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Efficient Use of Natural Gas Energy in Cogeneration in Households

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Abstract. **In order to save primary energy resources, the member states of the European Union are implementing the required measures for using alternative energy. There are various potential routes to zero carbon housing, but the most practical one is communal and household microgeneration. Microgeneration produces heat and even electricity for domestic households. By the year 2050 micro-cogeneration systems could provide 30–40% of the electricity demand in Great Britain. In Latvia, the consumption by households accounts for 38% of the total energy consumption. 87% of the total consumption of energy resources is used for heating houses and producing hot water; 13% (electricity) is used for operating household devices and lighting. The operating hours of a household heating unit are equal to approximately 5 800 hours per year; if a micro cogeneration unit with the electrical capacity 1–3 kW is installed, it can cover the self-consumption of an average household. The annual electricity generation can amount to 15 000 kWh.**

Keywords: **microcogeneration, energy efficiency and savings**

I. INTRODUCTION

During the time period from 2010 to 2030, the estimated increase in energy consumption is planned up to 50%; the largest share of the consumption will be used for providing heating, ventilation and cooling. Similar developments could look to alternative energy sources, such as wind or biomass, to supply the non-solar fraction, thus achieving truly zero carbon communities. How much solar or wind power is available at any given moment is completely unpredictable. Storing electrical energy surplus from wind turbines or solar photovoltaics (PVs) is more problematic than storing heat. More efficient production of energy contributes to the saving of primary energy resources, monetary resources and leads to the reduction of harmful emissions to the environment [1, 2, 14]. Cogeneration is simultaneous generation of electricity and production of heat within one thermal dynamic cycle by using the same type of fuel. This process is referred to as the combined production of heat and electricity. Energy can be produced by a steam or gas turbine, or internal combustion engine that is connected to a power generator.

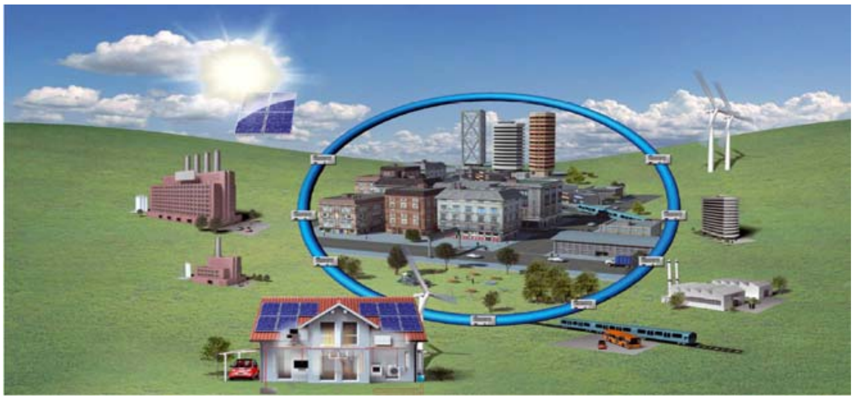

Fig. 1. Possible types of energy production.

Cogeneration is implemented by applying internal combustion engines, steam and gas turbines, fuel elements, and microturbines [1, 2]. The ratio of the installed thermal capacity of cogeneration equipment to the consumer's maximum heating load is the heating system rate and it is calculated as follows:

$$\alpha_{thermal} = \frac{Q_{cog}}{Q^{\max}} = \frac{Q_{cog}}{Q^{cog} + Q^{p.boiler}} =$$

$$= \frac{Q_{cog}}{Q^{\max(heat+vent)} + Q^{aver(hot.water)}} \quad (1)$$

where

α_{termo} – the coefficient of thermofication;

Q_{cog} – the ratio of the installed thermal capacity of cogeneration;

Q_{max} – the maximum heating load of consumer.

Index α is used for denominating this ratio, and this is the quality index of a cogeneration system describing how many kWh of electricity can be generated on the basis of one kWh of heat delivered to the customer. This index describes the possibilities of thermal engines in electricity generation within the cogeneration system, and it depends on a number of factors, including the heat consumption: load; the type of the heat carrier (steam, water); the parameters of the heat carrier (temperature, pressure). Thermofication factor normally ranges within 0.4–0.5 in order to get as many hours of use of cogeneration plant installed capacity as possible.

