ANALYSIS OF THE POSSIBILITY OF GAS-FUELED MICRO-COGENERATION APPLICATION IN SINGLE-FAMILY DWELLING BUILDINGS IN POLAND

WAŁEK Tomasz

Silesian University of Technology, Institute of Production Engineering
26-28 Roosevelt St., 41-800 Zabrze, PL
E-mail: tomasz.walek@polsl.pl

Abstract: Conditionings related to application of high-efficiency gas micro-cogeneration in single-family dwelling buildings were presented in this paper. Analyses of power and heat demand profiles in this type of buildings were shown and a selection process of micro-cogeneration system was conducted in two variants – devices with a Stirling type engine (1 kW electric and 3-5,8 kW heating capacity) and a piston internal combustion type engine (2,5-6 kW electric and 8-13 kW heating capacity). For both the variants technical and economical analyses of optimal application of this technology were performed. Low values of base-load consumption of heat and power in this type of buildings in a scale of a year, and hence a possibility of application of the smallest micro-cogeneration units available on the market only, significantly negatively influence an amount of running-cost savings obtained. Key-importance conditionings which should be fulfilled in the aim to obtain acceptable running-cost savings and return on investment periods were pointed.

Keywords: Gas micro-cogeneration, dwelling buildings, technical conditions, running-cost savings, return on investment period, prosumer energy system.

1 Introduction

Gas-fueled micro-cogeneration is a highly efficient technology of simultaneous production of power and heat in a single process and single device. Gas fuel (natural gas or LPG) feeds an internal combustion engine, which directly transfers mechanical energy to a drive of electric power generator. Internal combustion engine and power generator are cooled during their operation and heat gained in this way is transported with use of a liquid medium (water or glycol solution) and in this way transferred for utilization. The power generator produces alternating current electricity in a single or three-phase system. Two streams of energy are obtained simultaneously in this way. Hence we can speak of a combined, highly efficient energy production (Fig. 1).

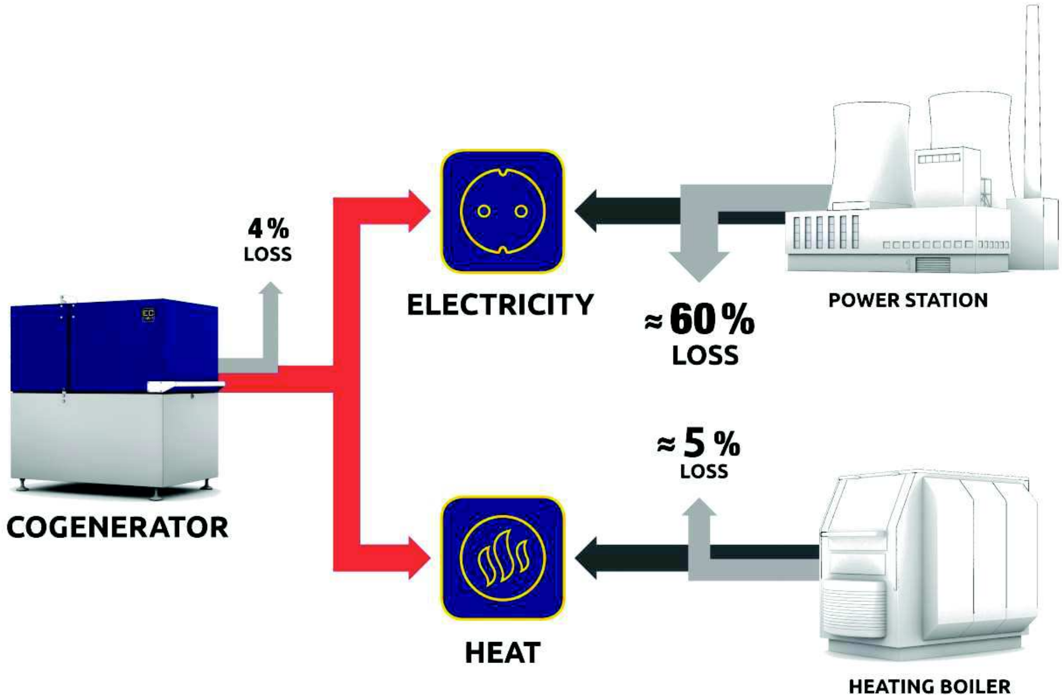

Fig. 1. Differences in loss occurrence in a separate and combined system of heat and power production

