Applicability of Tri-generation Energy Production for Air-conditioning Systems in Czech Republic

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Abstract: This contribution presents the analysis of possible utilizing of a tri-generation system for effective electricity, heat and cool production. A tri-generation offers more effective utilizing of primary energy sources in comparison with separate production of different kinds of energy. Natural gas is considered as the most common primary energy source utilized in tri-generation units. This analysis respects the legislation and technical directives valid in the Czech Republic in year 2006. The analysis synthesizes technical requirements for production of heat during a heating period and production of cool during a cooling period.

The studied tri-generation system consists from a cogeneration unit, based on a stroke engine technology, connected with a convenient absorption machine for production of cool water. The mixture of water and LiBr is considered as appropriate working-pair medium operating in the absorption cycle. This paper focuses on environmental benefit and economical assessment of a tri-generation technology in residences and mid-size buildings.

Key-Words: poly-generation, tri-generation, heating, cooling, absorption cycle, cogeneration

1 Introduction

Poly-generation of energy is the nowadays trend in an energy supply of buildings. Poly-generation offers significant advantages in comparison with separate energy production. Electricity is commonly produced in power plants. A primary chemical energy of fuel is transformed to electricity with the efficiency about 38 %. The rest of the primary energy leaves the power plants in form of a waste heat without utilizing. On the second side, the heat energy for heating of buildings is produced commonly in boilers with the efficiency close to 90 %. Cool for air-conditioning systems is the most frequently produced with utilizing of vapor cooling cycles driven by electricity. The cool production represents a technology with significant consumption of energy. The second possible way of the cool production is to utilize an absorption cycle technology driven by heat energy from different sources. Poly-generation of energy enables to utilize a waste heat released during power plant generation of electricity. So, poly-generation significantly increases effectiveness of primary energy sources utilizing and decreases production of CO_2.

The poly-generation represents effective production of energy close to a position of consumption. A short connection between the position of the generation and the position of consumption is an important advantage that enables to utilize majority of the generated energy. A combined production of electricity, heat and cool is called the tri-generation.

Residences and mid-size buildings are commonly connected with significant consumption of electricity, heat (during winter) and cool (during summer).

Cogeneration units represent the most common poly-generation systems producing electricity and heat. Small size cogeneration units are the most frequently based on the stroke engine basis. Another considered poly-generation system is a tri-generation. The trigeneration consists from a cogeneration unit connected with a convenient absorption cycle for production of chill water. Hot water or steam serves as a convenient source of a driving heat for an absorption cycle. The terminal cooling capacity of the absorption system depends on the temperature and quantity of the driving heat.

Vapor-compression cycles provide high COP values for a small temperature difference between the evaporator temperature and the condenser temperature in comparison with the absorption cycle. The temperature difference increase causes decrease of the COP value. An absorption cycle COP value is not so sensitive to the temperature difference between an evaporator and a condenser. But there are physical limitations of the working temperature range.

Utilizing of poly-generation requires simultaneity in consumption of all kinds of produced energy. In a different way, a control system has to decrease power output of the poly-generation unit or the superfluous energy must be rejected or accumulated.

2 Nowadays utilizing of poly-generation

The Czech Republic is country with numerous applications of district heating systems. Nearly all cities utilize any kind of a combined heat and power production. Cogeneration systems produce 16 % of electricity produced in the Czech Republic. The cogeneration systems with power output greater than 3 MW_e frequently use the coal and biomass as a primary fuel. These systems engage either thermal vapor cycles with stem turbines or combination of gas turbine cycles and steam turbine cycles. Also waste incineration plants utilize the steam turbine technology for cogeneration. Solo gas turbines are occasionally used in systems with power output range from 1.5 to 3 MW. Smaller cogeneration systems are nearly all fed by natural gas and based on the stroke engine technology. The fig. 1 shows percentage of different cogeneration systems operating in the Czech Republic.

Tri-generation systems are used only in limited number of applications with significant requirements on amount of heat and cool supply. Typical objects for applications are university buildings, hospitals, office buildings and some technologies.

