CONTRIBUTING TO A FLAGSHIP PROJECT OF THE STRATEGY

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$Co_2olBricks$

WP5 Education and Economic Promotion

Improving heat production/boiler

Educational product: New lecture material for training modules dealing with knowledge and skills how to apply suitable methods of energy efficient refurbishment of historic constructions and how innovation can be combined with cultural heritage

Improving heat production/boiler

Target group: energy audit students

Educational objectives: To give general understanding of heating systems in historic buildings and possibilities to improve existing systems.
This measure can help to save up to 17% of total energy used in building

Lecture course: 4 academic hours

References:

Nielsen, Steffen, and Bernd Möller. “Excess heat production of future net zero energy buildings within district heating areas in Denmark.” *Energy* 48.1 (2012): 23-31.

Lund, Henrik, et al. “The role of district heating in future renewable energy systems.” *Energy* 35.3 (2010): 1381-1390.

Gustavsson, Leif, et al. “Primary energy implications of end-use energy efficiency measures in district heated buildings.” *Energy and buildings* 43.1 (2011): 38-48.

Table of Contents

Energy sources are required for electricity and heat supply. The selection of Historic building power supplies are dependent on the specific design and constructional requirements that are set for the source from technological supply and their operating efficiency, environmental impact and economic evaluation. All these factors are summarized in figure 1.

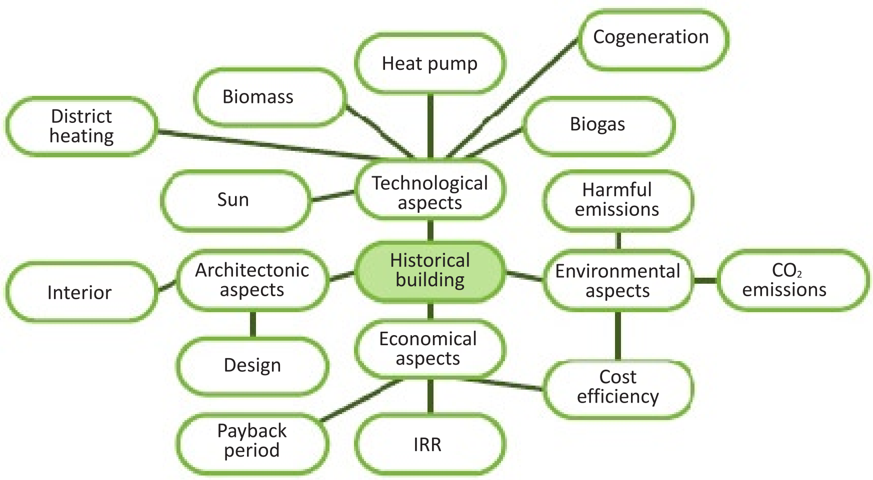

Fig. 1. Factors for choosing heat supply of historical buildings

Engineering solutions for the heat supply of historical buildings include a wide range of technologies:

- Boilers;
- Cogeneration plants;
- Heat pumps;
- Solar collectors;
- Equipment using geothermal water;
- District heating elements.

Historical buildings power supply is carried out manly using heat from centralized distribution networks. Solar panels which help to produce electricity can be installed only in special cases, where permitted by the interior. Creation of photovoltaic construction innovations is developing rapidly and they can already be integrated into roofs, walls and windows.

Boilers

One of the most commonly used heat sources are boilers and boiler houses. Chemical energy form energy sources in boiler technological devices are turned in into the thermal energy. Boiler technologies are designed so that this transformation takes place with minimal power loss. Technological solutions of boilers covers whole set of boiler elements that are related to the combustion process and the organization of heat and mass exchange processes.

Set of boiler elements can be divided into three groups.

Combustion technology and furnace equipment

Combustion process is organized in furnace. There the combustion products - flue gases, are formed. Combustion process is provided with the help of combustion technologies: burners, nozzles or grates that are placed in the furnace. Furnace walls can be covered with pipes, where circulates mixture of water and water vapor.

Boiler heating surfaces

Boiler heating surface is on one side surrounded by heat carrier (combustion products), but on the other side with work environment (liquid or liquid and vapor mixture). Heating surfaces play a key role in energy-efficient operation of the boiler, so they are placed in a specific order in the direction of exhaust gas flow (see Fig. 2.) Heating surface receives heat from hot flue gases, mainly due to the implementation of three heat transfer processes: radiation, convection and condensation. Heating surface is named depending on the dominating heat exchange type Radiation surfaces are placed in furnace, convection surfaces are installed in the convective part of the boiler, and condensation surfaces are placed behind the boiler unit in order to ensure steam condensation from steam-gas mixture.