Description “micro” in the name of micro-cogeneration means that it is a cogenerating system in which up to 40 kW of electric power and up to 70 kW of heat is produced in a single device [1]. The devices are characterized by small dimensions, which allow for their installation in every boiler room or technical space of existing or newly-designed buildings. It means a possibility of power and heat production directly in a place of their utilization, with no transmission losses and hence with an additional increase of system efficiency and running-cost savings. Usage of gas fuels is an element which allows for reduction of disadvantageous environmental emissions, and the high efficiency of the process contributes to reduction of primary resources consumption in comparison to separate production in traditional technologies.

All these elements mean that application of highly-efficient gas micro-cogeneration is beneficial both from economical and environmental aspects, however in a large extent the final effect will depend on proper selection of a cogeneration system capacity in relation to energy demand in buildings with differentiated power and heat consumption profiles [2]. For a cogeneration system installed, to bring expected savings, in the first place it is necessary that both streams of energy produced are constantly consumed. Such a permanent and simultaneous consumption of heat and power is necessary for the device to undertake and maintain its work. Every object is characterized with different power and heat consumption, which additionally varies in the scale of natural day and summer/winter seasons. This ensues a necessity of conducting an energy demand analysis for a building in subject and proper selection of cogeneration unit(s) capacity. Because of that, not every object meets the condition of simultaneousness of heat and power demand on a certain level, proper for the cogeneration system.

2 Energy performance of a single-family dwelling

A typical single-family dwelling in Poland is an object of around 100 m^2 square footage [3]. Most frequently such buildings are supplied with electricity from the grid through a three-phase electric installation. Thermal energy for heating is usually assured by a building central heating system with a heating boiler fueled with natural gas or hard coal. Most frequently the central heating system is a two-function system and at the same time hot domestic water is produced in it.

2.1 Power demand

From the point of view of cogeneration system application in dwelling buildings, one of the elements which has to be thoroughly analyzed is the building profile of power consumption. Figure 2 shows an example of electric power consumption in a single-family dwelling, registered during winter period.

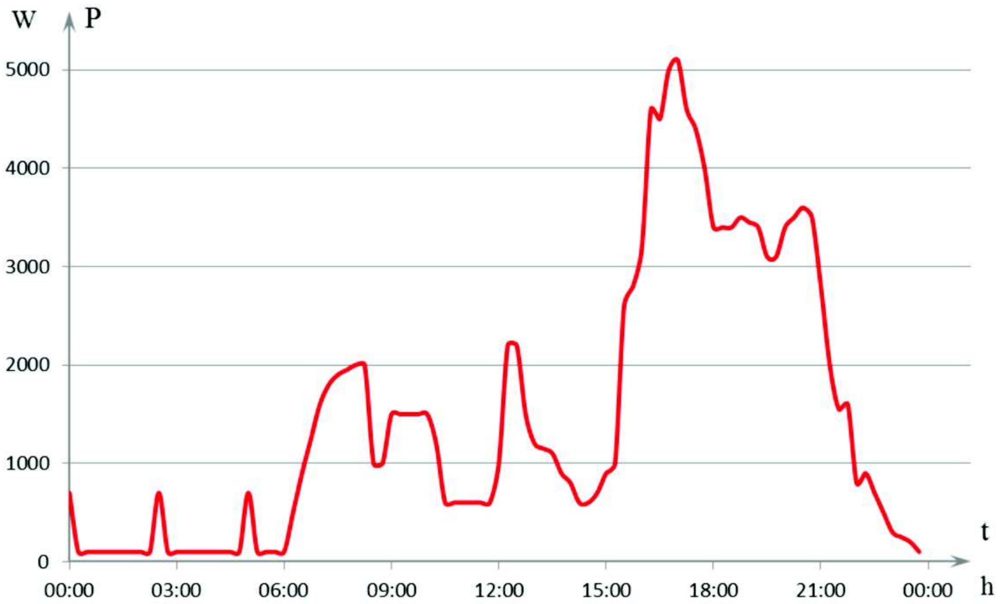

Fig. 2. Electric power consumption in a single-family dwelling
Source: [4]

