as a daily or yearly charts of temperature courses and energy consumption. For each circuit and heating device can be presented graph of the daily course of temperature which are saved to 16 months [6].

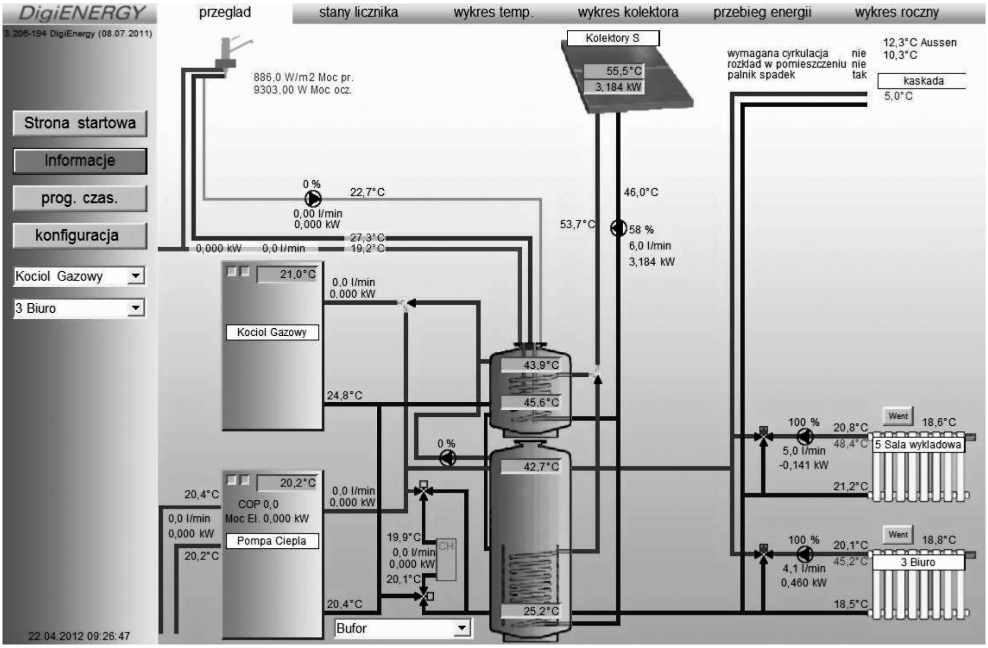

Fig. 3. Main window of master DigiENERGY

Rys. 3. Główne okno nadrzędnego DigiENERGY

By large amount of data independent optimization of each installation device is possible for the user. Prepared energy and cost balances for any selected time period are particularly useful in determining the actual costs of operating the given heat source. Modern control system additionally allows in a considered installation set of daily time intervals in which the hot water in the first place will be prepared from renewable sources, cooperation with the air handling unit, controlling rotation of the circulation pumps by PWM (Pulse Width Modulation) and determine the amount of them switching [1], alerting the emergency situations in the system [6].

More details about DigiENERGY can be found in [1] and [6].

4. Results

Figure 4 shows the graph changes in the amount of heat produced by the various heat sources from September 2011 to April 2012. The greatest amount of heat energy in the system was prepared by condensing boiler operating from the beginning of October 2011. From 15 February, when average daily outdoor temperature began to persist in the vicinity of 0°C most of the produced thermal energy in the system was obtained from working since mid-January 2012, the heat pump and fireplace. In the considered time period biggest daily yields of energy from the solar collectors was recorded in September 2011 and also March and April 2012.