Fig. 2. Organization of Flue gas flows through the heating surfaces

In hot water boilers the work environment is water, which heats up to a certain temperature by receiving heat from hot flue gases. Water heats up in coldest part of steam boiler heating surfaces, but phase transition processes and the formation of steam are organized in the hottest part.

Auxiliary equipment and mechanisms

The boiler is operated through balanced auxiliary activities. Auxiliary equipment can be grouped into three mutually independent, but related units:

• Fuel storage and supply facilities. Fuel facilities include biogas reactors and storage tanks, fuel oil tanks and feed pumps and biomass storage facilities with fuel supply mechanisms: moving floors, conveyor belts, screw mechanisms and bunkers.

• Air supply and flue gas removal unit. Air required for the combustion process is supplied through a duct system using a fan. Flue gas from the boiler is removed by a special gas duct and chimney (chimney stack). To overcome aerodynamic resistance of gas ducts it is often not enough with the drag caused by chimney, therefore a smoke exhauster that would feed flue gases into the chimney.

• The holding supply or feed water preparation.

Water-heating boiler feed water and steam boiler feed water is specially prepared in order to avoid forming of boiler scale and other sediments and to remove corrosion aggressive gases. Water supply unit includes pipes, pumps and heat exchangers for water heating before and after the water treatment plants.

Boiler design varies considerably and they are classified and grouped using a variety of

features:

• Fuel type - fossil and renewable:
- gas: natural gas, syngas and biogas;
- solid: coal, wood, biomass, waste;
- liquid: fuel, biofuels.

• Installed capacity: micro devices, small, medium and high capacity;

• Type of heat carrier (water, steam and hot air);

• Boiler design layout (horizontal and vertical);

• Furnace aerodynamics (primary, secondary and tertiary air supply).

These and other features affect the selection of boilers for historical buildings. It is important to define not only the usual conditions, but also the specific conditions for boiler selection:

• Choose boiler size so that it would be possible to put boiler in the room, given its restrictive size, location of the gas ducts.

• Select the capacity that provides necessary heat for heat supply system after the insulation of building, in order to operate boiler with the highest efficiency as long as possible during the year.

• Provide the necessary scattering of environmentally harmful emissions (nitrogen oxides, sulphur oxides, carbon monoxide, particulate matter) in the atmosphere, due to the position and height of chimney.

• Select boiler with the highest efficiency, changing load to ensure minimal energy resource consumption.

• Choose environmentally and climate-friendly fuel, that is CO2 neutral and in combustion of which a minimal amount of environmentally harmful emissions are formed, and the equipment ensures low vibration and noise levels.

• Select economically viable fuel whose selection is based on the optimal investment, energy prices and boiler plant operation efficiency.

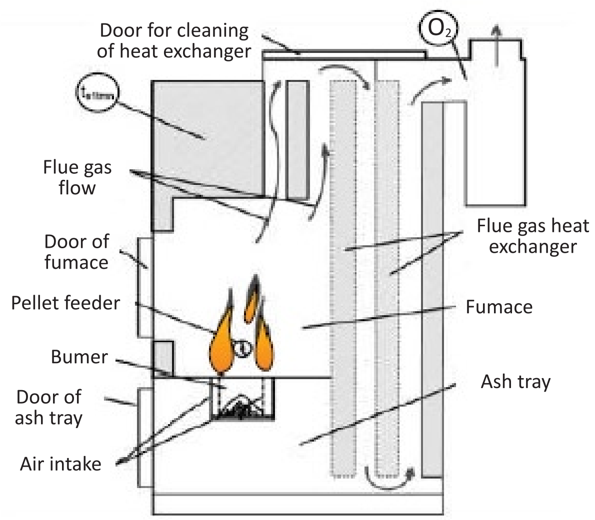

Fig. 3. Principal scheme of pellet boiler

In historical buildings one of the most suitable and promising is pellet boiler, which is compact in design, environment and climate friendly and economically feasible. Principal scheme of pellet boiler is showed in figure 3.

Cogeneration units

In the case of the combined system it is possible to simultaneously produce electricity and heat. The use of combined systems as energy sources of historical buildings is restricted by buildings design and interior decoration, the energy source is just auxiliary equipment, which is necessary to ensure power supply.

Definition. Cogeneration is the primary energy conversion process, where the generation of useful heat and electricity and mechanical energytakes place simultaneously with a plant-specific power relation to heat. Thermal and mechanical energy is produced, for example, using heat engines for drive (pump, compressor, etc.).

Useful thermal energy is the thermal energy produced from cogeneration process, supplied to the consumer to cover its economically justified heat or cold loads. Useful thermal energy is determined at output of cogeneration source, thus excluding the possibility to lower cogeneration efficiency assessments in the case of large networks heat losses. To support the cogeneration plants, additional conditions for energy tariffs are sometimes provided.

