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COMPARATIVE ANALYSIS OF TWO TRIGENERATION SYSTEMS FOR A REZIDENTIAL BUILDING

BY

BOGDAN-ANDREI TOFAN*, ION ȘERBĂNOIU and ALIN-ENVER HOBLEA

"Gheorghe Asachi" Technical University of Iași
Faculty of Civil Engineering and Building Services

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Abstract. Biomass is a global resource that is still being used in traditional ways almost all around the globe, resulting in a waste of its great potential in the production of energy. Romania is a part of those countries that aren't improving the way some natural resources are used and this was one of the reasons for conducting the study. The study is proposing a comparative analysis of two trigeneration systems, one using biomass and internal combustion engine, and another system that uses micro-turbine fed with natural gas that are supplying a five floor residential building with power, heat and chilled water. The intent was to compare the two most spread types of fuel that are used in the heat and energy production. For the analysis, the study was conducted by using Retscreen software version 4. It was determined that biomass trigeneration installations are feasible having great payback periods and a good cost-benefit ratio without any need of incentives or grants, but in order to be implemented in Romania, the cost should be supported by the government, because the cost for every family is very high in the economical present.

Key words: natural gas; biomass; fossil fuel; absorption; power; CCHP; micro-turbine; engine.

*Corresponding author: *e-mail*: tba.tofanbogdanandrei@yahoo.com

1. Introduction

The continuous need of energy for all types of buildings and the alarmingly rise of fuel consumption with more than 100% from 1972 to 2012 (Internat. Energy Agency, 2014a) has outlined the need to find new ways to use the global energy resources. The better solution in doing so is to improve the energy efficiency of the existing systems that are producing heat and power along with reducing the emissions of carbon dioxide.

One of the most important sector that is widely spread across the globe, is the building sector, composed of residential and non-residential buildings. Considering the data previously expressed, it is safe to say that the building sector has a major impact in the world energy consumption reaching 23% of global final energy consumption only for residential sector, in 2011. The energy consumption varies among countries and region due to, mainly, the technological development, the number of population or the wealth of the inhabitants. Along with the increase of energy consumption, the emissions of carbon dioxide have increase with 27% from 1995 to 2011, reaching 5 $GtCO_2$. (Internat. Energy Agency, 2014b). A technology that has been available for decades but its potential has been forgotten or not sufficiently sustained with energy policies or with adequate funding is the cogeneration system and trigeneration system. The reduction of carbon dioxide emissions and the decrease of fuel consumption is obtained because of the higher conversion efficiency and through a greater optimization of the system. Trigeneration system are available for a large range of fuels, from fossil fuels, such as diesel, natural gas, coal, to renewable energy resources such as biomass, biofuel and others (Internat. Energy Agency, 2014c, 2014d).

2. Biomass and Natural Gas in CCHP Plants

2.1. Biomass in CCHP Plants

Biomass has the largest contribution in producing heat and power because of its spread all across the globe and the various forms that can be found, the most common being: pellets, briquettes, charcoal, chips, wood logs. The market for charcoal and briquettes have a very small share in the worldwide production of heat and power, but the pellets sector is in a continuous development, having a great demand on the market and being supported by large investments. The market of pellets has been estimated to grow to 4-5 million tons per year for the next 5 years (Bassam *et al.*, 2013).

The market for producing power using biomass is difficult to record, but it can be noticed that there is an increasing trend mostly in Europe, which experienced an increase of 19% in 2004, 23 percent in 2005 and it is estimated to grow with 5.2% until 2020, United States, Brazil, China, India and Japan. The power capacity reached, in 2011, 72 GW, most of this being generated with solid biomass in cogeneration plants (Bassam *et al.*, 2013; Vos & Sawin, 2013).

