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RICERCA SISTEMA ELETTRICO

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A Report of Subtask C of FC+COGEN-SIM - Annex 42 of the International Energy Agency Energy Conservation in Buildings and Community Systems Programme

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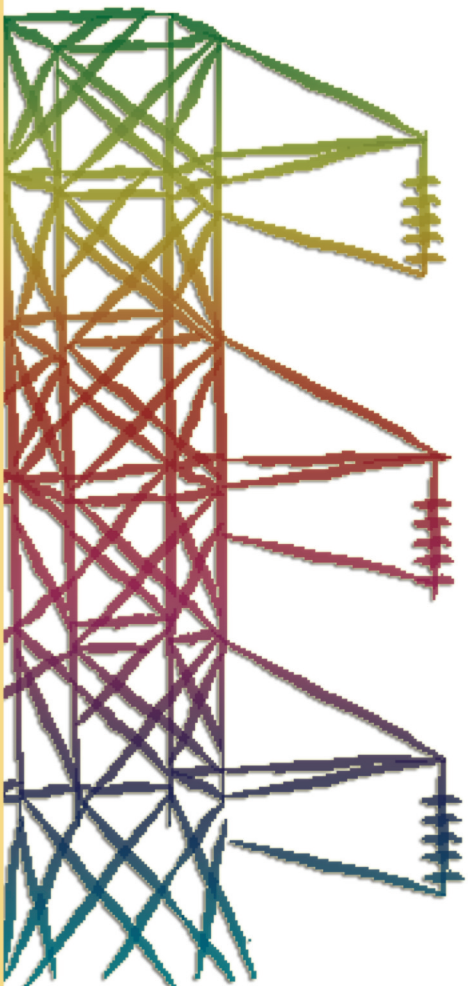

Report RSE/2009/3

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Biagio Di Pietra (ENEA)

Settembre 2007

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Responsabile Tema: Marco Citterio, ENEA

Performance Assessment of Residential Cogeneration Systems in different Italian climatic zones

A Report of Subtask C of
FC+COGEN-SIM
The Simulation of Building-Integrated
Fuel Cell and Other Cogeneration Systems

Annex 42 of the
International Energy Agency
Energy Conservation in Buildings and Community Systems Programme
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Copies of this report may be obtained from the Annex 42 web site at: www.cogen-sim.net or from the IEA/ECBCS Bookshop at: www.ecbcs.org.

DISCLAIMER

Participating countries in ECBCS:
Australia, Belgium, CEC, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden, Switzerland, Turkey, United Kingdom and the United States of America.

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D programme are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)

Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing
Annex 39: High Performance Insulation Systems
Annex 40: Building Commissioning to Improve Energy Performance
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning
Annex 49: Low Exergy Systems for High Performance Buildings and Communities
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

(*) - Completed

Annex 42

The objectives of Annex 42 were to develop simulation models that advance the design, operation, and analysis of residential cogeneration systems, and to apply these models to assess the technical, environmental, and economic performance of the technologies. This was accomplished by developing and incorporating models of cogeneration devices and associated plant components within existing whole-building simulation programs. Emphasis was placed upon fuel cell cogeneration systems and the Annex considered technologies suitable for use in new and existing single and low-rise-multi-family residential buildings. The models were developed at a time resolution that is appropriate for whole-building simulation.

To accomplish these objectives Annex 42 conducted research and development in the framework of the following three Subtasks:

- Subtask A : Cogeneration system characterization and characterization of occupant-driven electrical and domestic hot water usage patterns.
- Subtask B : Development, implementation, and validation of cogeneration system models.
- Subtask C : Technical, environmental, and economic assessment of selected cogeneration applications, recommendations for cogeneration application.

Annex 42 was an international joint effort conducted by 26 organizations in 10 countries:

Belgium	▪ University of Liège / Department of Electrical Engineering and Computer Science ▪ COGEN Europe ▪ Catholic University of Leuven
Canada	▪ Natural Resources Canada / CANMET Energy Technology Centre ▪ University of Victoria / Department of Mechanical Engineering ▪ National Research Council / Institute for Research in Construction ▪ Hydro-Québec / Energy Technology Laboratory (LTE)
Finland	▪ Technical Research Centre of Finland (VTT) / Building and Transport
Germany	▪ Research Institute for Energy Economy (FfE)
Italy	▪ National Agency for New Technology, Energy and the Environment (ENEA) ▪ University of Sannio ▪ Second University of Napoli
Netherlands	▪ Energy Research Centre Netherlands (ECN) / Renewable Energy in the Built Environment
Norway	▪ Norwegian Building Research Institute (NBRI) ▪ Telemark University College
United Kingdom	▪ University of Strathclyde / Energy Systems Research Unit (ESRU) ▪ Cardiff University / Welsh School of Architecture
United States	▪ Penn State University / Energy Institute

of America	▪ Texas A&M University / Department of Architecture ▪ National Institute of Standards and Technology ▪ National Renewable Energy Laboratory ▪ National Fuel Cell Research Center of the University of California-Irvine
Switzerland	▪ Swiss Federal Laboratories for Materials Testing and Research (EMPA) / Building Technologies Laboratory ▪ Swiss Federal Institute of Technology (EPFL)/ Laboratory for Industrial Energy Systems ▪ Hexis AG (Hexis) ▪ Siemens Switzerland AG (Siemens)

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This report of Subtask C of Annex 42 was reviewed by:

- Viktor Dorer (Empa, Swiss Federal Laboratories for Materials Testing and Research)
- Leen Peters (University of Leuven, Belgium)
- Peter Schild, SINTEF, Norway

ExCo reviewer :

- Marco Citterio: National Agency for New Technology, Energy and the Environment (ENEA-Italy)

The assistance of the other participants of Annex 42 in producing this report is also gratefully acknowledged.

Viktor Dorer
Subtask C Leader

CONTENT

SUMMARY

This report documents the potential assessment for residential cogeneration in Italy, conducted with the micro cogeneration device model developed within IEA/ECBCS Annex 42.

The aim of the study is the energy, environmental and economic performance assessment of an internal combustion engine as micro cogeneration device for a significant sample of the Italian residential building stock according to different climate zones, and to compare the cogeneration system with traditional energy supply systems for residential buildings.

The performance of the cogeneration plant was analysed by computer simulations and evaluated in terms of the Annex 42 selected criteria: primary energy demand, CO_2 emissions and cost. The TRNSYS tool was used for the building and cogeneration plant simulation.

Typical electricity demand load profiles for multi family houses and occupant types are considered in regard to geographic allocation of each simulated building. The DHW profiles for multi family house simulated have been produced directly using IEA Task 26 profiles.

In order to complement the potential assessment for the cogeneration plant, new buildings with better insulation according to Italian national code were also analyzed.