The term „economically justified load" means the load not exceeding what is really necessary and, according to market conditions, without the cogeneration it shall be covered with energy generated by another way.

The term „high efficiency cogeneration" means the equipment that meets the following conditions:

• Provides primary energy savings at least 10% compared to separate heat and electricity production;

• Provides primary energy savings in case of low power and micro cogeneration compared to separate heat and electricity production.

The use of cogeneration currently is an essential tool for energy efficiency improvement of energy development; it is rather a complex usage of technologies to meet customers' needs for heating, cooling, electrical or mechanical energy. The advantages of cogeneration as a type of energy production are evaluated in comparison with traditional separate energy development.

Technically, it is possible to produce the energy by cogeneration with lower fuels consumption, and it also means higher energy efficiency. Forms of energy production are compared in Fig. 4.

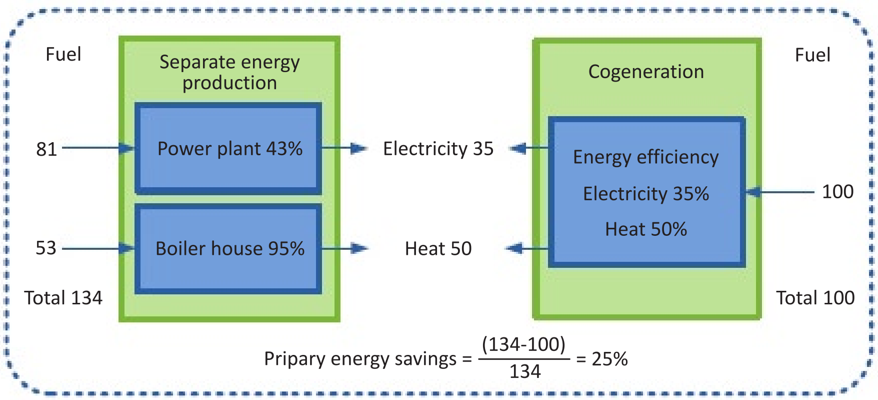

Fig. 4. Comparison of cogeneration and separate energy production

It is seen that the same amount of separate heat and electricity production requires a greater amount of fuel. Energy efficiency indicators for cogeneration of electricity and heat production are under 35% and 50%. They correspond to real values using internal combustion engines. Energy efficiency of separate energy production affects the primary energy savings (because it higher, the smaller savings). Figure 4 discussed the option in which electricity is generated by the power plant with efficiency coefficient of 43% and heat - boiler house with efficiency of 95%. As shown in the Figure 4, in case of cogeneration primary energy savings are 25%. Primary energy (fuel energy) savings is an effective indicator for the comparison of energy development methods. Comparison refers to the two diametrically opposed borderline cases of electricity and heat production necessary for the historic building: two forms of energy are produced in cogeneration and two forms of energy are produced separately.

Principle of operation, range of applications, economic, and environmental parameters for cogeneration technologies varies. In historical buildings only small capacity stations or microcogeneration can be installed.

To select one certain technological solution for the establishment of energy source, it is always necessary to analyze alternative scenarios of equipment.

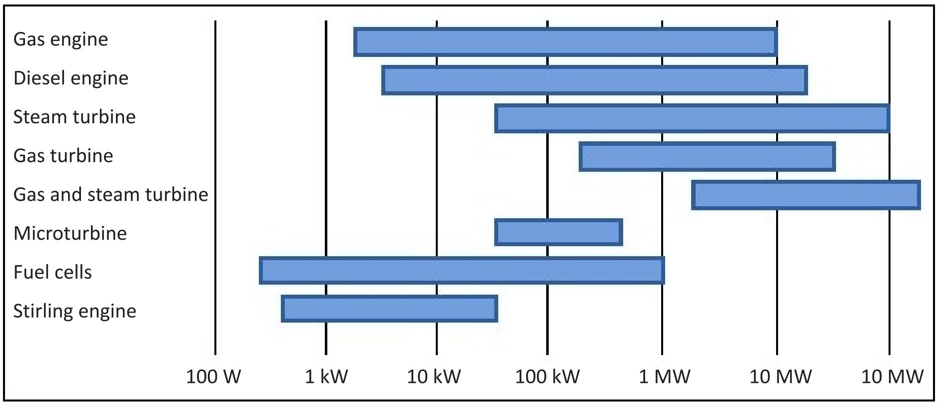

Fig. 5. Capacity usage ranges of cogeneration technology

Cogeneration technology operating ranges are shown in Figure 5. Traditional technologies - internal combustion engines, gas and steam turbines - have offered a wide capacity range. For new technologies - micro-turbines and Stirling engines - it is narrower, but it can be expected that with the development of innovative technologies offered capacity range will increase. Fuel cells equipment has a significant advantage - high power generation efficiency.

