THE EUROPEAN
GREEN BUILDING PROGRAMME

Technical Module on
Combined Heat and Power

Contents

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Foreword

The GreenBuilding Programme is a European Commission voluntary programme through which non-residential building owners and occupiers private and public organisations are aided in improving the energy efficiency and to introduce renewable energy sources in their building stock. Any enterprise, company or organisation (hereinafter defined as “organisation”) planning to contribute to the GreenBuilding Programme objectives can participate.

By becoming a GreenBuilding Partner, your company can demonstrate its commitment to significantly reduce the energy consumption in its non-residential buildings which are participating in this effort.

This document is subsidiary to the GreenBuilding "Partner Guidelines". It defines what a GreenBuilding Partner Action Plan should cover, if the Partner company's commitment includes a CHP system. In particular, it explains what a Partner does for each of the following steps:

- **Inventory** of *CHP* components and system functioning
- **Assessment** of the applicability of possible energy savings measures
- **Action Plan**, which defines what the Partner has decided to do to reduce operating costs by improving energy efficiency
- **Report** of progress on the Action Plan.

Note that documents relating to the Inventory and the Assessment are in house, confidential documents, while the Action Plan and the Report are reported to GreenBuilding.

In the following, you may find assistance for your process of assessing and realising the energy efficiency potentials of Combined Heat and Power (CHP) in your building(s).

1. Introduction

A cogeneration system also known as Combined Heat and Power (CHP) system is an energy production system that simultaneously generates thermal energy and electrical and/or mechanical energy from a single input of fuel.

The use of high-efficient cogeneration based on a useful heat demand can potentially help to save primary energy, avoid network losses and reduce emissions, in particular of greenhouse gases. In addition, efficient use of energy by cogeneration can also contribute positively to the security of energy supply.

The cogenerated heat can also be used to produce cooling through absorption refrigeration chillers. This type of systems that simultaneously produce electricity, heat and cooling are known as trigeneration systems. Trigeneration units offer significant relief to electricity networks during the hot summer months. Cooling loads are transferred from electricity to gas networks. This increases the stability of the electricity networks specially in Southern European countries since summer peaks are served by utility companies through inefficient stand-by units and overloaded electricity transmission lines.

The successful installation of CHP leads to a reduction of fuel consumption by approximately 10 - 25% compared with conventional electricity and separate heat production. The reduction of atmospheric pollution follows the same proportion.

Member States operate different support mechanisms for cogeneration at the national level, including investment aid, tax exemptions or reductions, green certificates and direct price support schemes.

One the other hand the new Directive 2002/91/EC on the energy performance of buildings requires the Member States to ensure that for new buildings with a total useful floor area of over 1000 m^2, the technical, environmental and economic feasibility of alternative systems, such as cogeneration of heat and power, is considered and taken into account before construction starts. Also existing buildings of this size undergoing major renovation will have to upgrade their energy performance. Transposition of this directive to the member States legislation should be made not later than 21 February 2006.

2. Inventory of the CHP system

The inventory of the CHP system can help the auditor to describe the existing energy supply system/structure in a systematic way. For new buildings it will help the user to identify the potential components that can be part of the new cogeneration system. A template for an Audit form is included in the Annex.

Basic System Description

CHP systems can be implemented in energy supply systems of any size. The definition of “small scale cogeneration” comprises, micro-cogeneration and distributed cogeneration units such as cogeneration units supplying isolated areas or limited residential, commercial or industrial demands with an installed capacity below 1 MWe. For a micro-cogeneration unit it is understood a cogeneration unit with a maximum capacity bellow 50 kWe.

The relevant cogeneration technologies that can be found in energy supply systems for buildings are:

Technology	Power range	Electric efficiency	Global efficiency	Comments
Gas turbine with heat recovery	500 kWe - > 100 MWe	32 – 45 %	65 – 90 %	Mainly for high temperature heat recovery
Internal combustion engine	20 kWe – 15 MWe	35 – 45 %	65 – 90 %	Engines of smaller capacity also available
Micro gas turbines	30 – 250 kWe	25 – 32 %	75 – 85 %	Some commercial models
Stirling engines	1 – 100 kWe	12 – 20 %	60 – 80 %	Still in development
Fuel Cells	1 kWe – 1 MWe	30 – 65 %	80 – 90 %	Very few commercial models

Also it is important to know the type and characteristics of existing Heating, ventilation and air conditioning related systems: boilers, heat pumps, electric chillers, cooling towers, air condensers, etc.

In the case of a refurbishment of an existing conventional energy system, the old system could be used as a back-up power for the new CHP system.