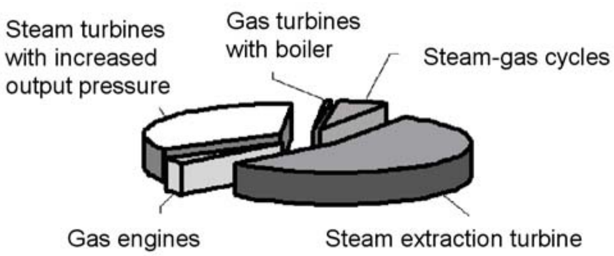

Fig. 1 Percentage of different cogeneration systems operating in the Czech Republic, 2005

3 Poly-generation of energy

3.1 Cogeneration

A cogeneration represents the most common type of poly-generation frequently based on a stroke engine basis. Different types of stroke engines are used at cogeneration units and their efficiency vary in range mentioned in the Table 1.

The particular cogeneration unit considered in this study for a detail analysis has technical parameters: energy of fuel is transformed to electricity with efficiency 32%, heat from flue gasses and from an engine cooling jacket is used as a source of heat with a sufficient temperature level (above 90 °C) for common heating systems – 59 % of the fuel energy.

Engine type	Efficiency %		
	Electricity	Heat	Total
Petrol	30 - 37	45 - 60	80 - 92
Diesel	35 - 45	40 - 50	80 - 92

Table 1 The efficiency of cogeneration units based on a stroke engine technology

9 % of energy is taken out from the system by thermal losses. The fig. 2 shows the real energy fluxes in the considered cogeneration unit.

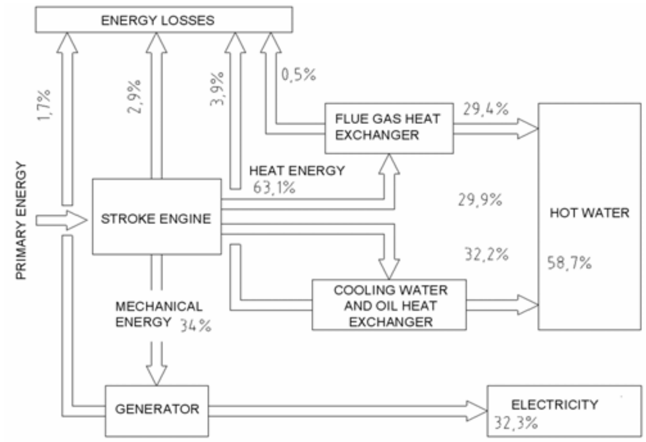

Fig. 2 Energy fluxes in the stroke engine cogeneration unit

3.2 Tri-generation

Cool for air-conditioning units is commonly produced in cooling cycles driven by electricity. Cool production requires significant consumption of energy. Majority of cooling systems utilize a vapor-compressor cycle.

The second possible way of the cool production is to utilize an absorption cycle technology driven by heat energy from a cogeneration unit. This system consists from a cogeneration unit connected with a convenient absorption system for production of cool water. Heat from a cogeneration unit is transported by hot water to a heat exchanger of the absorption cycle, see fig. 3. This system is called the tri-generation technology for combined production of electricity, heat and cool. The tri-generation can be used with advantage in energy central supply systems of buildings and its operation can be optimize to minimal consumption of the primary energy sources with conservation of full comfort in an energy utilizing.