The heat production from modern biomass reached, in 2011, 290 GW_{th} worldwide, in all areas of use. Using biomass in CHP (combined heat and power) plants has been increasing, because of the lower cost of producing the two products at the expense of natural gas or other fuels (Bassam *et al.*, 2013; Vos & Sawin, 2013). A factor of the large scale use of biomass in CCHP (combined cooling, heating and power) are the large number of prime movers that can be associated with this fuel such as: Stirling engine, reciprocating engine, ORC systems (organic ranking cycle), steam turbines, fuel cells and gas turbines. The selection criteria of prime movers that can be used in CCHP plant is the technology used to convert biomass: combustion or gasification. Another factor for selecting biomass as a fuel to a CCHP plant is the range of the power produces, that is situated between 1 kW and up to 4 MW (Bassam *et al.*, 2013; Maraver *et al.*, 2013; Beith, 2011).

2.2. Natural Gas in CCHP Plants

Natural gas is a fossil fuel found in oil well or natural gas fields and is mainly composed of methane, but also other gases such as ethane, propane and others. Nowadays, natural gas is used on a large scale such as heating cooking and power generation, the global consumption increasing annually to a 1,400 Mtoe (megatons oil equivalent) in 2012 (Internat. Energy Agency, 2014a; Dincer & Zamfirescu, 2014).

In CHP, natural gas is mainly used to supply a gas turbine, which can be a part of, depending on the power produces, micro, small or large scale plants. They all consist of a compressor, combustion chamber, turbine and generator and can have a efficiency up to 80% depending on the application (Beith, 2011). The micro-turbines can be used to produce up to 300 kW (http://www.oocities.org/pemnq/microturbinescan.pdf).

3. Case Studies: Residential Building in Romania

3.1. Building and Systems Description

This study well concentrated on evaluating the economical and environmental aspects of two different trigeneration systems that can be used to produce heat, chilled water and power for a residential building with five floors located in Iaşi, Romania. The difference between the two systems are that they used different fuel, one with biomass and the other with natural gas, and different prime mover, the biomass systems uses internal combustion engine (Fig. 1), and the natural gas uses a micro-turbine (Fig. 2). The PHL, peak heat load, considered in Fig. 1 is a boiler which also uses biomass and in Fig. 2 the PHL is a gas fired boiler.

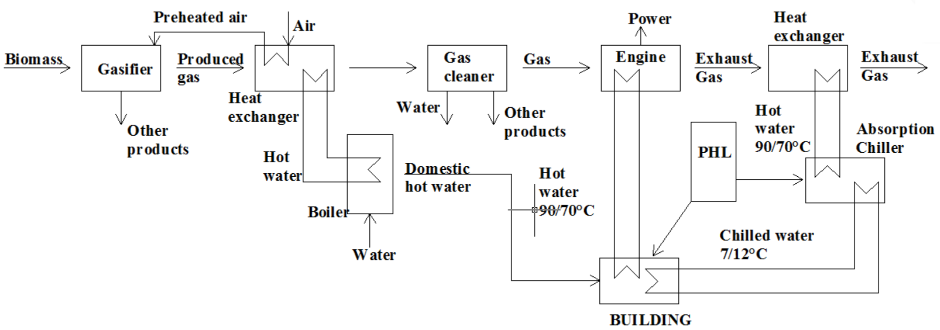

Fig. 1 – Biomass gasification trigeneration system.

