

Small-Scale CHP Technologies for Buildings

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Abstract: CHP (combined heat and power) is recognised as an established efficient and environmentally friendly technology suitable for the local generation and provision of thermal and electrical energy to the built environment. Small-scale CHP systems, which include micro-CHP systems with electrical capacity less than 5kW and mini-CHP systems with electrical capacity in the range of 5kW to 500kW, can achieve the total energy efficiencies from 75% to as high as 95% as compared to an average of 30-35% for conventional fossil fuel fired electricity generation systems. The most promising targets for the application of CHP systems lie in energy production for buildings. An up-to-date review of the various small-scale CHP technologies suitable for building application is provided in this paper. The properties of relevant technologies are briefly discussed, and the impact of CHP on building energy consumption is presented.

Keywords: small-scale CHP, energy efficiency, building

1. INTRODUCTION

Small combined heat and power systems which simultaneously generate thermal and electrical energy are beginning to emerge as a viable alternative to large and expensive power generating stations. The systems use fuel far more efficiently than separate heat and power based on power remote stations and onsite thermal supply because of heat recovery and onsite generation of electricity characteristics. CHP systems can convert up 95% of the energy in the fuel into electrical power and useful heat. This compares very favourably with conventional power generation which has a delivered energy efficiency of around 30-35%. For a wide range of buildings, CHP can offer an economical method of providing heat and power which is less environmentally harmful than conventional methods. In these buildings, CHP is the single biggest measure for reducing building related carbon dioxide (CO₂) emissions and running costs.

There is a growing potential in the use of CHP systems in residential accommodations, hotels, hospitals, leisure centres and office buildings. Micro-CHP systems typically provide around 5 kW electricity output and 10-15 kW heat for small groups of dwellings and small commercial applications. Mini-CHP systems are most commonly retrofitted to existing building installations with electrical outputs of up to about 500 kW. The CHP systems usually come as packaged units with all components assembled ready for connection to a building's central heating and electrical distribution systems.

2. CHP SYSTEMS

The main components in CHP system contain the engine (prime mover), heat exchanger, electrical generator, system integration connections, exhaust

system and controls. There are numerous small-scale generating technologies that could be used for CHP systems; these technologies use different methods to recover heat. Based on their prime movers, the small-scale power generation technologies most favorable for CHP are reciprocating engines, micro-turbines, Stirling engines and fuel cells.

2.1 Reciprocating engine based CHP systems

There are two primary reciprocating engine designs relevant to building power generation applications – the spark ignition Otto-cycle engines and the compression ignition Diesel-cycle engine. Reciprocating engines can also be classified by the type of fuel they use, natural gas and diesel are common. The primary difference between two cycles is the method of igniting the fuel. Spark ignition engines use a spark plug to ignite a pre-mixed air fuel mixture introduced into the cylinder. Compression ignition engines compress the air introduced into the cylinder to a high pressure, raising its temperature to the auto-ignition temperature of the fuel that is injected at high pressure.

Reciprocating engine is used to drive an electrical generator, usually synchronous, with heat being recovered from the exhaust and cooling systems. The heat from the jacket cooling water can be recovered to provide hot water at up to 95°C. The exhaust heat recovery can be independent of the engine cooling system or coupled with it. For example, hot water from the engine cooling can be used as feed-water or feed-water preheat to the exhaust recovery unit. In a typical heating system, cold return water passes through the engine heat exchanger to cool the engine, then flows into the exhaust heat exchanger to raise its temperature again as shown in Fig. 1.