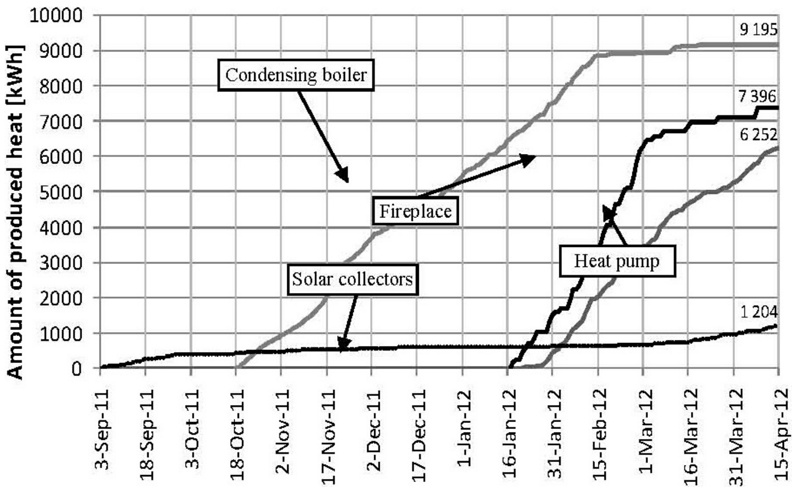

Fig. 4. Produced heat changes in the installation

Rys. 4. Zmiany wytwarzanej w instalacji energii cieplnej

Daily consumption of electricity and the amount of heat generated by the heat pump in 2012 are presented in Fig. 5. Measured electricity consumption includes a summary daily amount of energy required to control system of the heat pump, working the compressor and pumps of bottom and upper heat source of heat pump. In February, the amount of heat produced for most days was maintained between 60-230 kWh, and in March 25-150 kWh. Such distribution results from the increase in March the average daily outdoor temperature in comparison to February and thus lower energy demand for building heating.

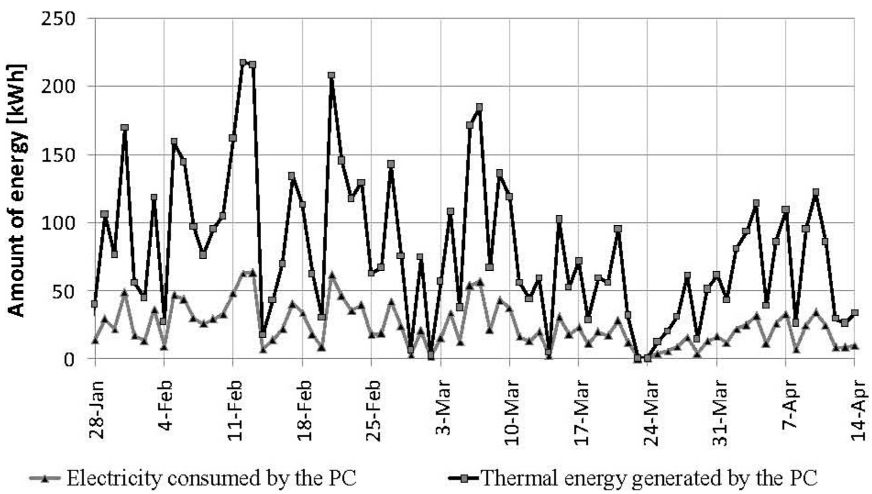

Fig. 5. Chart of daily electricity consumption and heating energy generated by the heat pump

Rys. 5. Dobowe zużycie energii elektrycznej oraz produkcja energii cieplnej przez pompę ciepła

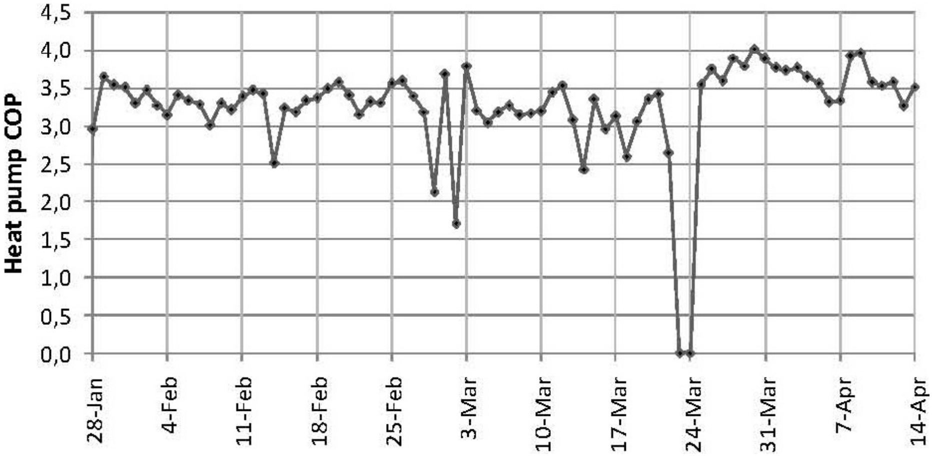

Fig. 6. Daily changes of heat pump COP in 2012

Rys. 6. Dobowe zmiany współczynnika COP pompy ciepła w 2012 roku

In this paper factor COP means the ratio of produced heat to electrical energy consumed for working the compressor, heat pump control system and circulation pumps of bottom and upper heat source of heat pump. In 2012 daily changing of the heat pump COP presented in the figure 6 for most days are in the range 3–4. The value of COP below 2.5 resulted from the absence of heat pump work or setting in which the circulation pump of upper heat source was tested to heat transport from the buffer tank to the air handling unit.