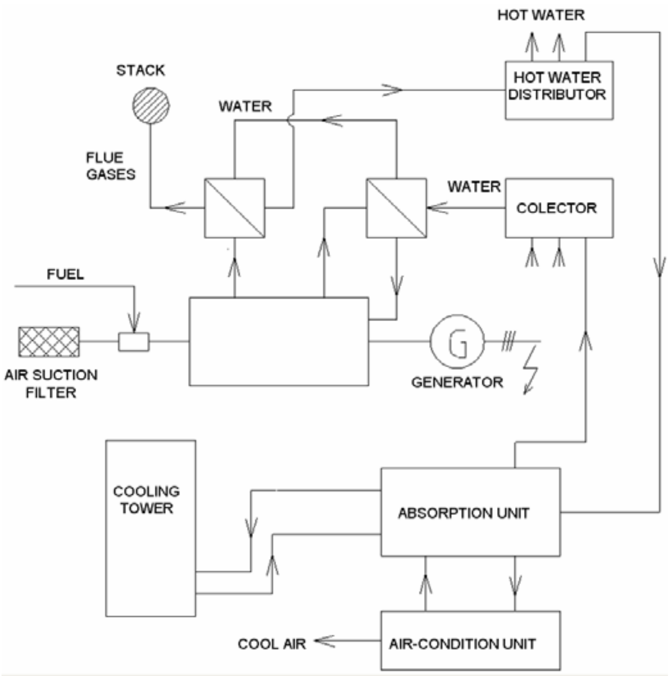

Fig. 3 The trigeneration technology with an absorption cycle

3.3 Environmental benefit of poly-generation

The poly-generation main philosophy is decreasing of consumption of primary energy sources. Poly-generation represents more effective utilizing of a primary energy in comparison with separate production of different kinds of energy. The power to heat ratio PHR is parameter for expressing of the quality of energy transformation processes and the entire technological efficiency of a poly-generation assembly

$$PHR = \frac{E_p}{H_p}, \qquad (1)$$

where E_p is a produced electricity output and H_p is heat supplied to a heating system.

The saving of a primary energy in the cogeneration systems can be expressed as

$$Q_{save}^{CHP} = \frac{E_p}{\eta_{PP}} + \frac{H_p}{\eta_{HP}} - \frac{E_p + H_p}{\eta_{CHP}}, \qquad (2)$$

where η_{PP} is the efficiency of a power plant, η_{HP} is the efficiency of a heating plant and η_{CHP} is the efficiency of a cogeneration plant.

The saving of a primary energy in tri-generation systems can be expressed as

$$Q_{save}^{CHCP} = \frac{E_p}{\eta_{PP}} + \frac{H_p}{\eta_{HP}} + \frac{C_p}{\eta_{CP}} - \frac{E_p + H_p + C_p}{\eta_{CHCP}}, \qquad (3)$$

where C_p means amount of cool supplied to air-condition system, η_{CP} is the efficiency of a vapor cooling unit and η_{CHCP} is the efficiency of a tri-generation plant.

Utilizing of the tri-generation technology significantly protracts a year operating period of a poly-generation system causing extended savings of primary energy sources.

The fig. 4 shows relation between the comparative saving of primary energy Q_{CR} and the power to heat ratio of a poly-generation unit *PHR*.

$$Q_{CR} = \frac{Q_{save}}{\dfrac{E_p}{\eta_{PP}} + \dfrac{H_p}{\eta_{HP}}} \qquad (4)$$

The curve labeled "1" was obtained for cogeneration systems. The curve "2" was obtained for tri-generation systems.

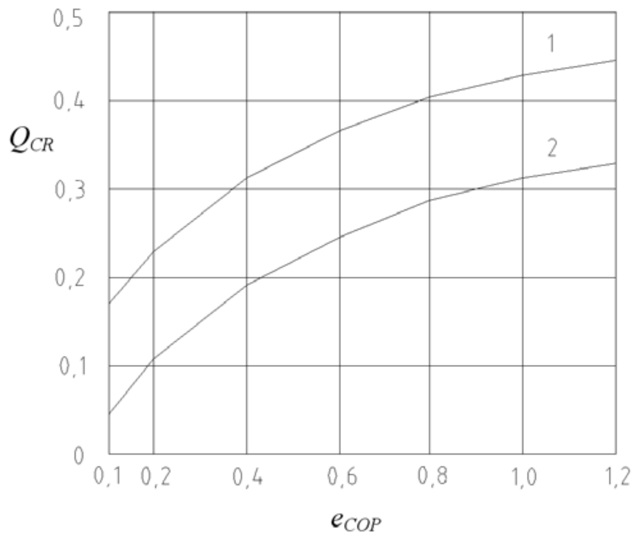

Fig. 4 The relationship between the comparative saving of primary energy Q_{CR} and the power to heat ratio of a poly-generation unit *PHR*.