If cogeneration equipment is designed in compliance with the heat demand it has several advantages:

- more efficient use of the fuel energy;
- emission reduction;
- considerable reduction in the energy production costs contributing to the competitiveness of a company;
- a possibility to offer cheaper energy to consumers, including households;
- less transmission loss in the decentralised system;
- the creation of competitive environment in the energy production sector;
- a comparatively short payback period of the equipment.

The heat that is produced within the cogeneration cycle can be used as follows**:**

- for heating and hot water production;
- for steam production;
- for cooling;
- in technological processes by using the heat of exhaust fumes.

The electricity generated within the cogeneration cycle can be used for the needs of the cogeneration plant – for ensuring its production processes; the surplus can be sold to a licensed electricity transmission or distribution company (see Table I).

Trigeneration is the combined production of electricity, heat and cooling. Cold can be produced: in the compressor-type cooling equipment, where electrical engines are used for drive; in the absorption-type cooling equipment, where instead of electricity cheap heat sources are used, such as emitted exhaust gases, hot water, etc.

II. Classification Of Cogeneration Equipment

Micro-cogeneration equipment – it can be used in households (in both individual and apartment houses), hotels, hospitals, swimming pools for heating, ventilation and hot water production; the possible electrical load is up to 50 kW.

Low capacity cogeneration equipment – it can be used in apartment houses, hotels, hospitals, swimming pools for heating, ventilation and hot water production; the possible electrical load is up to 1MW.

High capacity cogeneration plant – for the provision of energy supply and production processes: heating, ventilation and hot water production; the possible electrical load is above 1 MW.

Decentralised combined electricity and heat production is an important technological solution for improving energy efficiency, saving primary energy resources, improving the security of energy supply, reducing CO_2 emissions, and saving money resources at the same time. Small-scale local cogeneration plants have also lower energy transmission losses. Micro and low-capacity cogeneration plants operate with the module of an internal combustion engine or gas turbine [3].

Low-capacity cogeneration gives a customer an opportunity to choose the most profitable type of energy supply (see Fig. 2).

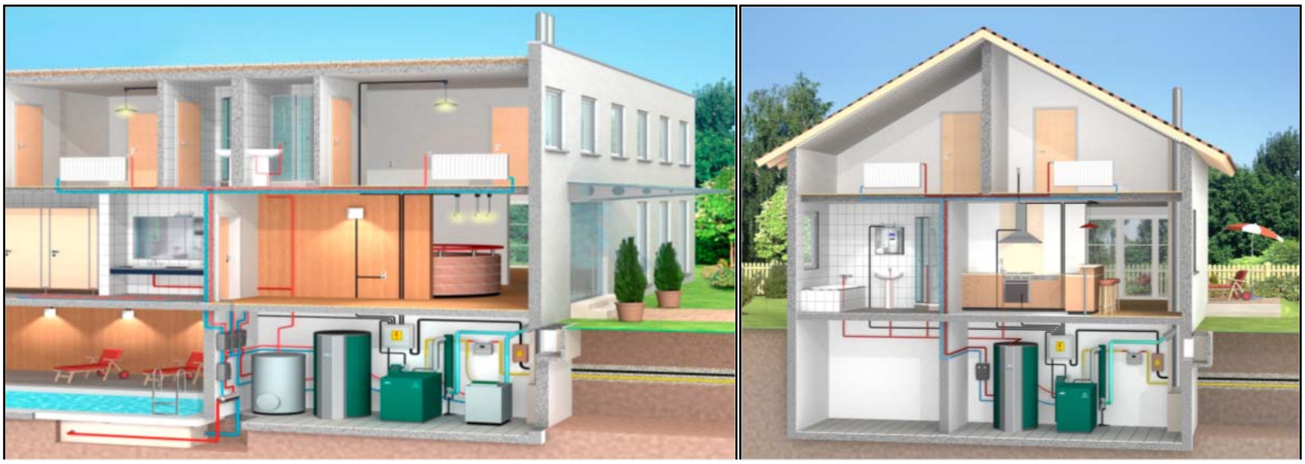

Fig. 2. The types of use of cogeneration units for commercial and public buildings and households.