Energy from fuel is converted into mechanical drive power and heat. The heat is released as engine

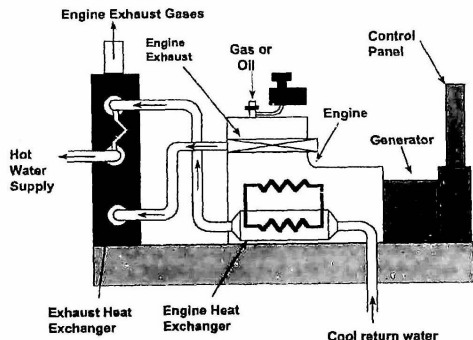


Fig. 1: Reciprocating engine based CHP

cooling jacket heat, which is removed by a fluid loop, and as heat in the combustion exhaust. Approximately 50 to 60 percent of the total input energy is converted to heat that can be recovered from the jacket coolant and engine exhaust. A closed-loop pressurized jacket hot-water cooling system is typically used for capturing engine heat, which accounts for about a third of the input energy. Distribution of energy for a typical reciprocating engine [1] is shown in Fig. 2.

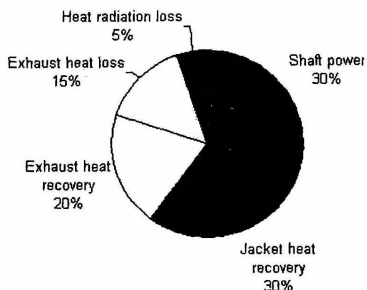


Fig. 2: Energy distribution of a typical engine

2.2 Micro-turbine based CHP systems

Micro-turbines are small gas turbines that burn gaseous and liquid fuels to create a high-energy gas stream that turns an electrical generator. The basic components of a micro-turbine are the compressor, turbine, generator and recuperator. The recuperator is an internal heat recovery heat exchanger to improve electrical efficiency. Micro-turbine system inlet air is compressed by the compressor, and then preheated in the recuperator using heat from the turbine exhaust. Heated air from the recuperator is mixed with fuel in the combustor and burned. The hot combustion gas is then expanded in the turbine, producing rotating mechanical power to drive the compressor and the generator. Afterwards the

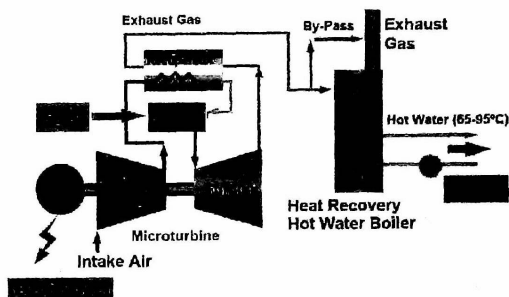


Fig. 3: Micro-turbine based CHP

exhaust gas flows into a second heat recovery heat exchanger-hot water boiler- to heat the hot water.

The exhaust gas of a micro-turbine is in the high temperature range of 450-550°C [2]. The exhaust heat can be recovered and used in a variety of ways, the most common being to generate hot water for water heating or for "drive" thermally powered cycles, such as absorption or adsorption refrigeration systems. The heat in the exhaust gas represents close to 70% of the inlet fuel energy. Fuel energy usage of a typical micro-turbine CHP system [3] is shown in Fig. 4.

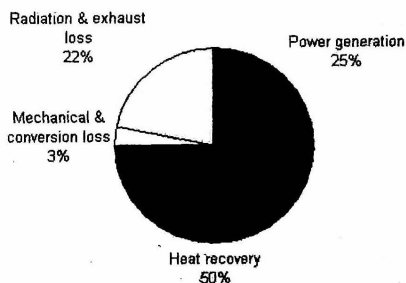


Fig. 4: Energy distribution of a micro-turbine CHP

2.3 Stirling engine based CHP systems

Stirling engine is an external combustion engine. The Stirling engine operates on the basic principle that heated gas expands and cooled gas contracts. This expansion and contraction within a cylinder will force a piston to move in and out, which can be harnessed to a linear alternator to generate electricity. In a simplest free piston mode, piston moves a working gas through hot and cold heat exchangers as shown in Fig. 5. The working gas in the cylinder is cycled back and forth by piston motion, so there is no valve gear and no air or fuel is taken into or out of the cylinder from the atmosphere.