The power consumption showed in Fig. 2 presents a summary consumption which occurs all-in on all three phases of electric installation of the building at a certain time. So it is possible that a situation occurs when phase load is non-evenly distributed – e.g. 5 kW on the first and 1 kW on the second and 1 kW on the third phase. Such the unevenness negatively influences the cogeneration system operation and one should aim to equal the load on phases at least by application of symmetrizing units [5]. In case when after application of a proper symmetrization device the phase load is equalized, only then we can start determining a base-load of power consumption, which means a value below which the power demand in building never decreases in the scale of a year through a certain time. The most optimal from the point of view of shortening the return on investment time is determining the base-load which occurs a whole year long, i.e. 8760 h, however not in every type of buildings it is possible – in great extent it depends on a type and number of electricity receivers operating in continuous mode.

2.2 Heat demand

Heat demand in single-family dwellings results from heat demands of buildings (during transition periods and during winter), and from the need of hot domestic water preparation (whole year long). Buildings of this type are mainly equipped with gravitational ventilation systems and no need of ventilating air heating occurs.

Depending on materials applied in the building construction and wall insulation, the heating demand will be located in the range of 10-20 kW. It is the heat source capacity which is supposed to assure heating for the building at computational temperatures used by designers, which in case of Poland mean -16 to -24 ºC, depending on geographical location. Hence it is a peak-demand estimated source capacity. Taking into consideration the thermal inertia of building, this capacity can be reduced in some degree while selecting a cogeneration system.

Demand for hot domestic water is determined on the basis of proper standards and regulations [6-8]. Heating for the need of hot domestic water production in winter period and partially during transition periods comes from building's central heating system which works in a two-function mode. So from the point of view of co-generation system, the heating capacity required for hot domestic water production in summer period will be crucial. The amount of hot domestic water used in dwelling does not depend on its cubic measure nor the way of construction – it depends on the number of dwellers only. Considering a 3-5 person family, the heating capacity of 1-2 kW will be sufficient when a proper volume hot domestic water tank is provided (200-500 dm^3).

3 Selection of the micro-cogeneration system

On the basis of analyses presented in Chap. 2, it is possible to estimate a capacity of micro-cogeneration system which could be possible to be applied in a single-family dwelling building. The base-load demand for electric power will reach 2 kW for ~5000 h in the scale of year, and herein 3.5 kW in the period of ~2000 h.

As for heat consumption in the building, the co-generation system should provide heating capacity around 10 kW and should be equipped with a heat storage tank(s) of 2-3 thous. dm^3 volume. Additionally, the heating installation should be completed with an independent system of electric heaters (as a backup and for the needs of antibacterial heating).

These values of heat and power consumption are low even when referred to micro-cogeneration unit series available on the market [9]. Because of this, for the need of further analyses, a micro-cogeneration unit based on Stirling engine with electric output of 1 kW (model Dachs Stirling) and a microcogeneration unit based on piston internal combustion engine with electric power modulated in the range of 2.5-6 kW (model EC Power XRGI 6). Because of the low values of base-load demands for heat and power, only single micro-cogeneration units can be considered for application in single-family dwellings, which though will not operate in a part of year or will work with modulation (reduction) of output capacity.

4 Analysis of running-cost savings and return on investment periods

When analyzing worthwhileness of cogeneration system application in dwelling buildings, including micro-cogeneration systems, there always appear a situation in which from one side cogeneration unit capacity must be reduced to conform to low values of base-load power consumption (whole year period) and heat consumption (in summer period), and from the other side reduction of the micro-cogeneration system capacity will result in lower running-cost savings and longer return on investment periods. Nevertheless, in this case adopting to the power and heat base-load consumption is overriding, because unduly oversizing of the micro-cogeneration unit capacity could lead to a situation in which power/heat consumed by the building is too low and the cogeneration unit does not start at all. Such the situation takes place in case when the heat/power output received from the co-generator is less than 50% of its nominal capacity. A control system stops the micro-cogenerator in this situation because its work with such low load on internal combustion engine would be economically unjustified and too much of fuel would be consumed for too small energy production.