Results of performance assessment study for climatic zone C show some differences about primary energy saving and CO_2 emissions compared to Annex 42 study of UniSannio for same Italian climatic zone. The different are due to:

- Different electric mix power plan adopted
- Different proposed systems: in ENEA study have been considered a different cogenerator that has different performance (electric efficiency and thermal efficiency) in comparison with the cogenerator considered by UniSannio

1. INTRODUCTION

Motivation

The reduction of greenhouse gas emissions in the building sector to a sustainable level will require tremendous efforts to increase both energy efficiency and the share of renewable energies. Apart from the lowering of energy demand by better insulation and fenestration, small combined heat and power systems (micro cogeneration) may help improve the situation on the supply side by cutting both the non-renewable energy demand for residential buildings and peak loads in the electric grid.

Purpose and objectives of sub task C

The general purpose of this ST C is to analyze the performance of selected cases in terms of energy, emissions, technical and economic criteria. Based on the results, the aim is to identify critical issues in the context of cogen technologies and to show the influence of major building, occupant and system parameters on the performance of fuel cell and other micro cogeneration devices.

The interaction of the cogen device with the other components of the cogeneration systems (e.g. hot water storage), and with other energy supply components such as heat pumps or with solar renewable energy systems (solar thermal collector, photovoltaic system), are to be analyzed by computer simulations and evaluated in terms of the selected criteria, such as primary energy demand and CO_2 emissions. Typical heat and electricity demand load profiles for different types of residential buildings and occupant types are considered, and compared with reference systems comprising traditional energy supply systems.

Based on these results, optimal cogeneration systems, storage configurations and control strategies are investigated and standard configurations for typical buildings and climates are developed. In short, the objectives of the performance assessment task are to:

- set up a generic framework for residential cogeneration evaluation
- demonstrate application potential of models and building simulation tools developed
- quantify the performance of selected cogen systems in terms of energy, emissions and costs, compared to conventional systems
- determine and show sensitivities and identify most influencing and thus most relevant parameters
- compare control strategies and methods
- document the successful elements of individual cogen configurations
- identify promising application fields for cogen systems
- gives examples of optimizing and sizing components and systems

Topics and aim of the ENEA study

The aim of this study is to evaluate the applicability and the potential of an internal combustion engine in a micro cogeneration application in terms of energy saving, emissions and costs reduction, and to compare it to conventional systems for a significant sample of Italian residential building stock.

The focus topics in this study are:

- evaluation in different Italian climate zones of benefits of using internal combustion engine in residential application including performance criteria;
- performance assessment simulation of internal combustion engine (ICE) for different types of Italian multi family house and for different heat and electrical load profiles accordingly to different climate zones,
- comparison with traditional building energy feeding: Italian electricity mix with an average global efficiency and traditional heating systems (natural gas heater),
- demonstration of application potential of models and building simulation tool developed.

Simulation tool and specific models used in the ENEA study

Values for energy demands have been produced by building simulation analysis. By mean of simulation of building integrated generation systems, the amounts of primary and thermal and electric energy delivered to the building have been determined.

For the building and cogeneration plant simulation, the TRNSYS tool (see appendix) was used.

The internal combustion engine was modelled using the IEA Annex 42 model, adapted as Type 154 to TRNSYS. (see appendix).

Buildings were modelled using the multi-zone building model Type 56, in order to estimate winter thermal loads and trend of temperatures inside the building.

Terminology

Term	Description
Case:	A specific installation with its data set in terms of environment, building, demand profiles and cogeneration system. A case may consist of several configurations.
Configuration:	A specific data set for an individual case in terms of cogen system and of components size/dimensions, and of the control strategy and algorithms used.
Cogeneration (cogen):	Combined generation of heat and electricity
Cogeneration device (cogen unit)	The cogeneration plant or appliance, as provided by the manufacturer
Cogeneration system	The system providing heat and electricity. This includes the cogeneration

Term	Description
(cogen system)	device and further components such as storage, external pumps, auxiliary heater, and other supply components such as solar collector, heat pump etc.
Criterion (objective)	Parameter used as a measure for the assessment of the performance of the system analyzed. In optimizations, the optimized parameter(s) is named objective.
Performance assessment (PA)	Assessment of the performance of the system under investigation in regard to the selected performance criteria, by simulation.

Abbreviations and indices

Abbr./index	Description
Bsim	Building Simulation (with the building and system simulation tools used within A42)
Build	Building
CGU	Cogeneration device (cogen unit)
CHP	Combined heat and power (= cogeneration)
DHW	Domestic hot water
DD	Degree Day
El	Electric, electricity
El-Back	Electricity exported to the grid
El-Grid	Electricity supplied from the grid
El-NetGrid	Net amount of electricity exported to grid or delivered from grid
ERFA	Energy reference floor area
Fuel	Delivered fuel
GB	Gas boiler, gas boiler system
ICE	Internal combustion engine
LHV	Lower heating value
MFH	Multi-family house
NG	Natural gas
NRPE	Non-renewable primary energy
PA	Performance assessment
SH	Space heating
Th	Thermal
UCTE	Union pour la Coordination de la Production et du Transport de l’Electricité, Luxembourg

Energy terms

All energies are based on LHV.

1	Energy demand:	Energy needed to fulfil the user's requirements for space heating, for domestic hot water, for ventilation, and for electric lighting and appliances.
2	Non-HVAC:	Energy part of the energy demand that is provided by "natural" (passive) energy gains (passive solar, natural ventilation, natural ventilation cooling, internal gains,etc.). Losses from the heat distribution system and from the HVAC system (incl. cogen system) may contribute as internal gains.
3	Net energy:	Part of the energy demand which is provided by the HVAC system to cover the energy demand for space heating, domestic hot water and electricity respectively.
4	Delivered energy	Energy, represented separately for each energy carrier (fuel, electricity, heat, incl. auxiliary energy), that is entering the individual building envelope (the system boundary) in order to be used by the heating, hot water, lighting systems and appliances. This is expressed in energy units or in units of the energy ware (kg, m^3, kWh, etc.).
5	Exported energy	Energy (electricity) generated on the premises and exported to the market.
6	Primary energy	Represents the energy usage associated to the delivered energy which is embodied in natural resources (e.g. natural gas)
7	Primary (exported) energy	Represents the primary energy associated with exported energy, which is subtracted from (7) to calculate the (net) primary energy use

Symbols for energy parameters and related factors

Parameters starting with a capital letter refer to amounts of energy, parameters starting in lower case represent energy mounts per reference area.
Energy values are based on LHV.