We must strictly distinguish an area scale for the environmental assessment of a poly-generation technology. Utilizing of a poly-generation decreases a produced emission rate in large areas (involving distant power plants).

If we asses an environmental burden in local scale areas, a poly-generation system can present a significant local source of emissions located directly in urban areas. Exposure of population to these emissions can be more danger than exposure to emissions from distant power plants. From this reason, emission threshold values of stationary stroke engines must be minimized.

4 Heating and cooling requirements

The particular mid-size building located at the central part of the Czech Republic was used for assessment of the applicability of tri-generation energy production for air-conditioning systems. The building parameters and energy requirements can be considered as representative parameters of mid-size buildings in the Czech Republic.

4.1 Heating requirements

The heating season is 245 days/year for the region of the studied building. A temperature at this region varies from -15 °C in winter to +35 °C in summer. The fig. 5 shows the air temperature distribution curve for the average heating period.

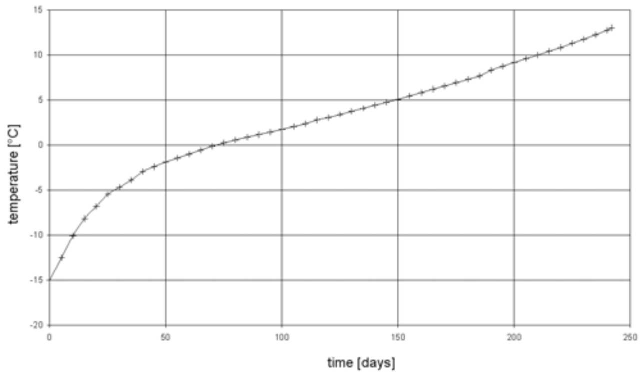

Fig. 5 The air temperature distribution curve for the average heating period

The building altitude is 420 m. Heat supply requirements were calculated in accordance with an actual legislation and the valid technical standards. The calculation took in to account the building heat loss, the heat required for necessary air exchange and hot water production.

Results of the calculation are present in the fig. 6 in form of the heat requirement distribution curve. A decreasing trend of the heat requirement distribution curve is characteristic for the heating season commonly taking 580 hours/year. The rest of a year, only a constant heat supply for preparing of hot water is required. In the fig. 6, the area labeled *KJ* represents heat supplied by cogeneration unit. The area labeled *PK1-3* represents heat supplied by supplementary heat sources. In this study, we considered gas boilers operating in the term of very low external air temperatures. Gas boilers are convenient as a supplementary source of heat for a cogeneration unit because they use the same fuel.

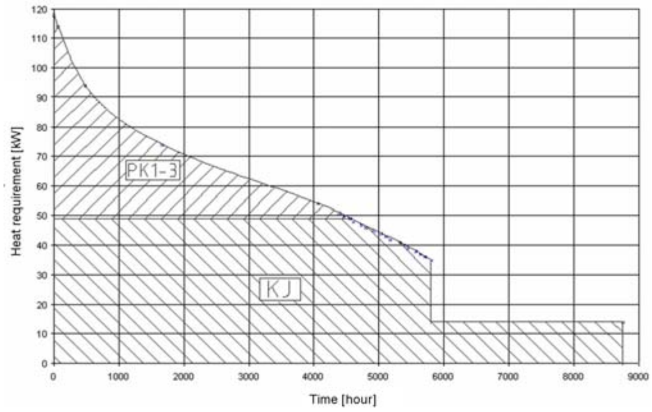

Fig. 6 The heat requirement distribution curve for a cogeneration unit

4.2 Cooling requirements

The cooling season in the studied locations takes about 90 days per year. An air-conditioning system must take away a heat load of a building and keep temperature of an indoor air on a required temperature level. Three main contributions of a heat load was considered, namely a heat load released from building equipment, a solar heat load by windows and a heat load penetrating by walls. The solar heat load by windows is a function of an actual solar heat flux and building parameters – a building orientation, an area of windows, a type of windows.