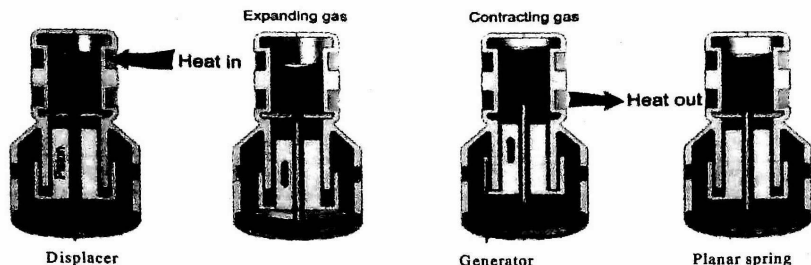


Fig. 5: Stirling engine cycle

Heat needs to be supplied to the hot heat exchanger by a simple external flame. Heat recovers from the cold heat exchanger and the exhaust gas will be used for hot water and central heating. Fuel energy distribution for a typical Stirling engine based CHP system [4] is shown in Fig. 6.

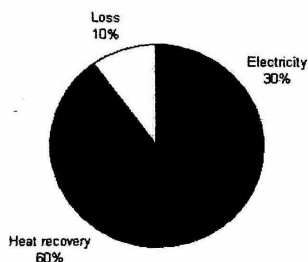


Fig. 6: Energy distribution of a Stirling CHP

2.4 Fuel cell based CHP systems

A fuel cell is an electrochemical device that combines hydrogen fuel and oxygen from the air to produce electricity, heat and water. The fuel cell operates without combustion. In a simplest form, the fuel cell contains two electrodes (anode and cathode) separated by an electrolyte (catalyst) as shown in Fig. 7. The fuel, hydrogen, releases electrons on the anode, which are conducted to the cathode via an

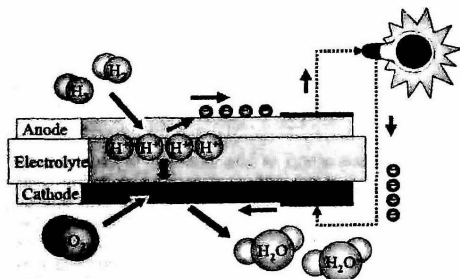


Fig. 7: Schematic layout of fuel cell

external circuit. The hydrogen ions (protons) diffuse directly through the electrolyte material to the cathode, and are then converted into water reduction with the oxygen of the air. Electricity and heat are generated in this electrochemical process.

Two main types of fuel cells being developed for small-scale CHP applications are PEM (proton exchange membrane) and SOFC (solid oxide fuel cells). PEM fuel cell runs at temperature of up to 95°C and its heat can be recovered for hot water and space heating. SOFC unit has the advantage of reforming natural gas into hydrogen without the need for a separate reforming process, reducing the cost and complexity of the unit. Energy distribution of a typical PEM fuel cell CHP system [5] is shown in Fig. 8.

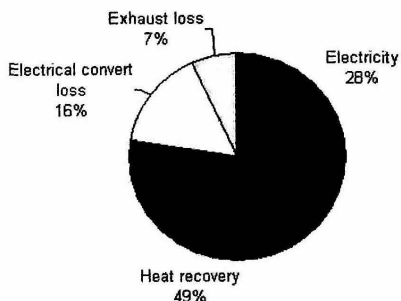


Fig. 8: Energy distribution of a fuel cell CHP

3. CHP SYSTEM TECHNICAL CHARACTERS

Small-scale CHP applications in the buildings offer opportunities in terms of improving energy efficiency and reduction of CO₂ emissions. The technical performances of the above four types CHP systems are summarized in Table 1, the fuel cell is PEM type. Their properties are described in Table 2 for comparison.