A micro-cogeneration unit based on Stirling engine (with 1 kW no-modulation output of power and 3-5.8 kW modulated heat output) applied in a single-family dwelling could possibly work ~5000 h per year. It means that running-cost savings can be obtained on the basis of avoided costs of electricity purchased from the grid on the level of 5000 kWh, which at the price of 0.5 PLN/kWh gives savings of 2500 PLN/year. Additionally, an owner of the cogeneration system can obtain a subsidy related to power production in highly efficient cogeneration system (so called yellow certificates) on the level of ~0.1 PLN/kWh. It means additional savings in amount of 500 PLN/year. At a price of ~60 thous. PLN for the micro-cogeneration system it means the return on investment time on the level of 20 years.

A micro-cogeneration unit based on a piston internal combustion engine (with 2.5-6 kW modulated power output and 8-13 kW modulated heat output) applied in a single-family dwelling could possibly work with modulation (on the level of about 3.5 kW) for 2000 h only (this limitation comes from the power consumption profile). It means that running-cost savings can be obtained on the basis of avoided costs of electricity purchased from the grid on the level of 7000 kWh, which at the price of 0.5 PLN/kWh means savings of 3500 PLN/year. Additional savings resulting from yellow certificates will amount 700 PLN/year. At a price of ~120 thous. PLN of the micro-cogeneration system it means the return on investment time on the level of 28 years. [2]

It is necessary to consider also maintenance and service costs here, which will increase the return on investment periods by extra ~5%. So it can be seen that in case of Stirling engine (1 kW el.) the device is of too low output capacity to be able to provide significantly high savings, and in turn, in case of internal combustion engine (6 kW el.) the device works with a partial load in a part of year and hence is also not able to generate optimal savings and short return on investment time. Similar results were presented for micro-cogenerators of different ranges of power and heat output capacities [9]. It means that in case of micro-cogeneration system working for own needs of a single-family dwelling building, it is not an optimal solution because of limited and non-permanent consumption of heat and power.

5 Possibilities of system effectiveness improvement

To achieve optimal application of micro-cogeneration systems in single-family dwelling buildings, some activities aiming to elimination of barriers created by power and heat consumption profiles of this type buildings should be undertaken.

The barrier created by electricity demand can be eliminated by transferring the excess of electricity produced to the grid. It is a technically possible solution, however it is difficult to be executed from a formal point of view and does not bring such great savings as in case of avoiding cost of power purchase from the grid. The Energy Law [10] foresees some simplifications in connecting and operation so called micro-installations to the grid, however the term “micro-installation” is defined as a renewable energy source up to 40 kW electric power, and the gas micro-cogeneration, besides a proper range of output power, cannot be qualified so because natural gas or LPG are not treated as renewable fuels. The avoided costs of power purchase from the grid mean savings of ~0.5 PLN/kWh, and while selling electricity to the grid the building’s owner can obtain

~0.15 PLN/kWh only. Nonetheless this solution allows for significant increasing of cogeneration system operation time, and thereby increase of running-cost savings.

The fact of delivering electricity to the grid with no limitations will increase the operating time of the system with Stirling engine (1 kW el.) to 8760 h, so the system will operate 3760 h longer with selling during this time 3760 kWh of electricity to the grid at the price of ~0.15 PLN/kWh. Along with the basic time of 5000 h (when savings amount 0.5 PLN/kWh) and yellow certificates it gives total running-cost savings on a level of 3940 PLN/year. Return on investment time is reduced from 20 to 15 years.