For the 3 months period of time the value of the seasonal heat pump performance factor SPF which is the ratio of the total amount of generated heat to electricity consumed by heat pump was 3.37. If the calculation of SPF would refer only to the electricity consumed by the heat pump compressor, the obtained result had been higher.

Table 1 presents data concerning a condensing boiler operation since December 2012. With the assumed calorific value of gas supplied to the boiler equal to 39,5 MJ/m^3 calculated average efficiency of condensing boiler was 89%. Low efficiency in March 2012 results from frequent and very short periods of work of the boiler.

Table 1

Data relating to condensing boiler

Year	2011	2012			Sum
Month	December	January	February	March	
Produced thermal energy [kWh]	2648.2	2168.0	1419.9	235.1	6471.2
Amount of gas consumed [m^3]	264.6	229.0	142.3	29.3	665.2
Boiler efficiency for the calorific value of gas equal 39.5 MJ/m^3	91%	86%	91%	73%	89%

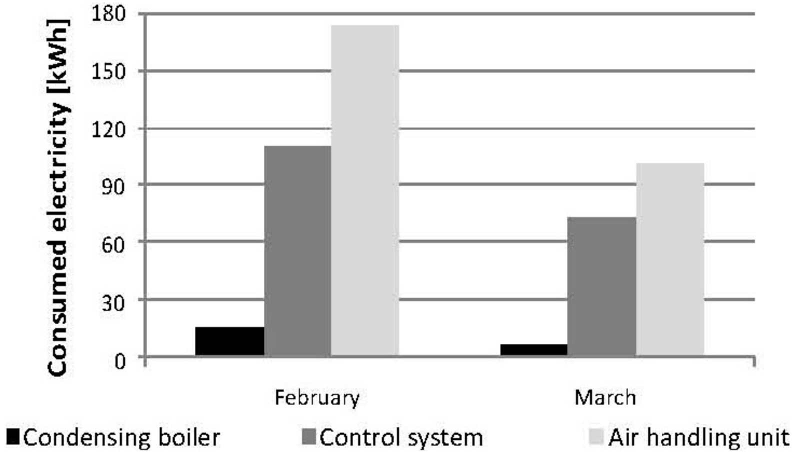

Fig. 7. The electricity consumption of particular installation devices

Rys. 7. Zużycie energii elektrycznej przez poszczególne urządzenia instalacji

The largest amount of electricity, in addition to the heat pump is consumed by the air handling unit (Fig. 7). DigiENERGY control system, along with circulation pumps and motors of heating circuits three-way valves, solar system and biomass boiler devices and all flowmeters absorbs monthly 60–120 kWh electricity. Working condensing boiler consumes monthly about 16 kWh electricity.

5. Conclusions

Combining several heating devices, including renewable energy sources in one hybrid installation offers greater opportunities for clean, affordable heat for heating a residential building. Important role in optimizing plant operation plays a steady operating DigiENERGY advanced control system.

Assuming that in the installation 100% of thermal energy generated from solar collectors and fireplace, and 70% from heat pump (with SPF = 3.37) is derived from RES during considered period of time were produced almost 13 000 kWh of clean energy. If in Polish conditions producing one kWh of energy consumed by the final consumer is associated with emissions 0.9 kg of CO_2 [7] was avoided emissions of around 11.7 tones of CO_2 to the atmosphere. Summary by the installation during considered period of time was produced 24 047 kWh of thermal energy, of which 9 195 kWh came from gas condensing boiler.

In the present building, it is difficult to relate the amount of energy needed for heating per m^2 floor area, because during heating season only a portion of the surface of the ground floor and first floor of the building was heated to a temperature of 21°C. In the rest part of building the temperature was remained around 14–16°C. Given the above was estimated that energy consumption per floor area heated to a temperature of 21°C was about 100 kWh/m^2. Representative data may be sought only after the whole heating season and for the uniform heating of the object.

Symbols

COP – coefficient of performance
DHW – domestic hot water
SPF – seasonal performance factor
RES – renewable energy sources

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