TABLE I

THE TYPES OF USE OF THE ENERGY PRODUCED IN THE MICRO AND LOW-CAPACITY COGENERATION CYCLE

	Use of heat	Use of electricity
District heating – boiler houses	Heating, hot water production	Lighting, operation of pumps, the surplus is sold to the grid
Offices, buildings – hotels, hospitals, swimming pools	Heating, hot water production	Lighting, ventilation, the surplus is sold to the grid
Households	Heating, hot water production	Lighting, operation of pumps, the surplus is sold to the grid

The European Union and the governments of some countries, for example, Germany and Great Britain, promote the use of cogeneration for attaining both the international and national goals as regards the reduction of carbon dioxide emission. For example, the government of Great Britain has set the goal to reduce CO2 emissions in the household sector to 60% by 2050. By the year 2050 micro-cogeneration systems could provide 30–40% of the electricity demand in Great Britain. Generally, large- and small-scale cogeneration systems for industrial use or for the application in small-scale organisations, for example, schools, hospitals, district centres or residential areas, have demonstrated good results. However, the research is on-going for ensuring that micro-cogeneration systems could be used on a wider scale in households. Micro-cogeneration is particularly interesting to small and medium family houses, smaller buildings, small and medium businesses due to the following technical and operational features:

- high total energy transformation efficiency (for example, above 90%);
- low maintenance costs in comparison with a similar gas-fired heating boiler for a house;
- low noise and vibration level for devices at home;
- low NOx, CO2, SOx and particle emissions.

By installing a cogeneration unit, the following benefits can be obtained:

- the provision of the heat supply and partial electricity supply of a building;
- the reduction in the building electricity costs;
- the reduction in the total building energy costs;
- the reduction in CO_2 emissions.

The following benefits cannot be obtained by means of cogeneration:

- free of charge electricity (fuel has to be consumed for its generation);
- instant savings of money;
- money savings if the unit is not operated.

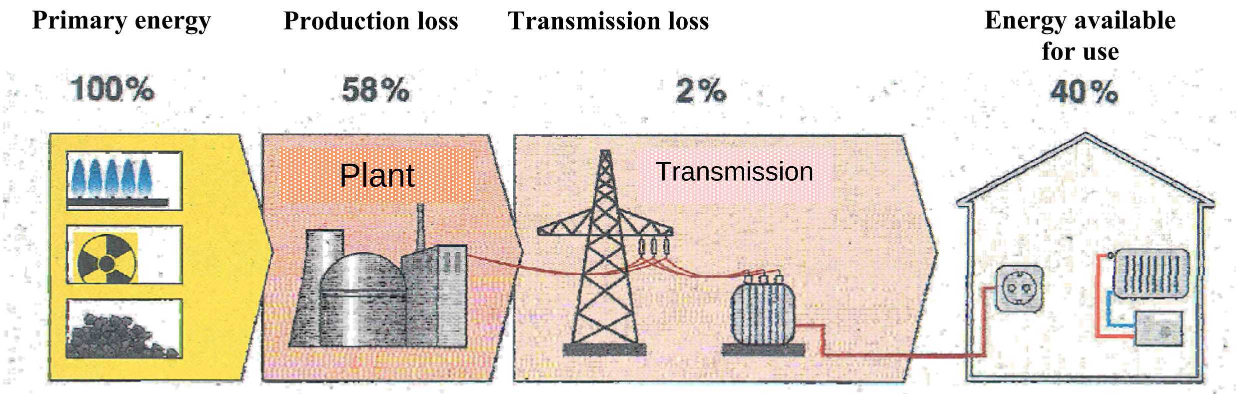

Fig. 3. Energy produced in the condensing mode.