In turn, in case of the co-generation system with piston internal combustion engine (2.5-6 kW el.) the operation time could also be increased to 8760 h in a year, but in this case the profile of building heat demand becomes a limitation. Even when the unit works with modulation on the lowest output level, the stream of heat is too big for a permanent receiving by the building. Heat storage tanks will be used, but the operating time of the system during a year will be reduced anyway. In this case it is possible to gain 2000 h of operating hours in year with full nominal output, and because of the heat demand profile in summer period and in parts of transitional periods the system can work next 3000 h with modulation. Along with yellow certificates, running-cost savings of total 9125 PLN/year will be gained and it means shortening of return on investment time from 28 to 13 years.

Only in case of complete elimination of barriers also on the side of heat receiving, which could be possible by connecting a greater number of dwelling buildings into a common, internal shared heating network, the micro-cogeneration system could work uninterruptedly whole year with full nominal output. This would mean savings on a level of 16.6 thous. PLN/year, which would result in return on investment time on the level of 7.2 years.

Conclusion

The conditionings presented in this paper, related to application of high-efficiency gas micro-cogeneration in single-family dwelling buildings, point to too large discrepancy between levels of electricity/power consumed in such buildings in the scale of a year and a required load of cogeneration system which may assure its optimal work in relation to running-cost savings and a short return on investment time. For the cogeneration system to be able to operate efficiently and bring benefits for the object it is necessary to have a full simultaneous reception of output energy produced, both heat and power. The base-load demand of heat and power in this type buildings is of such low level that eventual application of smallest micro-cogeneration units from series available on the market is the only possibility, and additionally, the units have to operate in modulation mode with reduction of output energy. This dependence has a negative influence on running-cost savings possible to obtain because the lower capacity of the co-generation system is, less power can be produced in it and hence a ratio between electricity purchased from the grid and produced in the building changes in an unfavorable way. The highest is the part produced by the building itself, the savings are more favorable.

Small capacities of micro-cogeneration units which are possible to be applied in this type of buildings, their operation in a modulated mode, periodical breaks in the scale of a year, all of it causes that return on investment time for such installations in single-family dwellings exceeds 20 years. Elimination of the barrier related to low electric power consumption in a way of transferring its exceed to the grid will result in shortening of the return on investment time to around 13 years and it is still a relatively long period. For a comparison, an analysis of return on investment time of micro-cogeneration in objects with higher and permanent power and heat demand can be quoted, as in case of sport and recreational objects, hospitals, swimming pools and hotels, where the return on investment time reaches 4-5 years [11].

Among all the improvement possibilities mentioned in Chap. 5, which could increase worthwhileness of micro-cogeneration system application in single-family dwellings, only the possibility of selling the power exceed to the grid is a solution which is practically achievable with no significant rebuilding of building installations needed. This solution, besides a standard declaration of connection of a generating unit to the grid, will require an agreement of energy selling and installation of a bi-directional energy meter with safety and telemetric hardware. More difficult in implementation is the increase of heat reception from the cogeneration unit by connecting of neighboring buildings in a common, shared heating network – both because of formal issues, investment cost division and in a later stage division of maintenance costs and running-cost savings. More simple from the point of view of formalities and clearances solution seems to be a construction of underground tanks for heat storage on the premises of a relevant dwelling building, but in situation when a co-generator while operating produces heat in amount of 8-13 kW all year long, storage of its exceeding part (the part which is not used by the building) makes no sense because when the cogenerator operates permanently, there would be no periods in a scale of a year in which the heat stored could be utilized.

A building micro-cogeneration as an element of a prosumer energy system, to be able to optimally function in a frame of dissipated prosumer energy system must be extended at least by the possibility of transferring the produced power surpluses to the grid. For such the system to be able to function more commonly, facilitations in law regulations should be introduced in relation to connecting of energy sources to the grid and power selling also for micro-installations (devices up to 40 kW of electric power) fueled with gas fuels like natural gas or LPG. Also increase of prices of selling electricity to the grid for private prosumers and upholding the system of yellow certificates for cogeneration together with increasing their price will be factors favoring development of this area of prosumer energy system in Poland.