Symbols	Description	Unit
DE	Delivered energy (No 4)	MJ
NE	Net energy (No 3)	MJ
PE	Primary energy (No 7)	MJ
XE	Exported energy (No 6)	MJ
pef	Primary energy factor (ratio of primary energy to delivered energy)	-
η	Energy performance factor of system: ratio net energy output to consumed delivered energies (ηDE) or to the primary energies respectively (ηPE)	

Indices

DE	Delivered energy
DHW	Domestic hot water
El	Electricity
El-Grid	Electricity from grid
El-Back	Electricity delivered back into the grid
El-NetGrid	Net amount of electricity exported to grid or delivered from grid
El-CGU	Electric energy output of cogen unit
Fuel	Fuel
NRPE	Non-renewable primary energy
NG	Natural gas from grid
PE	Primary energy
SH	Space heating
Th	Thermal
Th-CGU	Thermal energy output of cogen unit

Evaluation period

Italian building energy codes divide Italy in six different climatic zones, according to their degree days (DD) ranges: A, B, C, D, E and F. Each zone indicates a heating period to activate heater central plant for MFH, as following:

Zone A: until 600 DD, heating period 1st Dec – 15th Mar, limit of daily heating: 6 hours
Zone B: from 600 to 900 DD, heating period 1st Dec - 31st Mar, limit of daily heating: 8 hours
Zone C: from 900 to 1400 DD, heating period 15th Nov-31st Mar, limit of daily heating: 10 hours
Zone D: from 1400 to 2100 DD, heating period: 1st Nov - 15th Apr, limit of daily heating: 12 hours
Zone E: from 2100 to 3000 DD, heating period: 15th Oct - 15th Apr, limit of daily heating: 14 hours
Zone F: over 3000 DD, heating period: no limitation, daily heating hours: any limitation

Performance assessment analysis concerns only four Italian climatic zones: B, C, D, and E since MFH are not very common in climatic zones A and F.

Energies considered and control volume

Three types of energies have been considered for the assessment of the energy consumption:

- Net energy demand :energy demanded from the cogeneration, gas boiler systems and electric grid to cover the demands for space heating, for domestic hot water and for electricity;
- Delivered energy: energy delivered to the building as fuel, heat or electricity;

- Primary energy: fossil energy. Total primary energy demand values are differentiated into primary energy demand for delivered grid electricity and for the fuel.

Fossil energy is related to the emission criteria. Delivered energy is used for cost evaluations.
In this study renewable energies were not considered.
The control volume for the simulation includes the building with the cogeneration system (figure 1). The primary energy consumption for the reference case was calculated from delivered energy by means of conversion factors as defined in the following paragraphs.

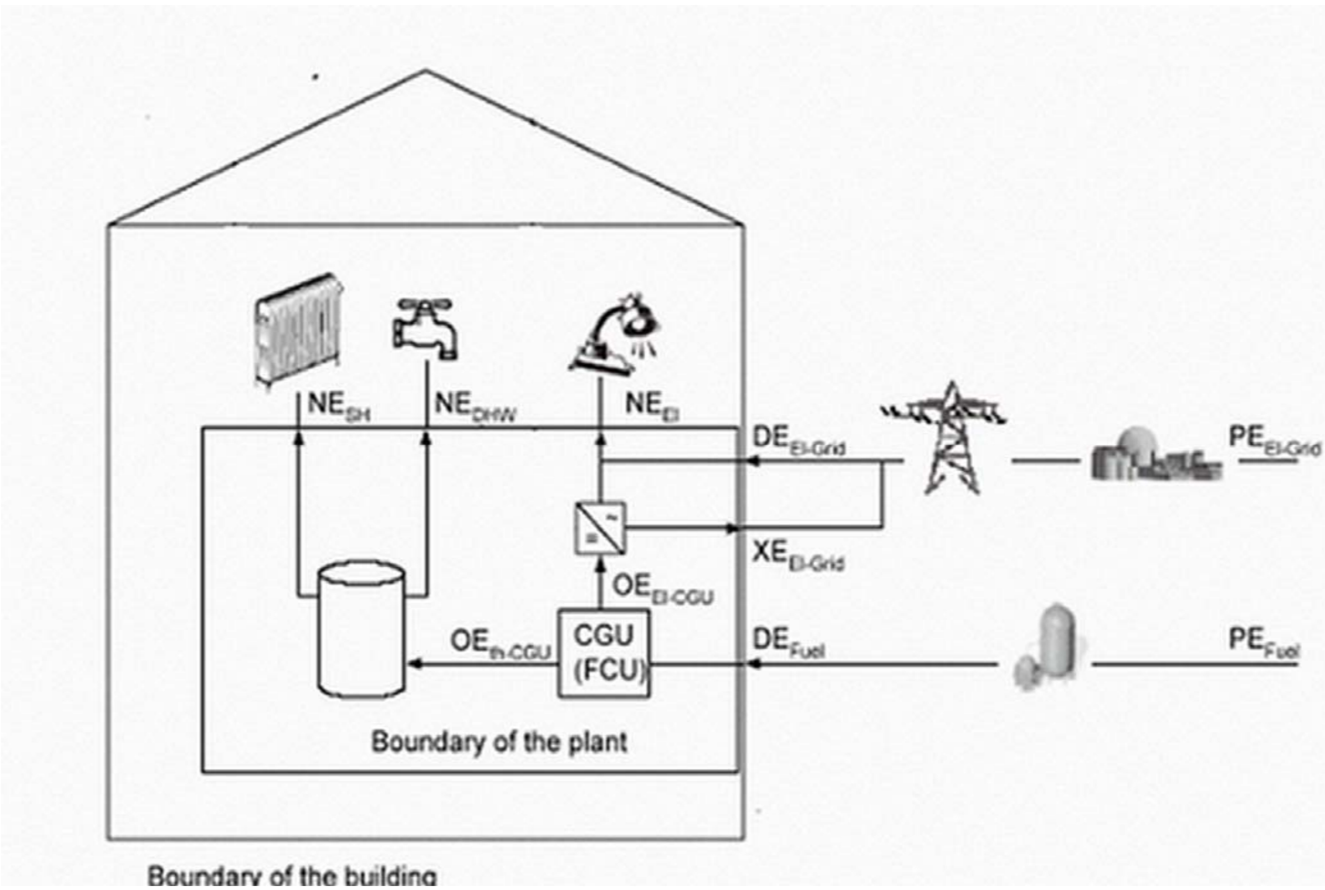

Figure 1: Control volume

Reference and units for energy values

In order to compare different cogen system and building type cases, delivered and primary energies are related to the energy reference floor area (ERFA) of the building. The energy reference floor area is based on external dimensions and considers all heated spaces of the building. The energy values are thus expressed in MJ/m2/a for all heating period.

2. PERFORMANCE ASSESSMENT CRITERIA

Types of performance assessments

The following performance assessment analysis is based on:
- Energy analysis
- CO_2 emission analysis (environmental impact analysis)
- Economic analysis (Specific costs for electricity and for natural gas)
- Simplified approach.

In this study, performance values of cogeneration system are compared with those of a reference system for selected performance parameters and respective time period.