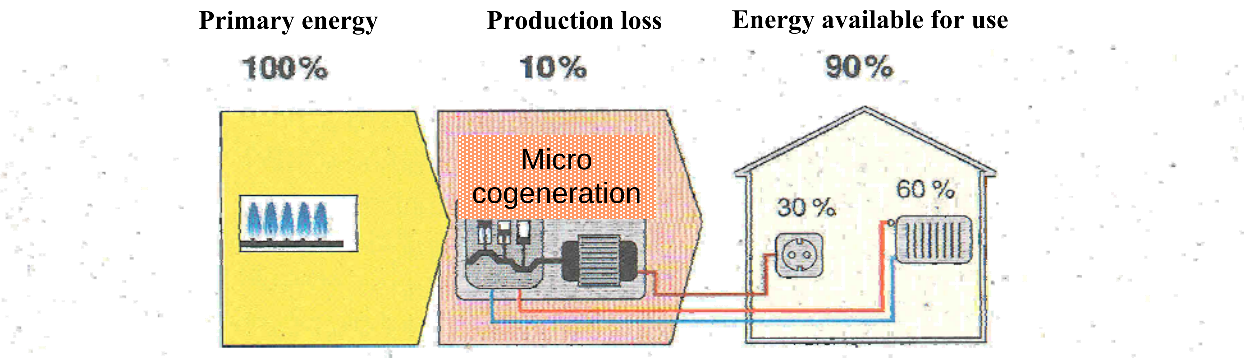

Fig. 4. Energy produced in micro and low-capacity cogeneration units.

III. Use Of Natural Gas In Cogeneration In Households

Within the framework of the project implemented by the International Energy Agency on the simulation of the fuel elements and other cogeneration systems integrated in buildings, a common approach to the implementation of micro and low-capacity cogeneration units in the residential sector was developed [4].

The results of the research demonstrated considerable benefit. The efficiency of the power generation by small-scale fuel elements, Stirling and internal combustion engines was within the range from 9% to 28%, and the total efficiency was 55% and above for certain units. In recent past the use of cogeneration systems in the residential sector was restricted because of the unavailability of equipment. Thanks to the successful development of the manufacturing of micro cogeneration units and the elimination of technical drawbacks, a vast and accessible market of cogeneration units is becoming a reality [11].

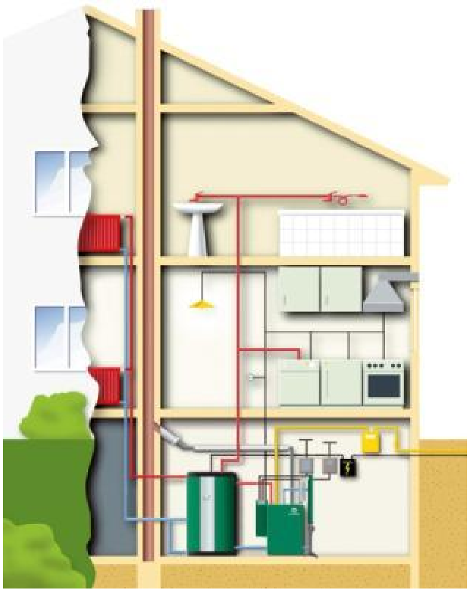

Fig. 5. The operation of a micro and low-capacity cogeneration system

When micro cogeneration units are installed as the replacement of conventional boilers the fuel consumption decreases, thus reducing releases of harmful emissions into the environment.

A broader application of cogeneration in households is a way to reduce carbon dioxide emissions, thus complying with the obligations imposed upon the European countries by the Kyoto Protocol. Natural gas is the most popular fuel that is used in low-capacity cogeneration units. This is one of the most profitable and environmentally friendly types of fuel as it produces less CO2 and NOX, does not produce ash and sulphur compounds (SO2 and SO3) as opposed to coal or HFO. Warehouses or reservoirs are not required for storage of natural gas, and the full automation of equipment is also possible, etc.

During a research project financed by the European Union and including the analysis of the potential market for micro cogeneration units in the old member states it was concluded that approximately 13.5 million households were potentially suitable for installing this type of units with the electrical capacity in the range of 1 to 5 kW. The Dutch experts have estimated that the reduction in carbon dioxide emissions will amount to approximately 1000 kg per household micro generation unit. The annual primary energy consumption is calculated as follows:

$$Q_p = (Q_h + Q_w) \times E_p , \qquad (2)$$

where

Q_p – the annual primary energy consumption, m^3/h;

Q_h – the annual energy demand for heating, m^3/h;

Q_w – the annual energy demand for hot water production, m^3/h;

Ep – the efficiency rate of the equipment.

From the external visual appearance and the heat capacity, the household micro cogeneration unit is identical to the existing gas-fired boilers installed in kitchens. In addition to heat, the unit also generates electricity. Depending on the required heat load, the micro engine is supplemented with a highly efficient gas burner and also with a heat accumulation tank, if it is required. The automated control system ensures that the unit generates electricity only when there is demand for heat.