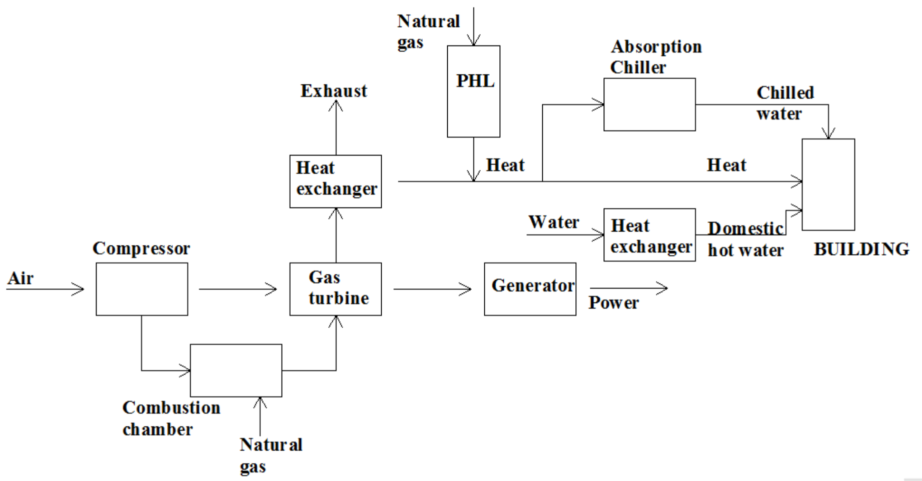

Fig. 2 – Micro-turbine trigeneration scheme using natural gas.

As it has been mentioned before, the residential building is situated in Iaşi, Romania, where the average winter temperature is –18°C and in the summer, it exceeds 32°C. It has been built in the middle of the 1980s, has a concrete frame structure, thermally insulated and with low U value windows. It has five floors, almost 1,100 m^2 area for apartments (4 apartments on every floor). It has been considered that every apartment is inhabited by 3 people. The average power consumption has been determined during a year, for every month. Every apartment is equipped with a TV set, a refrigerator, a washing machine, a PC, small household items, fluorescent lighting, a split unit for cooling and a gas fired boiler for heating and domestic hot water.

The biomass trigeneration system consists of an internal combustion engine that is fed with biomass producing 125 kW_e and for peak loads of power, the building will be also connected to the national power grid. The internal combustion engine also supplies 234 kW_{th}, but for peaks of heating load (PHL) it will be used a biomass boiler with a capacity of 250 kW and an efficiency of 80%. The chilled water will be produced by using an absorption chiller with 123 kW cooling capacity and a COP (coefficient of performance) of 0.7.

For the second system, fed with natural gas, the absorption chiller will remain the same but the engine and the boiler will be modified with a micro-turbine that produces 105 kW_e and 196 kW_{th} and a gas fired boiler with a capacity of 211 kW.

3.2. Retscreen Software

The analysis of the two cases proposed was done by using Retscreen software version 4, which can be found from the Retscreen International Empowering Cleaner Energy Decisions website. The software has climate data from all around the world and has the capability to analyze a large number of heating, cooling or power producing systems, using fossil fuels or renewable energy resources.

Retscreen allows us to evaluate correct costs of implementing a new technology taking into consideration the initial costs, costs for feasibility study and other engineering costs, maintenance and operating costs, costs for improving efficiency of the system, the costs of fuels and calculates the annual savings made and also, by taking into account different financial parameters, the financial viability.

3.3. Economic Parameters

For the analysis to be made there were a series of parameters that had to be introduced such as the cost for power, expressed in €/kWh, for natural gas, in €/m^3 and the cost for biomass, in €/t. Also the costs for the feasibility study, the development, the engineering work, spare parts and contingencies where expressed as percentage from the total cost of implementing the project. All the parameters expressed above where kept constant and there can be observed in Table 1.

Table 1
Economical Parameters

Parameter	Cost
Cost for power, [€/kWh]	0.101
Cost for natural gas, [€/m^3]	0.352
Cost for biomass, [€/t]	70
Cost for feasibility study	1.8% from the total initial cost
Cost for development	1.8% from the total initial cost
Cost for engineering	1.8% from the total initial cost
Cost for spare parts	10% from the cost of the equipment
Contingencies	10%
Fuel escalation rate	2.5%
Inflation rate	2.0%

The costs for the equipment, including here the cost for installation, were expressed per kW, depending on the type of fuel used. The values consider in the project can be observed in Table 2.