Measurement of parameters

The sample data to be collected regarding operation of the CHP system is:

- Boiler capacity and efficiency: Supply and return temperatures and hot water flow rate or directly heat supplied using heat meters.
- Fuel consumption (flow rate counter or meter) on a monthly basis and hourly for a typical day (usually a summer and winter day).
- Electric power consumption profile in hourly or monthly basis
- Heat pump or chiller capacity and efficiency: Supply and return temperatures and water flow rate. Power consumption or heat consumption if it is a compression or absorption system, respectively.
- Cooling tower parameters: web bulb temperature, supply and return cooling water temperatures and water flow rate.

System performance indicators

To assess the implementation of a CHP system it is necessary to calculate some energy related indicators, for the entire installation and the systems/components under examination.

Cogeneration efficiency is defined by the primary energy savings obtained by combined production instead of separate production of heat and power. Usually cogeneration systems are sized to cover the on-site thermal demand. If an excess of electricity exists it is exported to the grid or imported from it if the electricity demand is higher than the cogenerated electricity produced. The useful heat (Q_{cg}) is the heat produced in a cogeneration process to satisfy an economically justifiable demand for heating or cooling. The calculation of electricity from cogeneration (E_{cg}) can be made based on the power to heat ratio (*PHR*), that is, the ratio between electricity and useful heat from cogeneration.

$$E_{cg} = PHR \cdot Q_{cg}$$

Type of unit	**Default power to heat ratio, PHR**
Combined cycle gas turbine with heat recovery	0.95
Steam backpressure turbine	0.45
Steam condensing extraction turbine	0.45
Gas turbine with heat recovery	0.55
Internal combustion engine	0.75

The electric efficiency (η_{cg}) is the electricity cogenerated divided by the fuel input (H_f). The fuel input should be calculated on the basis of the “lower calorific values” of fuels (*LHV*):

$$\eta_{cg} = \frac{E_{cg}}{H_f} = \frac{E_{cg}}{m_f \cdot LHV}$$

where m_f is the fuel flow rate. Thermal efficiency (η_q) is the useful heat recovered divided by the fuel input:

$$\eta_q = \frac{Q_{cg}}{H_f} = \frac{Q_{cg}}{m_f \cdot LHV}$$

The overall efficiency (η_q) is the annual sum of electricity production and useful heat output divided by the fuel input used:

$$\eta_g = \frac{E_{cg} + Q_{cg}}{H_f} = \frac{E_{cg} + Q_{cg}}{m_f \cdot LHV}$$

Calculation of primary energy savings (*PES*) due to the implementation of a CHP system can be obtained using the following expression:

$$PES = E_{cg} \cdot \left(\frac{1}{\eta_e} + \frac{1}{PHR \cdot \eta_b} - \frac{1}{\eta_{cg}} \right)$$

where η_e is the electricity grid efficiency and η_b is the efficiency of the conventional boiler considered.

3. Assessment of technical energy saving measures

Further energy savings in cogeneration can be obtained with the integration of the following technologies:

Trigeneration systems

Such systems are very good candidates mainly for tertiary sector installations. They employ absorption chillers to make use of waste heat from the CHP system when there is a low demand for heating and/or domestic hot water. Absorption chillers are driven by heat instead of electricity like the more conventional vapour compression systems. They use natural refrigerants, have a low decrease of performance at part load, very low electricity consumption, low noise and vibration and very few moving parts. As the capital cost for absorption chillers is higher than that of compression systems, a complete viability analysis should be performed. In addition, chiller-heaters, which use absorption technology to provide cooling, heating, or both cooling and heating as required, are available. Adsorption chillers are another option to use waste heat to produce chilled water. In adsorption chillers the adsorbent is a solid not a liquid as in absorption systems. The main advantage of adsorption chillers is their lower driving temperature although they have some limitations such as a much more limited number of commercial units available.

Poligeneration systems with integration of renewable energy sources

Energy integrated systems can involve the energy integration of different elements: electric generator, heat recovery system, chillers, desiccants, solar energy, etc to simultaneous produce electricity, heat, cold and air conditioning with a high internal energy recovery. An integrated system permits low fuel consumption and a lower emissions level compared with the non-integrated energy systems.

Thermal Energy Storage (TES)

The use of cooling and/or heating storage also known as Thermal Energy Storage (TES) technologies can help to reduce energy costs. For example chilled water can be generated at off-peak hours (when utility demand and rates are lowest) and used at peak cooling periods to supplement or replace chilled water from the electric driven chiller. Also lower outdoor temperatures allow the chiller to reject heat more efficiently. Additionally a smaller capacity chiller system can be selected. The cost effectiveness of cool-storage systems varies considerably depending on the specific application.

4. Action Plan

This section intends to help you to establish an action plan to study carefully the proposed actions, set a timetable to implement the actions and estimate the expected savings. A template for an Action Plan form is included in the Annex.