Domestic microgeneration gives the same comfort as a gas boiler, but with lower energy payment and CO2 emission [5]. The gas microgeneration systems are being installed in the Netherlands, Germany, and Great Britain. The power generation capacity of the unit is intentionally designed low, up to 5 kW to ensure that it covers the basic load of the power consumption by an average household. The results of the study carried out by the International Energy Agency demonstrated that a cogeneration system reduced the consumption of primary energy resources by up to 33% and the emission of greenhouse gases by up to 23% in comparison with the conventional steam boiler or water heater.

In Europe, the following companies manufacture micro cogeneration units – Viessmann, WhisperGen, Bosch Thermotechnik/ Buderus, Baxi, Vaillant, Senertec.

Technical Parameters of a Micro Cogeneration Unit

Natural gas consumption – 2.1 m3/h; heat capacity – 12.5 kW; electrical capacity – 5.5 kW; heat capacity of the condensing gas burner – 15.5 kW; total efficiency rate – 89%; efficiency rate in the condensing mode – 100%, dimensions – 720x1070x1000 mm; weight – 530 kg; service after the operation of 3500 h.

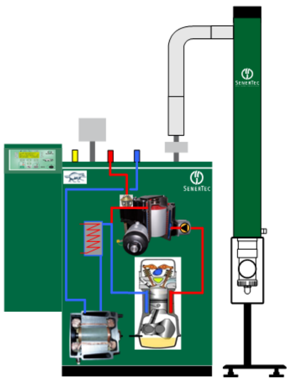

Fig. 6. The scheme of the operation of a micro cogeneration unit.

In the Netherlands, gas-fired heating systems are installed in more than 6 million houses and approximately 400 000 units are replaced by more modern ones every year [12]. In Germany, a village of 30 residential houses with installed micro cogeneration units has been built. In Germany, 85 thousand of micro and low-capacity cogeneration units have

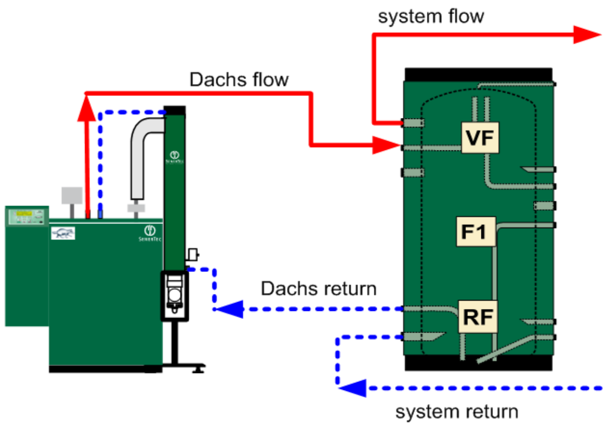

Fig. 7. Household micro cogeneration unit.

been sold to ensure the energy supply of households, commercial enterprises and public buildings [13].

It has been calculated that 13.5 million households in the European Union are suitable for this microgeneration installation. The best microgeneration option for a project may be a combination of two or more separate but compatible technologies [15].

Volume of natural gas consumption has increased in recent years in Latvia. Major part of gas in Latvia is consumed for heat production, as well as it is consumed on an everyday basis in manufacturing and households. The company, which provides natural gas to consumers, should forecast the volume of gas consumption for the next years in order to make timely changes in supply volumes, thereby satisfying the consumers and efficiently utilizing its own resources.

In Latvia, the consumption by households accounts for 38% of the total energy consumption. 87% of the total consumption of energy resources is used for heating houses and producing hot water; 13 % (electricity) is used for operating household devices and lighting.

In Latvia, there is a high deficit of electricity generation capacity. In 2010, households in Riga region consumed 580 GWh of electricity, and it accounted for approximately 25% of the total energy consumption in Riga region (see Figure 8). If state support instruments are provided for the installation of micro cogeneration units in households, and also if households are motivated to invest their resources in their energy independence additional electricity generation by households is feasible and this would reduce the electricity deficit [6, 7].