Energy performance criteria

In order to evaluate how efficiently primary energy is utilized by the analyzed micro cogeneration system to cover the electricity and heat demand, dimensionless energy performance factors η_{PE} are calculated in the simulations.
The energy performance factor for primary energy is defined as

$$\eta_{PE} = \frac{NE_{El} + NE_{SH} + NE_{DHW} + XE_{El-NetGrid}}{PE_{EL-NetGrid} + PE_{Fuel}}$$

using annual net energy consumption *NE* and primary energy *PE*, in conjunction with indices for electricity (*El*), space heating (*SH*), domestic hot water (*DHW*), net excess of electricity produced locally and delivered back into the grid (*El-NetGrid*), grid electricity (*El-Grid*) and the fuel (natural gas).
Excess electricity locally produced (XE) is calculated adopting a net metering rule with the power company: excess energy produced is delivered back into the grid and used as credit for times when not enough energy is produced to meet electric needs.
To evaluate $PE_{El-NetGrid}$, the net amount of electricity locally produced and delivered back into grid substitutes the same amount of electricity produced according to the electricity mix of the grid, therefore:

$$PE_{El-NetGrid} = PE_{El-Grid} - PE_{XE-El-Grid}$$

Where:

$$PE_{XE-El-Grid} = pef_{El-Grid} * XE_{El-NetGrid}$$

Emissions analysis

In this study the emission analysis is based on the amount of CO_2 emitted during the simulation period (valuated as [t/a]) by

a) the cogen system

b) the production chain for fuel (using emission factors like following indicated)

c) the production chain grid for electricity (depending on the electricity generation mix).

Economic analysis

The economic analysis has been focused on the evaluation of energy costs for delivered energy (imported fuels and electricity minus revenue from electricity export) for the cogeneration system and the traditional system. Electricity and thermal costs were evaluated as normalized over the total net electric and delivered thermal energy (space heating and DWH) during simulation period as following:

$$\text{Electricity\_cost} = \frac{Cost_{El-grid}(El\_grid - El\_back)}{NE_{El}} \quad [€/kWh]$$

$$\text{Thermal\_cost} = \frac{Cost_{NG\_GB}(NG_{GB}) + Cost_{NG\_CGU}(NG_{CGU})}{DE_{Th}} \quad [€/kWh]$$

Where:

Cost $_{El-grid}$:	Delivered grid electricity cost (€/kWh)
Cost $_{NG-GB}$:	Natural gas cost for traditional plant (€/mc)
Cost $_{NG-GB}$:	Natural gas cost for cogeneration plant (€/mc)
El_grid :	Electricity supplied from the grid
El_back:	Electricity exported to the grid
NE_{el} :	Net electric energy
NG_{GB}:	Natural Gas feeding gas boiler
NG_{GB}:	Natural Gas feeding cogeneration unit
DE_{Th}:	Total delivered thermal energy

A simplified approach

As proposed by University of Sannio, a simplified study of cogeneration systems has been realized comparing performances of the alternative system (AS = cogen unit) to the traditional energy system based on separate “production” (TS = electric grid and gas boiler). Both alternative and conventional systems have to satisfy the electric and the thermal (heating and domestic hot water production) end user demand.

To compare the alternative energy system to the traditional system, both covering the same demand values, Primary Energy Savings (PES) have been evaluated as:

$$PES = \frac{(PE_{Fuel-GB} + PE_{El-Grid}) - PE_{Fuel-CGU}}{PE_{Fuel-GB} + PE_{El-Grid}} = 1 - \frac{\eta^{TS}{}_{NRPE}}{\eta^{AS}{}_{NRPE}}$$

The environmental impact with the simplified approach is based on the evaluation of the emissions of equivalent CO_2 of the compared energy systems. The parameter used is the avoided greenhouse gas emissions defined as:

$$\Delta CO_2 = \frac{(CO_{2,Fuel-GB} + CO_{2,Fuel-Grid}) - CO_{2,Fuel-CGU}}{CO_{2,Fuel-GB} + CO_{2,Fuel-Grid}} = \frac{CO_2{}^{TS} - CO_2{}^{AS}}{CO_2{}^{TS}}$$

List of primary energy factors and CO_2 emission factors

To evaluate primary energy consumption and CO_2 emissions for grid electricity and natural gas, pef have been calculated considering European mix electric power plan according to UCTE (considering the liberalisation of the electricity market, and the respective transport and exchange of electricity between countries and industrial centres) and traditional gas boiler as following:

- Mix European Electric grid primary energy factor:	3.25 MJ primary per MJ delivered energy
- Mix European Electric grid CO_2 emission factor:	0.142 kg CO_2/MJ delivered energy
- Primary energy factor for natural gas:	1.13 MJ primary per MJ delivered energy
- Natural gas CO_2 emission factor: (including combustion)	0.073 kg CO_2/MJ delivered energy

3. DESCRIPTION OF CASES, CONFIGURATION AND INPUT PARAMETER

Cogeneration system description

The main components of the cogeneration system layout are shown in figure 2

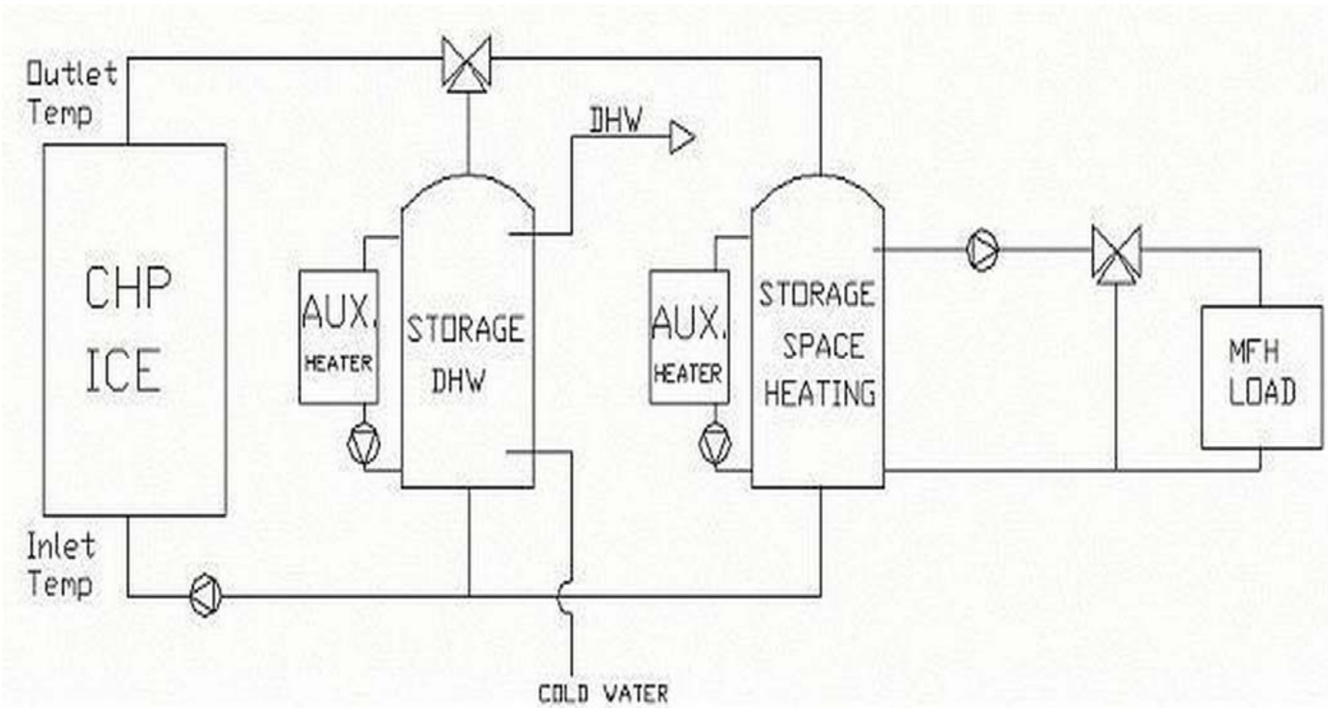

Figure 2: CHP system layout

In the following an outline for the description of the individual system components is given:

1) CHP-ICE:
   Type: ICE, grid connected
   Fuel type: NG
   Nominal Electric Output: 35 kWe
   Nominal Thermal Output: 78 kWt
   Modulation range: 100% - 50%
   Electrical Efficiency: 28,2 % (Nominal Power) related to LHV
   Thermal Efficiency: 62.9 % (Nominal Power) related to LHV
   Thermal inertia: 677600 J/K

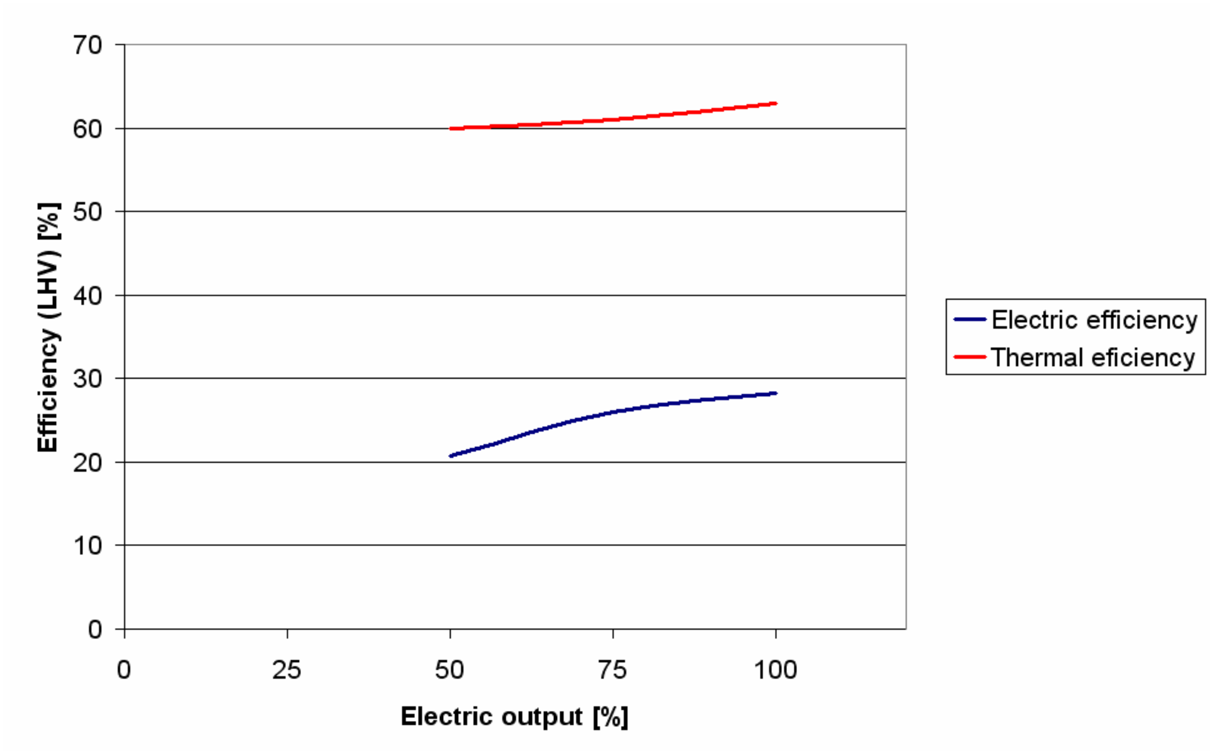

Figure 3: Thermal and electric CGU part load performance based on % electric load

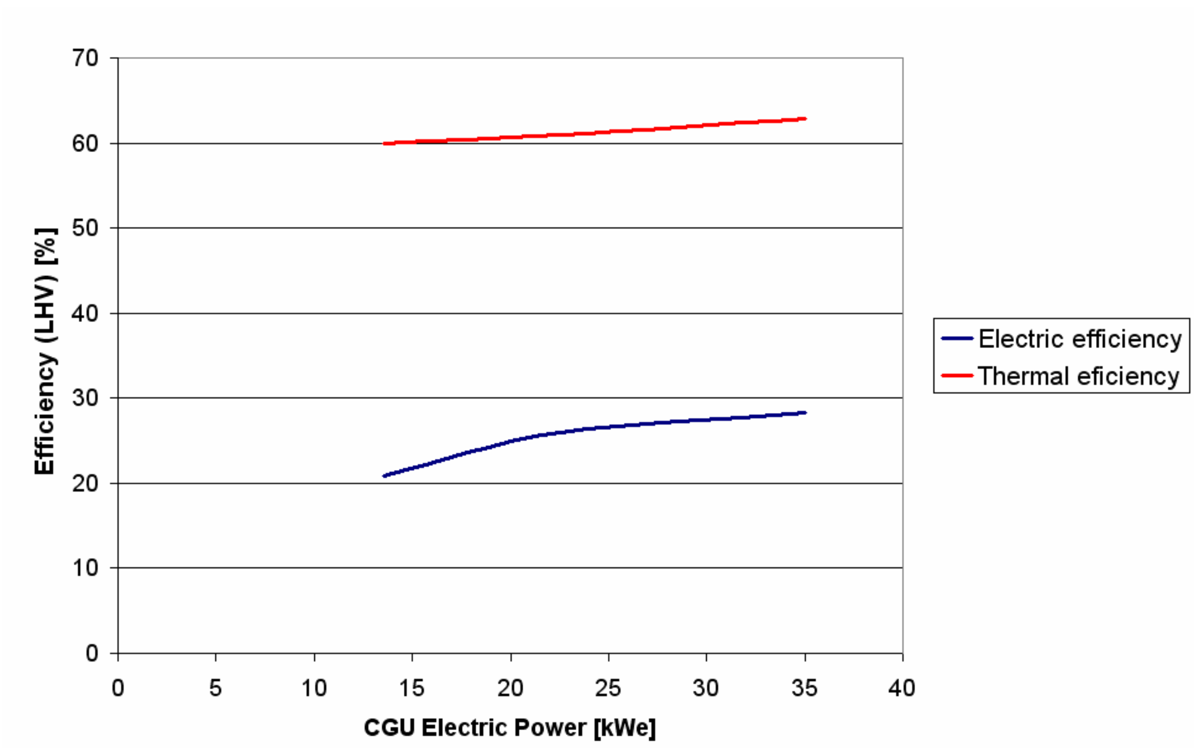

Figure 4: Thermal and electric CGU part load performance based on generated electric power

2) Auxiliary Heater
   Type: boiler
   Fuel Type: NG
   Thermal output: different for each climatic zones
   Modulation range: On Off
   Thermal efficiency: 88 % related to LHV

3) Auxiliary DHW
   Type: boiler
   Fuel Type: NG
   Thermal output: 5 kW
   Modulation range: On Off
   Thermal efficiency: 88 % related to LHV

4) Hot water storage space heating:
   Storage type:
   - stratified
   - only for space heating
   Geometry:
   -Tank Volume: 3 m^3
   - Height: 2 m
   Insulation:
   - tank loss coefficient per unit area: 2.0 kJ/(h*m^2*K)
   Auxiliary heater: gas burner
   Electric resistance auxiliary heating elements: None
   Control strategy for the auxiliary heating elements:
   - set point temperature for heating (Tset) : 75 °C
   - dead band temperature (Tdb): 10 °C
   - The thermostat will enable the heating element (Auxiliary Heater) when the temperature of the fluid in the node containing the thermostat falls below (Tset-Tdb) and continue to heat the fluid until it reaches the set point temperature.