4. APPLICATION

A typical semi-detached house in the UK is adopted for CHP system application. The building

Table 1: Technical performances of CHP systems

	Reciprocating engines	Micro-turbines	Stirling engines	Fuel cells
Electrical power (kW)	1-370	25-105	0.6-55	1.0-150
Electrical efficiency (%)	20-40	15.5-30	10-30	25-50
Total efficiency (%)	75-90	75-91	80-95	75-95
Power to heat ratio	0.3-0.7	0.2-0.65	0.15-0.6	0.1-1.25
Grade of heat (°C)	75-105	60-85	60-80	60-80
Fuel	Natural gas LPG Diesel propane	Natural gas, LPG, Propane, Butane, Kerosene and biogas	Natural gas Liquid gas	Hydrogen Natural gas LPG
Maintenance interval (hr)	3500-20000	6000-30000	5000	

Table 2: CHP system properties

CHP system	Advantages	Disadvantages
Reciprocating Engines	•High power efficiency with part load operation •Good load following capability •Low capital cost (investment) •Proven reliability •Fast start-up •Significant heat recovery (exhaust & cooling jacket)	•High maintenance cost •High emissions (Diesel/compression ignition type) •High levels of low frequency noise.
Microturbines	•High reliability •Low emissions •Compact size and light weight •Low maintenance •Quick start •Low noise	•High costs •Difficulty in following large load transients •Performance sensitive to the inlet air condition
Stirling Engines	•High thermodynamic efficiency •Low emissions •Low noise •Low maintenance costs •Robust	•Low load following capability •Complexity of the motion •Limit speed •Low electrical efficiency
Fuel cells	•High efficiency over load range •Low emissions •Low noise •Modular design	•High costs •Slow startup (especially for high temperature cells) •Poor load following capability •Fuels requiring processing (unless pure hydrogen is used)

heating and power requirements are shown in Fig. 9. If the heat and electricity are supplied separately by boiler with 78% heating efficiency and conventional power generation with the electrical efficiency 33%, the total energy consumption of this building is 39681 kWh per year. If a Stirling engine based micro-CHP module, SOLO Stirling 161 with electrical efficiency 24% and heating efficiency 68% [6], is used to provide power and heat for the building, the total energy consumption is 24814 kWh per year. The

energy consumption of the building is obtained by consideration of the energy consumption of the CHP system and the interaction with the grid. The energy consumption of the CHP system is calculated on the basis of the building heating load, and there is electricity import or export between the building and the grid. The building monthly energy usages are displayed in Fig. 10 for both systems. The building energy consumption can be decreased by 37.5% with the CHP system.

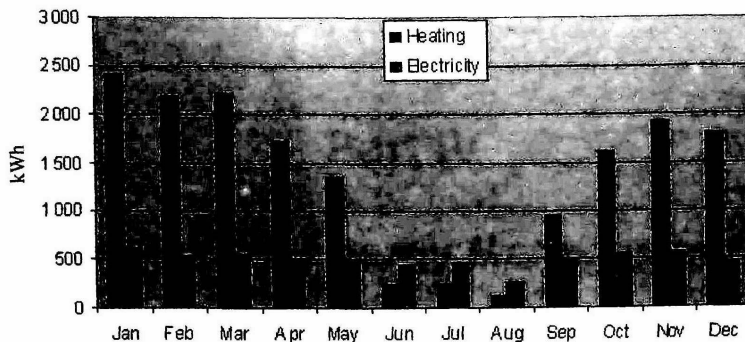


Fig. 9: Building heating and electricity requirements

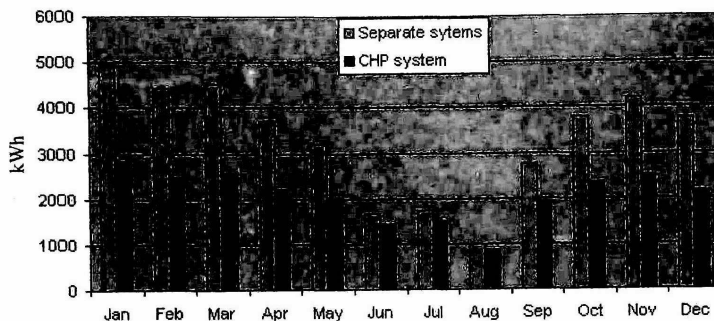


Fig. 10: Building energy consumption

5. CONCLUSION

Small-scale CHP systems for building application are presented in this paper, their technical characters and system performances are discussed. A practice application of the CHP system in building is studied and the result showed 37.5% energy can be saved with the CHP system for a semi-detached house in the UK.

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