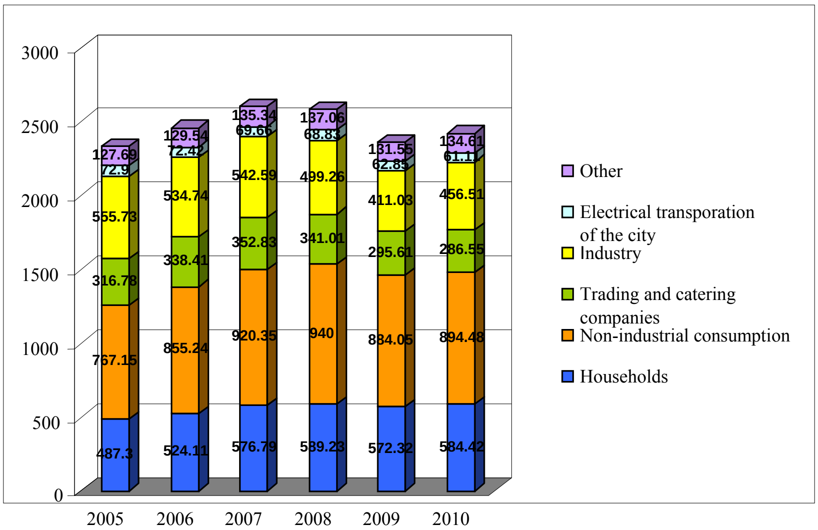

Fig. 8. Sales of electricity to consumers in Riga region (GWh).

In the territory of Latvia, gas-fired heating units are installed in 39 thousand households of which 60% (24 thousand households) are located in Riga region; their allowed load is up to 6 m3/h. The operating hours of a household heating unit are equal to approximately 5 800 hours per year; if a micro cogeneration unit with the electrical capacity 1–3 kW is installed it can cover the self-consumption of an average household. The annual electricity generation can amount to 15 000 kWh.

If micro cogeneration units were installed in 30% of the households (7.2 thousand) in Riga region, the annual power generation could amount to 108 GWh or 18% of the electricity demand of the households in Riga region [8].

It is necessary to estimate the maximum hourly consumption of natural gas (m^3/h) to ensure the stability of gas supply, the secure operation of the units for the current gas consumers, as well as provide the possibility of installing innovative units.

The estimated hourly consumption of natural gas Q_d^h (m^3/h) has to be estimated by adding up the rated gas consumption of gas-fired devices and taking into account the rate of their simultaneous operation:

$$Q_d^h = \sum_{i=1}^{m} K_{sim} \cdot q_{nom} \cdot n_i \, , \qquad (3)$$

where

$Q_d^h = \sum_{i=1}^{m}$ – the sum of the multiplication of the values;

$K_{sim} \cdot q_{nom} \cdot n_i$ from i to m;

K_{sim} – the rate of simultaneous operation, for residential houses in compliance with the standard LVS 417:2011 [9];

q_{nom} – the rated gas consumption (m3/h) of the device or a group of devices based upon the data of the unit certificate or the technical description;

n_i – the number of the units or groups of units of the same type;

m – the number of types of the devices or groups of devices.

Based upon the estimations of natural gas consumption, it is also necessary to perform the hydraulic assessment of the system of gas pipelines [9, 10]; as regards the current low pressure gas supply system, the allowed pressure drops should also be evaluated. At present, the existing low pressure external distribution gas pipelines are heavily loaded and pressure drops in them start to exceed the standards; however, the existing system of medium pressure gas distribution pipelines can supply the load of additional units in the residential areas. If the replacement of gas distribution pipelines is necessary, also the technical cost-benefit analysis should be carried out for the purpose of assessing eventual investment.

IV. Conclusions

The European Union experience regarding the installation of micro cogeneration units in households has been evaluated.

The possible consumption of electricity generated in cogeneration per household has been estimated.

By the installation of cogeneration units in households, the savings of primary energy resources are gained; in Riga region it is possible to generate up to 25% of the electricity required for households.

It is necessary to develop a field standard for the design and installation of gas-powered cogeneration plants in the territory of Latvia.

The existing medium pressure gas distribution pipelines in the residential areas provide for the installation of innovative devices – micro cogeneration units.

The support of the government is required for the installation of micro cogeneration units in households where natural gas is consumed.

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