5) Hot water storage DHW:
   Storage type:
   - stratified
   - only for DHW
   Geometry:
   -Tank Volume: 2 m^3
   - Height: 2 m
   Insulation:
   - tank loss coefficient per unit area: 3.0 kJ/(h*m^2*K)
   Auxiliary heater: gas burner
   Electric resistance auxiliary heating elements: None
   Control strategy for the auxiliary heating elements:
   - set point temperature for heating (Tset) : 45 °C
   - dead band temperature (Tdb): 5 °C

- The thermostat will enable the heating element (Auxiliary DHW) when the temperature of the fluid in the node containing the thermostat falls below (Tset-Tdb) and continue to heat the fluid until it reaches the set point temperature.

6) Distribution system for space heating
System type: radiators

CHP control strategy and methods

- Method: Build thermal load following
- Controlled Variables: Storages temperatures.
- Controlling parameters: ICE Modulation, On-Off auxiliary heaters.
- Building heat demand control:
  - PID controlled supply temperature to radiators
  - Rooms thermostats

The top level heater storage temperature value establishes the modulation rate for ICE (figure 6) from nominal electric power to 0.5 electric power rate.
The supply radiator temperature is used by PID(1) to modulate radiators recirculating valve position.
An additional PID-controller (PID2) is used to modulate flow rate from ICE to DHW storage to ensure the DHW temperature in the top storage segment.

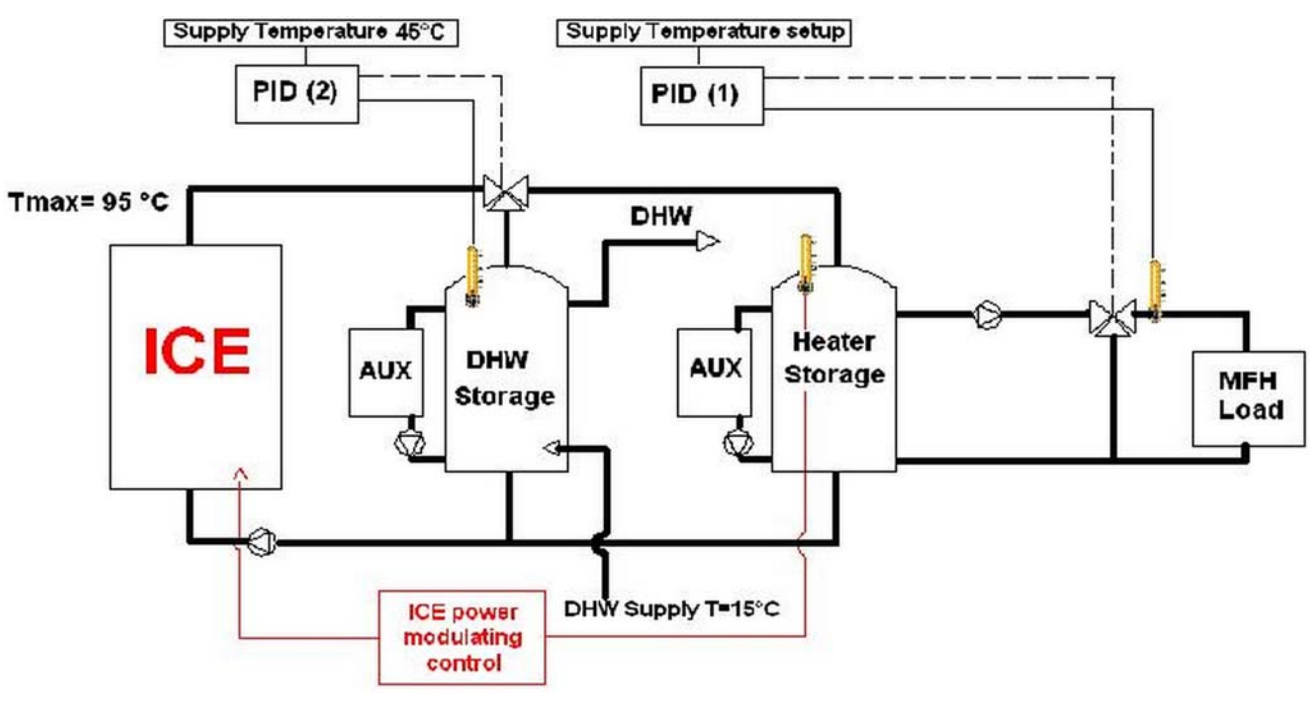

Figure 5: Scheme of PID and modulating control

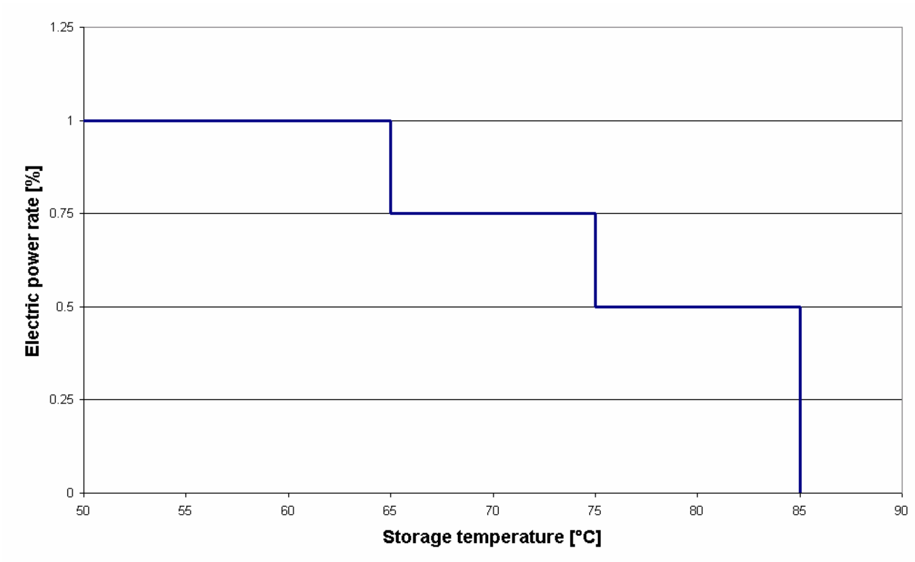

Figure 6: ICE power modulating control

Italian building stock related factors

The performance assessment study has been made for average social multi family houses, representative of Italian building stock (built between 1976 and 1985, see appendix 7.2) and described in the following table, in terms of size, use, energy level and construction type for each Italian climatic zone. Walls typology has been defined by means of a statistical analysis conducted to the above mentioned building stock (built between '80 and '90).