The fig. 7 shows the results of a calculation for one day of the top cooling season. The maximal solar heat load was determined nearly exactly in the noon. A part of the solar load is absorbed by a building structure during day and released during night in due to decreasing of the indoor air temperature. From this reason, we can decrease the solar heat load by an accumulation capacity of the building, see fig. 7. The difference between the solar heat load minus the accumulation and the total heat load of the building is caused by a heat production from building equipment (lightning, computers and technology) and a heat load penetrating by walls.

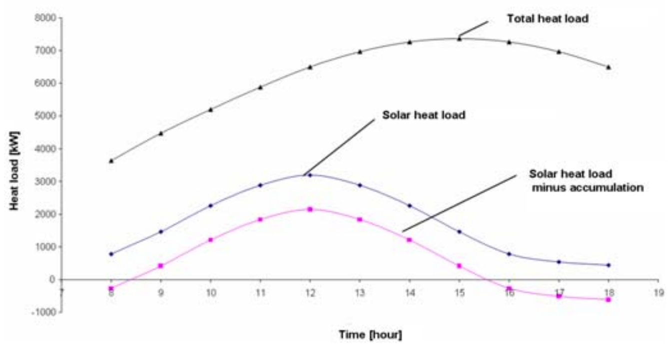

Fig. 7 The building heat load for one particular day of the top cooling season

A tri-generation technology is used for production of cool water supplied to air-conditional units in this study.
This system consists from a cogeneration unit connected with a convenient absorption system for production of cool water. Heat from the cogeneration unit is transported by hot water to a heat exchanger of the absorption cycle. Water cooled by an absorption cycle circulates between the air-condition units and the absorption cycle.

4.3 Cooling absorption cycle

Utilizing of an absorption cycle is the only difference between cogeneration and tri-generation. From this reason, it is important to focus on detail performance of the absorption cycle for correct evaluation of tri-generation.
The absorption cycle consists from a generator, an absorber, a condenser and an evaporator, see fig. 8.

These parts are connected by pipes for transport of liquid mixtures and vapors. Throttle valves are used for depressurizing of fluid mixtures. A pump enables to pressurize liquid mixtures.
A liquid refrigerant evaporates in the evaporator. The heat flux Q_2 is taken away from cooled medium. The refrigerant vapors are led to the absorber, where the poor liquid mixture absorbs the refrigerant vapors. The absorption heat Q_4 is released during the absorption process. The saturated liquid mixture is transported to the generator operating on a higher-pressure level.

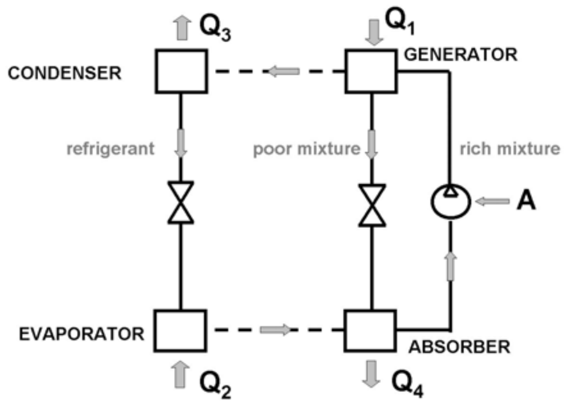

Fig. 8 The simple one-stage absorption cycle

The driving heat Q_1 is supplied to the generator by hot water from a cogeneration unit. The refrigerant vapors release the mixture during increasing of the mixture temperature. The poor hot mixture returns to the absorber via a throttle valve. The released refrigerant vapors continue to the condenser. The vapors are cooled to lower temperature and condensate to the liquid form. The condensation heat Q_3 is released during this process. Then the liquid refrigerant passes through another throttle valve and enters the evaporator.

The coefficient of performance (COP) evaluates absorption cycle effectiveness.

$$COP = Q_2 / Q_1. \quad (5)$$

The mixture of water and LiBr is considered as the most frequently used working medium in absorption systems. There is a physical limitation for convenient working temperatures of an absorption cycles [1]. The COP is approximately constant for all variations of convenient temperatures.