The action plant is to be used as a starting point to study the technical and economical viability of a new cogeneration system or to improve the performance of an existing one. It comprises the following four stages.

Energy audit (for new and existing cogeneration systems)

An energy audit is a systematic gathering and analysis of energy use information and can be used to determine energy efficiency improvements of a building, plant/equipment or a specific process. The energy audit can include the following parts:

a) Collect basic information and description of the existing energy supply and demand system. The sources of information for this task can be the technical documents of the plant, walkthrough inspection, information on the equipment plates, etc.
b) Collect information on the operating conditions, such as, pressures, temperatures, operating hours and schedule, type and characteristics of the connection to the electric and gas grid, etc.
c) Determine all energy savings measures not related to CHP and their effect on the energy consumption.
d) Prepare the building's electricity, heating and cooling load profile as accurate as possible using counters, electricity and fuel bills, etc.
e) Calculate the actual energy supply unit prices and other energy related costs.

Selection of measures to be implemented

Equipment selection and sizing (for new cogeneration systems only)

The selection and sizing of equipment should be made using the following criteria: performance, capacity and spatial requirements, first cost, operating cost, reliability, flexibility and maintainability.

More than one cogeneration system configuration can supply the building required energy. Thus it is required to generate different energy supply alternatives based on different technologies and number of units to finally select one by the procedure indicated bellow.

For the cogeneration sizing the calculation of the demand cumulative curves can be of help.

For the sizing of absorption cooling for a trigeneration plant the general basic steps are:

- Quantify your cooling demands
- Reduce the electrical demand (determined previously by the audit) to allow for cooling from absorption chillers
- Convert the cooling demand to heat
- Quantify the other site heat demands
- Calculate the new heat demand
- Establish the type of CHP unit that is likely to be appropriate
- Establish the operational strategy (export or import electricity to the grid, supplementary heating, etc). If it is necessary modify the selected configuration

Upgrade of existing on-site energy systems (for existing cogeneration systems only)

The energy audit will reveal the possibilities for the efficiency improvement of the existing cogeneration equipment. The following aspects can be checked:

- Obsolescence of part or the total energy supply system
- Reduction of the operation time at part load
- Integration of new control systems and strategies
- Use thermally activated cooling technologies (trigeneration) to reduce the electric demand and at the same time increase the recovery of useful heat.
- Use of some kind of thermal storage systems (hot and cold water)

Evaluation of alternatives (for new and existing cogeneration systems)

Perform the complete energy balance (exported / imported energy, auxiliary energy required, fuel consumption, etc.) for each alternative identified in the previous stage 2 (selection of measures to be implemented). For this task a template format to calculate the energy balance for each considered alternative is given in the annex.

Calculate the economic performance and investment parameters (NPV, Payback period, etc) for each alternative

Implementation of the best alternative

The best alternative from the technical, economic and socio-economic point of view should be selected according to the obtained specific site results and conditions considered in the previous steps of the action plan and define a timetable to carry out the project.

5. Reporting

This section provides you assistance to periodically report to the Commission on the improvements undertaken and the degree of completion and maybe on what is planned for the future. It is important to know the effect of improvements on energy consumption/ indicators, as well as the resulting money savings.

The report should include the following:

a) Description of the original energy supply system for existing buildings or the base case for the separate production of electricity and heat in the case of a new building.
b) Energy and economic performance of the original energy supply system for existing buildings or the base case for the separate production of electricity and heat in the case of a new building.
c) Energy and economic performance after the implementation of the new cogeneration system or of the new components or changes introduced in the existing cogeneration system.
d) Summary of energy and economic improvement comparing the previous points 2 and 3.

A template for a Reporting form is included in the Annex.

Annex

TABLES FOR AUDIT

Description of the existing energy supply facilities

Electricity
Type of supply: Grid locally generated both grid and local
Brief technical description of the electricity supply system (type of interconnection equipment, voltage, etc)
Unitary price of electricity (electricity imported and exported to the grid)
Fuel
Brief technical description of type(s) of fuel used (type, low calorific value, ...)
Unitary cost of fuel
Heat
Brief technical description of the heating supply system (type of equipment, temperatures, etc)
Domestic Hot Water (DHW)
Brief technical description of the DHW supply system
Cooling
Brief technical description of the cooling supply system
Block diagram of the energy supply system

Electricity from the grid (kWh or MWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
0–2												
2–4												
4–6												
6–8												
8–10												
10–12												
12-14												
14–16												
16–18												
18–20												
20–22												
22–24												
Total												

Electricity from cogeneration (kWh or MWh)

Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec

Non cogenerated Heat (kWh or MWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
0–2												
2–4												
4–6												
6–8												
8–10												
10–12												
12-14												
14–16												
16–18												
18–20												
20–22												
22–24												
Total												