Table 2
Costs for Equipment

Equipment	Cost, [€/kW
Internal combustion engine	1,500
Other equipment for heating with biomass	400
Biomass boiler	400
Micro-turbine	1,700
Other equipment for heating with natural gas	200
Gas fired boiler	200
Absorption chiller	250

3.3. Results and Discussion

For the first system proposed, the total initial costs for implementing the project are around 540,000 €, with 64,000 € annual costs for operation and maintenance and 33,000 € annual savings. The internal rate of return (IRR), pretax and after tax, was determine to be 9.6%, with a simple payback period of 6.6 years, as it can be seen in Fig. 3, and a net present value of 332,000 € determining a ratio cost-benefit of 1.6. The costs for transporting the other products resulting from the operation of the system (tar, ash, particles) were not included in the analysis.

Using a micro-turbine fed with natural gas has lower initial costs, with almost 28% lower than the biomass engine, but has higher costs for maintenance and operation with over 80%. Although the annual income and savings are around the same value, the financial indicators are negative, the investment having a payback period over 20 years and with a cost-benefit ratio of only 0.22.

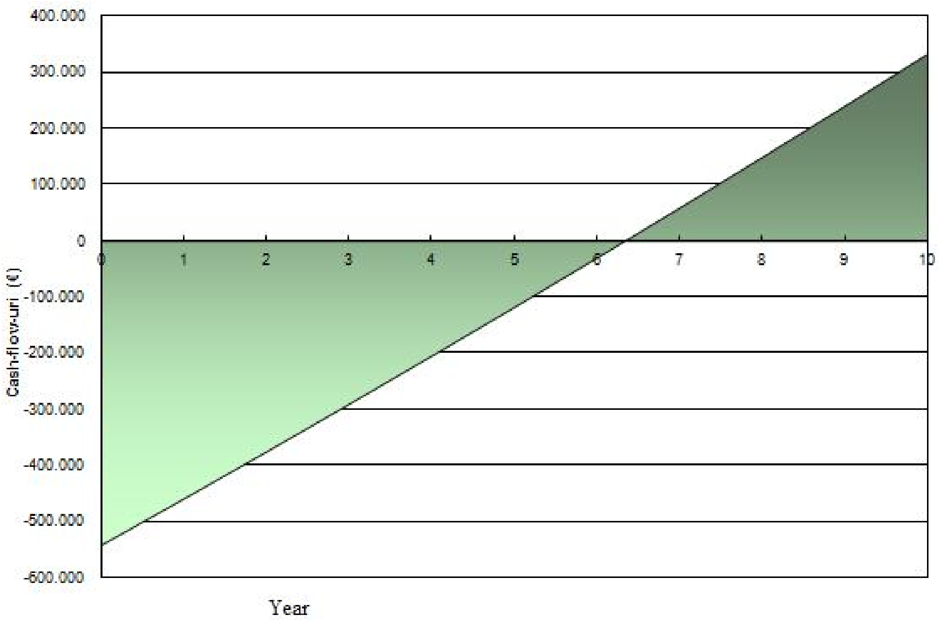

Fig. 3 – Payback period for a biomass trigeneration system with internal combustion engine.

Regarding the carbon dioxide emissions, the system that makes significant reductions in GHG emissions is the biomass solution with over 586.4 tCO_2 every year unlike the natural gas system which saves only 27.2 tCO_2.

4. Conclusions

Romania has large biomass potential, but these resources are still used in traditional ways, for cooking or for heating, using local systems, such as stoves or boilers, with low energy efficiency and wasting them, although the technology for using them in CHP or CCHP plants are present and are feasible. Regarding the study conducted in this paper, for a residential building with five floors, it can be seen that trigeneration systems using internal combustion engine fed with biomass have a greater payback period that the systems using natural gas micro-turbine systems and makes it feasible to implement or, at least, to be studied more.

A conclusion that can be easily be drawn is the fact that although the cost of implementing the biomass system is more expensive than the natural gas one, the payback period and the cost-benefit ratio for the biomass system are more positive than the second system proposed. The explanation for this fact are many, one of them is that the annual cost of operating and maintenance for the biomass system is much lower than the cost for the natural gas one. Another fact that sustains the biomass system is that the annual savings and income are greater than the natural gas systems. One aspect that we consider to have a great influence is that the building is already heated with natural gas and the savings from the fuel aren't having enough influence in the annual savings so that the system can be feasible. Another conclusion that can be related with the idea expressed earlier is the carbon dioxide emissions savings, that are less significant than the biomass system, but it still makes the air cleaner.