The temperature of a hot water leaving the cogeneration unit is required 95°C for correct operation of the absorption cycle driven by a hot water. The theoretical *COP* value is 0.82. The cooling capacity is calculated as

$$Q_2 = Q_1 \times COP. \quad (6)$$

Utilizing of a cool producing absorption cycle driven by hot water from a cogeneration unit increases the heat requirement during summer period. The corresponding heat requirement distribution curve is shown in fig. 9.

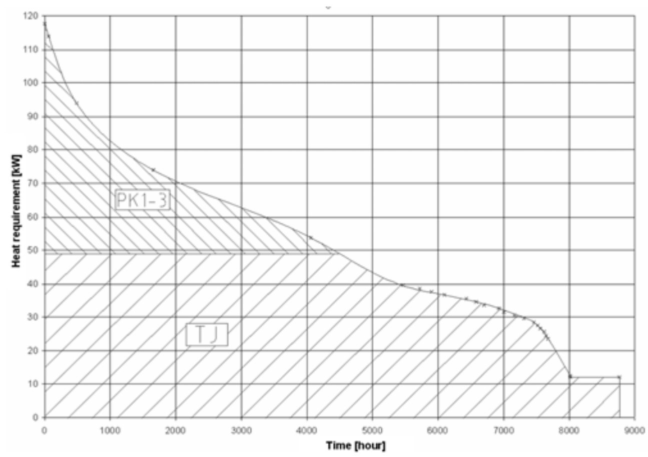

Fig. 9 The heat requirement distribution curve for tri-generation unit

5 Results and discussion

The Czech Republic legislation encourages utilizing of all kinds of poly-generation systems. Local distributors of electricity must buy at a special price all electricity produced by poly-generation systems. Year operation hours of poly-generation systems are limited only by actual heat requirements.

The cogeneration unit used in the studied building runs 6350 hour per year without utilizing of an absorption cycle. This period is extended to 7250 hour per year in a case of utilizing of the tri-generation technology driven by heat from a cogeneration unit. This extension enables to operate the cogeneration unit effectively even during summer period, commonly without heat requirements.

Poly-generation of energy is connected with saving of a primary energy sources. The cogeneration technology decreases consumption of the primary energy by 29 %. The tri-generation technology decreases consumption of the primary energy by 20 %. We calculated the payback period as a basic economical criterion. Input parameters correspond to situation in the Czech Republic in the year 2006. The payback of the cogeneration and the tri-generation technology was evaluated close to 4.5 years in comparison with the separate production of electricity, heat and cool. An investment of a tri-generation technology is more expensive in comparison with a cogeneration technology. But a tri-generation technology offers higher annual saving and higher profit during the life-time period.

In this contribution we assumed not utilizing of waste heat from the tri-generation technology. This low temperature heat can be utilized for preheating of water or heating of swimming pools. In these cases the saving of the primary energy is more significant.

A tri-generation technology connected with an air-condition unit is profitable assembly convenient for mid-size building in conditions of the Czech Republic. Other advantages of this system are: uniform annual consumption of electricity, air-conditioning without burden of an electricity distribution net, back up source of energy.

6 Conclusion

This paper introduces connection of poly-generation systems and an air-condition unit for mid-size buildings. A cogeneration unit based on a stroke engine is considered as the most frequently used ply-generation system. The paper focused on connection of a cogeneration unit with an absorption cycle. This assembly forms a tri-generation unit simultaneously generating electricity, heat and cool.

The particular mid-size building was used for detail analysis of the cogeneration and the tri-generation technology. Utilizing of a cogeneration technology causes 29 % decreasing of primary energy sources consumption. Tri-generation decreases consumption of primary energy sources by 20 %.

A tri-generation system offers another advantage namely more uniform operation of a poly-generation system during the entire year period. A cogeneration unit used in the studied building runs 6350 hour per year without utilizing of an absorption cycle. This period is extended to 7250 hour per year in a case of utilizing of a tri-generation technology driven by heat from the cogeneration unit. The payback period of the studied poly-generation system was calculated 4.5 years. A tri-generation technology connected with an air-condition unit was evaluated as profitable assembly convenient for mid-size building in conditions of the Czech Republic.

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