Heat from cogeneration (kWh or MWh)

Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec

Cooling from non cogenerated heat (kWh or MWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
0–2												
2–4												
4–6												
6–8												
8–10												
10–12												
12-14												
14–16												
16–18												
18–20												
20–22												
22–24												
Total												

Cooling from cogenerated heat (kWh or MWh)

Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec

	Fuel for Cogeneration	**Fuel for other energy supply systems**
	KWh or MWh	**KWh or MWh**
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		
TOTAL		

Summary of operating economic costs (euros/unit of time)

	Electricity[1]	**Fuel for cogeneration**	**Fuel for other energy supply systems**
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
TOTAL			

[1] In the case of an existing cogeneration plant it can be positive or negative depending on the relative amount of electricity imported or exported to the grid.

Template for Action Plan

Energy Audit
Summary of results
Description of measures considered[1]
Measure No. 1
Description
Reason for being selected or rejected
Measure No. 2
Description
Reason for being selected or rejected
Measure No. 3
Description
Reason for being selected or rejected
Detailed description of the selected measure
Working plan and time table for implementation of the selected measure

[1] Add as many action measures as required.

Templates for Reporting

Template for the description of the original energy supply system for existing buildings or the base case for comparison for the separate production of electricity and heat in the case of a new building.

Electricity
Type of supply: Grid locally generated both grid and local
Brief technical description of the electricity supply system (type of interconnection equipment, voltage, etc)
Unitary price of electricity (electricity imported and exported to the grid)
Fuel
Brief technical description of type(s) of fuel used (type, low calorific value, ...)
Unitary cost of fuel
Heat
Brief technical description of the heating supply system (type of equipment, temperatures, etc)
Domestic Hot Water (DHW)
Brief technical description of the DHW supply system
Cooling
Brief technical description of the cooling supply system
Block diagram of the energy supply system

Template for the description of the new energy supply system

Electricity
Type of supply: locally generated both grid and local
Brief technical description of the electricity supply system (type of prime mover, type of interconnection with the grid, voltage, etc)
Unitary price of electricity (electricity imported and exported to the grid)
Fuel
Brief technical description of type(s) of fuel used (type, low calorific value, ...)
Unitary cost of fuel
Heat
Brief technical description of the waste heat recovery system and auxiliary heat supply system if it exists (type of equipment, temperatures, etc)
Domestic Hot Water (DHW)
Brief technical description of the DHW supply system
Cooling
Brief technical description of the cooling supply system
Block diagram of the new energy supply system

Template for the description of the energy performance of the energy supply system

	Previous to the action (KWh or MWh per year)	After implementation of the action (KWh or MWh per year)
Electricity		
Electricity cogenerated		
Electricity from the grid		
Total electricity demand		
Heat		
Heat cogenerated		
Heat from other sources		
Total Heat demand		
Domestic Hot Water		
DHW from cogenerated heat		
DHW from other sources		
Total DHW demand		
Cooling		
Cooling from cogenerated heat		
Cooling from other sources		
Total cooling demand		
Fuel		
Fuel consumption in CHP		
Fuel consumption from other systems		
Total fuel consumption		

Template for the description of the economic performance of the energy supply system

	Previous to the action (€/year)	After implementation of the action (€/year)
Operation costs		
Cost of electricity		
Cost of fuel		
Other operation costs		
TOTAL		
Investment costs		
Equipment 1		
...		
...		
TOTAL		
Operation and maintenance costs		
...		
...		
TOTAL		
Other costs		
...		
TOTAL		

Economic annual saving	**€/year**
Payback Period	**years**
Net Present Value	**€**

References

An Introduction to Absorption Cooling, Good Practice Guide 256, ETSU, U.K., 1999

Gives a comprehensive look at all issues related to absoprtion cooling, including the benefits that using CHP provides.

Less is More. Energy Efficient Buildings with Less Installations. Thermie Programme Action NºB097

EU project on rational use of energy in Buildings.

The Operation and Maintenance of Small-scale Combined Heat and Power. Good Practice Guide 226, ETSU, U.K., 1998.

Intended to help users and potential users of small-scale CHP, i.e. less than 1 MW_e generating capacity, establish and manage the most appropriate O&M arrangement for their site.

DIRECTIVE 2004/8/EC of the European Parliament and of the Council of 11 february 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

Educogen - An educational tool for cogeneration, second edition (2001)

The key document of the Educogen project. Comprehensive explanation of cogeneration principles, technologies, applications, economies, etc. on 176 pages

Links

the Green Building Council of Australia	http://www.gbcaus.org/
TriGeMed project (Promotion of Tri-generation Technologies in the Tertiary Sector in Mediterranean Countries).	http://www.trigemed.com/