An aspect that can have an impact on deciding to choose a system or another, is the space for implementing the system. This aspect was neglected in the analysis, but it still has an importance, because a biomass system has more components than a natural gas micro-turbine system, and the fact that the biomass system needs a lot of space for storing the fuel and the products that result in operating the installation. With the natural gas system, this problem is less significant because the fuel is fed through a pipe and there are no other products that result from operating it.

At this moment, in accordance with the economical outlook, the implementation of both systems by inhabitants of the residential building it is a closer subject because the economical effort for every family reaches over 20,000 €. This been said, the only solution to implement trigeneration projects is that they are financed by the government or with nonrefundable funding from the European Union.

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ANALIZA COMPARATIVĂ A DOUĂ SISTEME DE TRIGENERARE PENTRU O CLĂDIRE REZIDENŢIALĂ

(Rezumat)

Biomasa reprezintă o resursă energetică disponibilă la nivel global, dar care nu este valorificată la adevăratul ei potenţial, fiind încă utilizată în modul tradiţional, în clădirile rezidenţiale, pentru încălzire sau pentru prepararea hranei. La ora actuală România este una din ţările în care potenţialul acestei resurse nu este valorificat la capacitatea maximă acest lucru constituind şi unul din motivele realizării studiului de faţă. Prin acest studiu s-a realizat o analiză, economică şi financiară, comparativă a două sisteme de trigenerare, altfel spus, de producere a energiei electrice, agentului termic şi apei răcite pentru o clădire rezidenţială dispusă pe cinci nivele, parter şi patru etaje superioare, localizată în oraşul Iaşi. Cele două sisteme se pot implementa pentru o astfel de construcţie datorită capacităţilor mici de producere, atât a energiei electrice cât şi a celorlalte componente din structura unei scheme de trigenerare. Sistemele se deosebesc între ele prin două caracteristici majore: prin natura combustibilului utilizat, prima instalaţie este alimentată cu o sursă de energie regenerabilă şi anume biomasa, iar cealaltă soluţie utilizează gazul natural, şi prin tipul de echipament utilizat pentru producerea energiei electrice, soluţia cu alimentare cu biomasă producând energie prin intermediul unui motor cu ardere internă iar cea de-a doua soluţie printr-o microturbină.

Pentru analiza economică şi financiară s-a utilizat software-ul pus la dispoziţie de Retscreen International, software versiunea 4.0 care realizează astfel de analize pentru o gamă largă de instalaţii şi cu o gamă largă de combustibili. Programul realizează o analiză ţinând cont de datele introduse de utilizator pentru indicatori economici şi financiari necesari pentru a realiza analiza.

Rezultatele obţinute în urma analizei realizate în studiu au permis evidenţierea unor aspecte de natura economică şi organizatorică dar, de asemenea, permit şi evidenţierea unor aspecte care pot influenţa anumite politici din domeniul creşterii eficienţei energetice şi sporirii independenţei energetice. S-a ajuns la concluzia că sistemul propus, alimentat cu biomasă, este mai fezabil datorită: costurilor mici de exploatare, a raportului cost-beneficiu supraunitar şi a unei perioade de amortizare a

cheltuielilor mai mică decât perioada de garanție a echipamentelor. Astfel că sistemul care este alimentat cu gaz natural se deosebeşte de sistemul cu biomasă prin faptul că, investiția nu se amortizează decât după o perioada care depăşeşte durata de viață a echipamentelor, deşi costurile de implementare sunt mai reduse decât sistemul cu motor cu ardere internă şi biomasă. Nu au fost luate în calcul cheltuielile de transport a produselor rezultate în urma arderii biomasei şi, de asemenea, s-a pornit de la premiza că există spațiu suficient pentru a instala cele două sisteme.