Internal combustion engines

Internal combustion engines are the most effective, widely used in low-power nondirectional power plants. They are quickly triggered, reach full capacity in a short period of time, and have relatively low capital cost. These devices are available in a wide power range and have relatively high power generation efficiency and high operation reliability. Thanks to the fast-start engine options, they are widely used as emergency or backup equipment in case of a power outage.

Cogeneration plant combustion engines must be equipped with optional heat recovery devices, so their capital investment is growing. The equipment has a high power generation on the developed thermal unit (ratio of electricity to heat can be in the range from 0.7 to 1.5) The relatively high operating costs, noise and relatively high nitrogen oxide emissions can be mentioned as disadvantages of an internal combustion engine. This can be reduced by changing the combustion process, but then there will be a drop in engine efficiency indicators.

To reduce emissions in flue gases uses tested treatment technology - catalytic converters.

Microturbines

Microturbines expands gas turbine technology offer in low capacity range. These are new technologies that offer capacity in 30-200 kWe range. These technologies are used as a low wattage cogeneration plant to cover electricity loads and the generation of heat in a form of steam or hot water.

One of the characteristics of microturbines is high number of turns. Low combustion temperature results in low nitrogen oxide emissions. The noise level of microturbines is lower than that of the internal combustion engines with a similar power.

Main disadvantages of microturbines are relatively low usage experience and high capital investment in comparison to internal combustion engines. Electricity price increase expands the usage market. A significant reduction in capital investment can be expected due to increasing demand and production. Principle scheme of microturbines is illustrated in Figure 6.

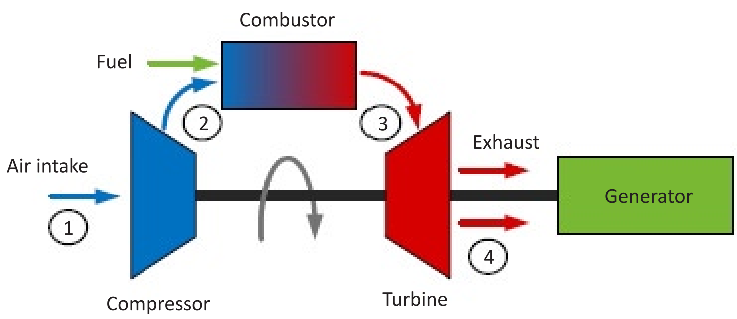

Fig. 6. Biogas microturbine

Fuel cells

Despite the fact that the basic principles of fuel cell were discovered in 1839, the wider use was hampered by relatively high capital costs. Forecasts show that fuel cells can become one of the most common energy transformation facilities of cogeneration plants. Their main advantages are high efficiency, compactness, convenient maintenance and quiet operation.

Since the machine does not have high-temperature combustion processes nitrogen oxide emissions are small. The main disadvantage is the high capital investment.

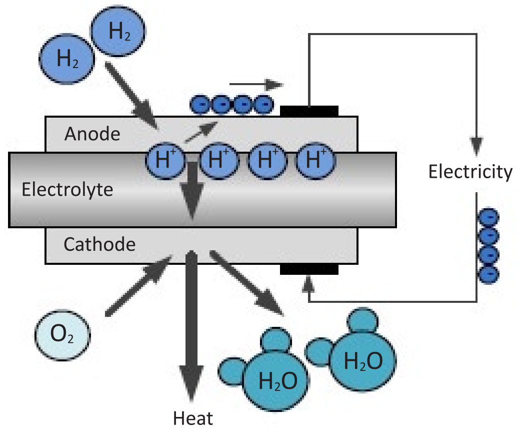

Fig. 7. Principal scheme of the fuel cell

In fuel cells hydrogen and oxygen is used in an electrochemical process to produce electricity, heat, water and carbon dioxide. Therein chemical energy is directly converted into electricity through a reverse electrolysis process. Hydrogen is supplied to the negatively charged anode, at which the hydrogen atom is divided into positively charged protons and negatively charged electrons. Proton continues its way through the electrolyte and on the positively charged cathode connects with the oxygen atoms and electrons to form water molecules. Electricity is directly obtained from the separated electron flow, which cannot move through the electrolyte, but is moving in a roundabout way. Catalysts are used to speed up the electrochemical process. The principle of fuel cells circuit is shown in Figure 7.

Fuel cells that work with a high temperature can be used in cogeneration to produce electricity and heat. Such plants have high efficiency - up to 85%.

Operation of fuel cells requires hydrogen, whose source can be, for example, pure hydrogen produced in other technological process (or biohydrogen). The emissions related to fuel cells are formed during the fuel conversion process.