For each climatic zone, MFH studied is a five floor building with 20 apartments and dimensions 30 l, 12 w, 17.5 h. Energy reference area of MFH is 2135 m^2 and main axis orientation is NE-SW.

Climatic Zone	**B (Palermo, DD =751)**	**C (Napoli, DD 1034)**	**D (Roma, DD 1415)**	**E(Biella, DD 2850)**
Heating period	1^{th} Dec - 31^{th} Mar	15^{th} Dec - 31^{th} Mar	1^{th} Nov - 15^{th} Apr	1^{th} Dec - 31^{th} Mar
SH demand [MJ/m^2a]	67.17	100.86	152.91	327.37
DHW demand [MJ/m^2a]	46.63	52.11	62.12	65.02
Electric demand [MJ/m2a]	36.21	39.14	46.32	42.32
Roof UV [W/mqK]	0.60	0.60	0.60	0.60
Wall UV [W/mqK]	1.4	1.4	1.21	1.21
Window UV [W/mqK]	2.83	2.83	2.83	2.83
Window g value	0.755	0.755	0.755	0.755

Table 1: MFH simulated

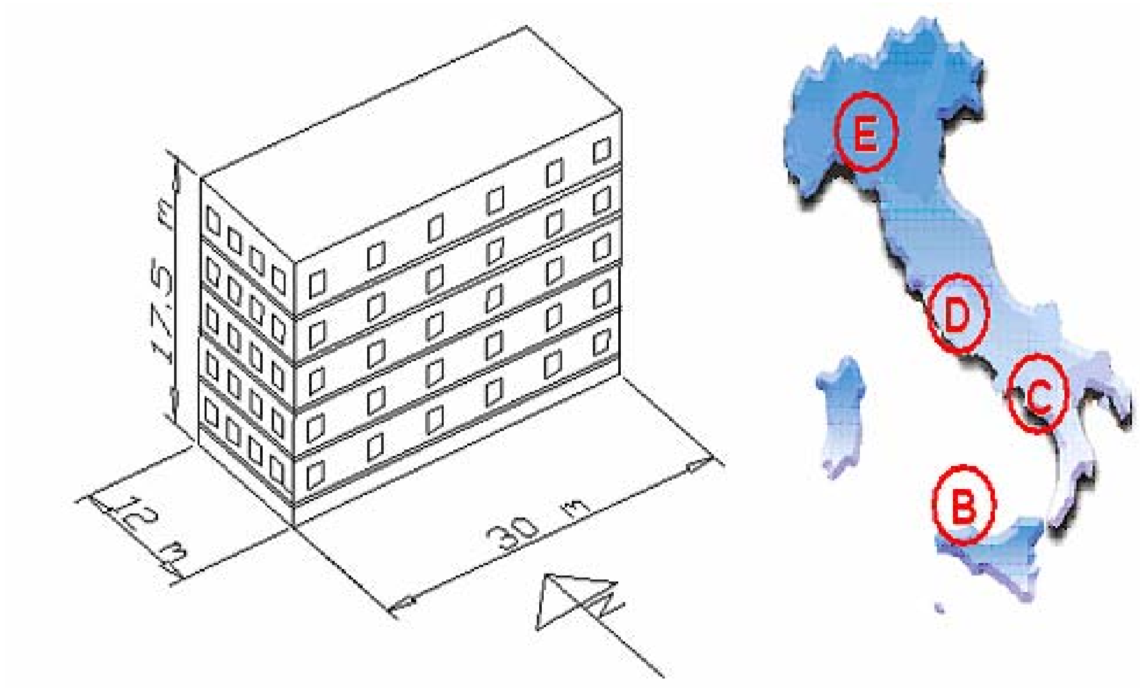

Figure 7: Geometry and orientation of MFH simulated and Italian climatic zones

New buildings

Italian new buildings built after 2006 must respect new Italian code about energy saving, to reduce space heating demand. This code (DLgs. 311/06) accomplishes EPBD (European Directive on Energy Performance of Buildings) requirements.

Performance assessment analysis of micro cogeneration plant for Italian building stock has been compared with micro cogeneration plant for new buildings, as described in the following table in terms of construction type and heating demand. Type of new MFH is same of building stocks studied ; this is a five floor building with 20 apartments and dimensions 30 l, 12 w, 17.5 h. Energy reference area of MFH is 2135 m^2 and main axis orientation is NE-SW.

Climatic Zone	B (Palermo, DD =751)	C (Naples, DD 1034)	D (Rome, DD 1415)	E(Biella, DD 2850)
Heating period	1th Dec - 31th Mar	15th Dec - 31th Mar	1th Nov - 15th Apr	1th Dec - 31th Mar
SH demand [MJ/m^{2}a]	34.45	48.42	81.49	195.94
DHW demand [MJ/m^{2}a]	46.88	52.47	62.21	64.94
Electric demand [MJ/m2a]	38.97	42.48	50.88	48.18
Roof UV [W/mqK]	0.42	0.42	0.35	0.32
Wall UV [W/mqK]	0.50	0.46	0.40	0.37
floor UV [W/mqK]	0.55	0.49	0.41	0.39
Window UV [W/mqK]	2.83	2.83	2.83	2.4
Window g value	0.755	0.755	0.755	0.755

Table 2: Parameters of new buildings with better insulation

Input parameters

3.5.1 DHW demand profiles

The volume of DHW provided in the profiles assumes a supply temperature of 45°C and a cold feed water temperature of 15°C. The DHW profiles for multi family house simulated have been produced directly using "IEA SHC Task 26" profile [Jordan, Vajen, 2001] for a load volume of 3200 liters per day and with a time step of 1 hour. A short sequence of the profile is shown in figure 8