CZ PL
PŘEKRAČUJEME HRANICE
PRZEKRACZAMY GRANICE
2014—2020

EVROPSKÁ UNIE / UNIA EUROPEJSKA
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

Projekt jest współfinansowany ze środków Europejskiego Funduszu Rozwoju Regionalnego
oraz z budżetu państwa RP „Przekraczamy Granice"

References

[1] Renewable energy sources, Bill of Feb. 20th, 2015, Journal of Laws of the Republic of Poland, 2015, item 478, and its subsequent amendments.

[2] Popczyk J., Wałek T., Kaleta P., Juszczyk J., Skrzypek A., Referential applications of MCHP XRGI gas micro-cogeneration in prosumer building energy systems [in Polish], The Source Library of Prosumer Energy Systems, 2014.

[3] Central Statistical Office of the Republic of Poland, Energy consumption in households in 2015, Warsaw, Poland, 2017.

[4] Fice M., EV as a storage tank for PE – costs of energy storage in real-life containers [in Polish], The Source Library of Prosumer Energy Systems, 2014.

[5] Wałek T., Combined generation of heat and power in multi-family buildings as an element of prosumer energy systems development [in Polish], Supporting Systems in Production Engineering, 7(6)2017, p. 267-276.

[6] Standard PN-92/B-01706, Water supply system installations. Requirements in designing.

[7] Standard PN-EN 15316-3, Heating installations in buildings. Calculation method of energy requirement of installations and installation efficiency.

[8] Regulation of the Minister of Infrastructure, Nov. 6th, 2008, in re of methodology of energy performance calculation for buildings, dwelling apartments and parts of buildings which account for stand-alone technical-utile entireties, and the way of preparation and specimens of their energy characteristics, Journal of Laws of the Republic of Poland, No. 201, item 1240, 2008.

[9] Iwan A., Paska J., Analysis of heat and power production in a micro-CHP system for the needs of households [in Polish], in: Electricity market – politics and economy, Lublin University of Technology, 2017, p. 123-138.

[10] Energy Law, Bill of Apr. 10th, 1997, Journal of Laws of the Republic of Poland, 1997, No. 54, item 348.

[11] P. Kaleta, T. Wałek, Comparison of effectiveness and return on investment periods of MCHP XRGI gas micro-cogeneration installation in buildings with differentiated heat and power demand. Part 2. [in Polish], Heating, Centralized Heating and Ventilation, No. 8, 2015, p. 300-306.

ANALIZA MOŻLIWOŚCI ZASTOSOWANIA MIKROKOGENERACJI GAZOWEJ W JEDNORODZINNYCH BUDYNKACH MIESZKALNYCH W POLSCE

Abstrakt (Streszczenie): W artykule przedstawiono uwarunkowania dotyczące aplikacji wysokosprawnej mikrokogeneracji gazowej w jednorodzinnych budynkach mieszkalnych. Przedstawiono analizę profili zapotrzebowania na ciepło i energię elektryczną w tego typu budynkach i przeprowadzono dobór układu mikrokogeneracji w dwóch wariantach – urządzeń z silnikiem Stirlinga (1 kW mocy elektrycznej i 3-5,8 mocy grzewczej) oraz z tłokowym silnikiem spalinowym (2,5-6 kW mocy elektrycznej i 8-13 kW mocy grzewczej). Dla obu wariantów przeprowadzono analizę techniczną i ekonomiczną optymalnego zastosowania tej technologii. Niskie wartości podstaw poboru energii elektrycznej i ciepła w tego typu budynkach w skali roku i co za tym idzie możliwość stosowania jedynie najmniejszych urządzeń mikrokogeneracyjnych spośród typoszeregu dostępnych na rynku jednostek znacznie negatywnie wpływają na wielkość uzyskiwanych oszczędności eksploatacyjnych. Wskazano na kluczowe uwarunkowania jakie powinny być spełnione w celu uzyskania akceptowalnych oszczędności eksploatacyjnych oraz okresów zwrotu nakładów inwestycyjnych.

Klíčová slova (Słowa kluczowe): Gazowa mikrokogeneracja, budynki mieszkalne, uwarunkowania techniczne, korzyści eksploatacyjne, czas zwrotu nakładów inwestycyjnych, energetyka prosumencka.