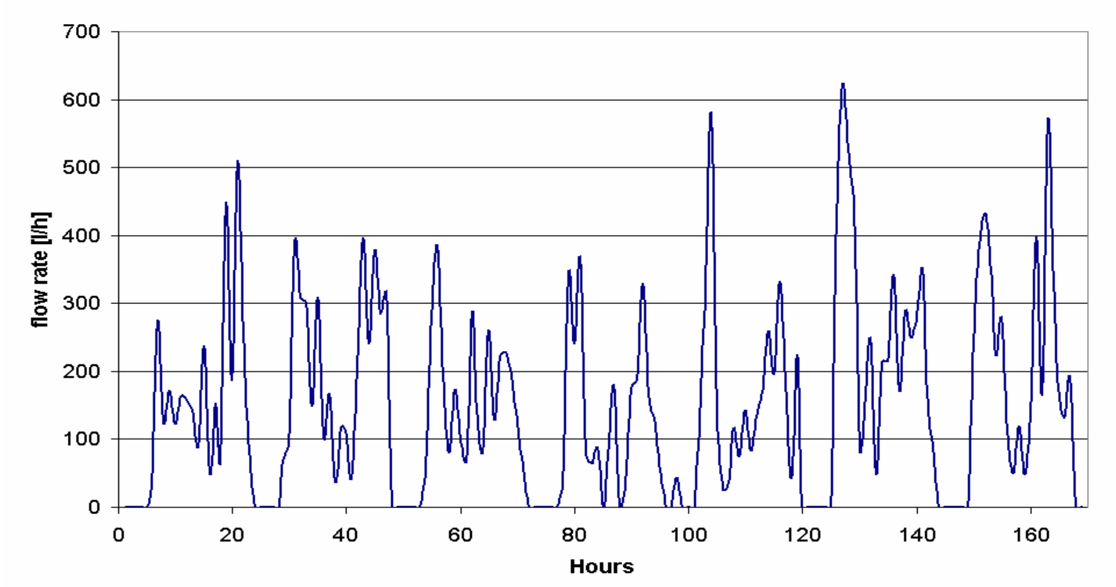

Figure 8: One Week DHW profile, 1st -7th January

3.5.2 Electricity demand profiles

Electrical non-HVAC profiles has been obtained from a report of CESI of Milan [4] derived from on site measurements of the electric consumptions in a MFH of 40 apartments with households of 4 people and floor area 100 m^2 for each different climatic zones.

According to these electrical load profiles, it was possible extrapolate two different domestic electrical energy consumption profiles for a MFH of 20 apartments in regard to geographic allocation of each simulated building [CESI Research 2007] with 30 minutes time resolution as following :

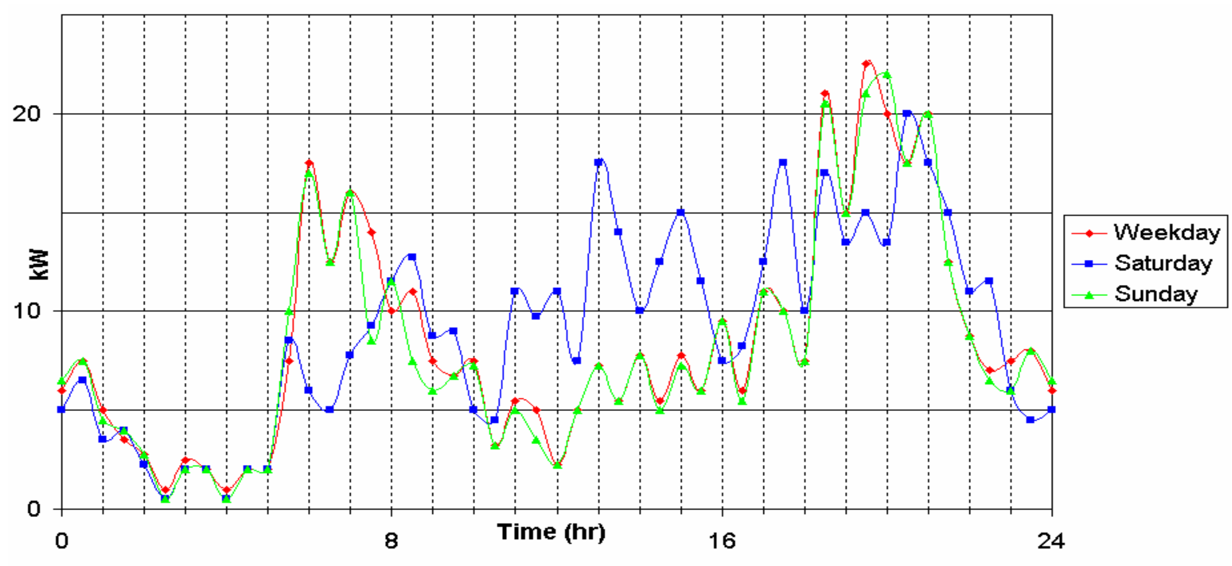

Figure 9: Zones B and C: electricity demand profile

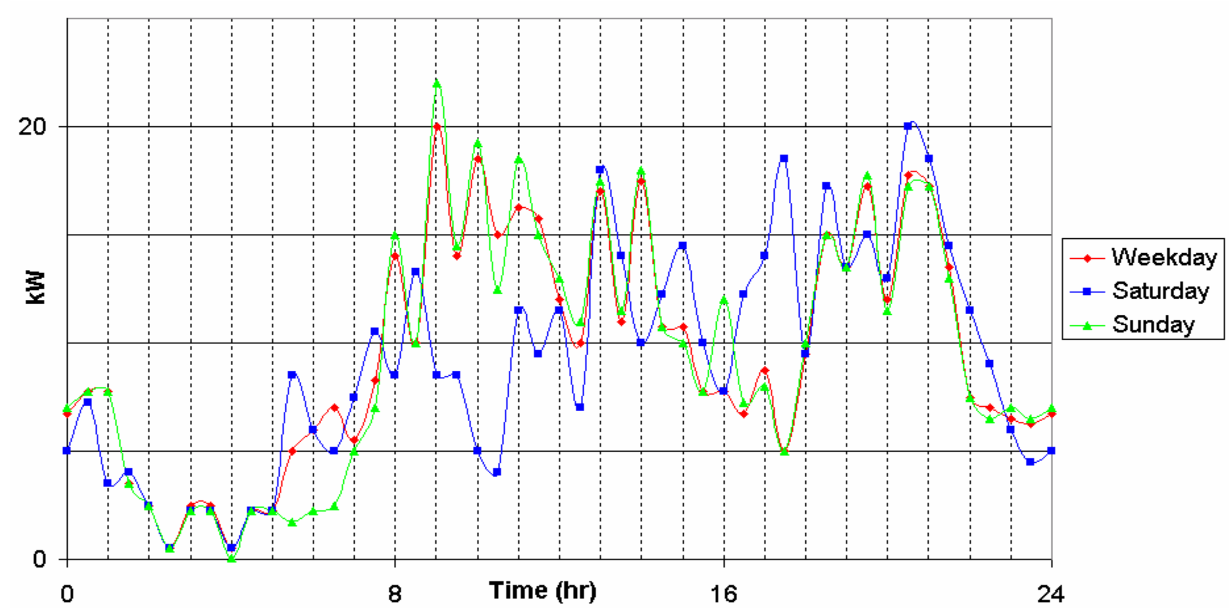

Figure 10: Zones D and E: electricity demand profile

3.5.2.1 Electricity demand profiles: compare with electrical load profiles used to Annex 42 Sub Task A profiles

The Italian domestic electrical non-HVAC dataset used to STA profiles has been obtained from a report of the Politecnico of Milano derived from on site measurements of the electric consumptions in the Italian residential sector for the SAVE EURECO and MICENE projects. This report considers data for 110 SFH located in 5 Italian regions for 3 years; the 77% of the sample consists of households of 3 or 4 people, and that the average household floor area is around 106 m^2.

In order to describe difference between STA average electrical profile and profiles used to ENEA performance assessment study, dimensionless daily electrical profiles have been compared as showed in figure 11:

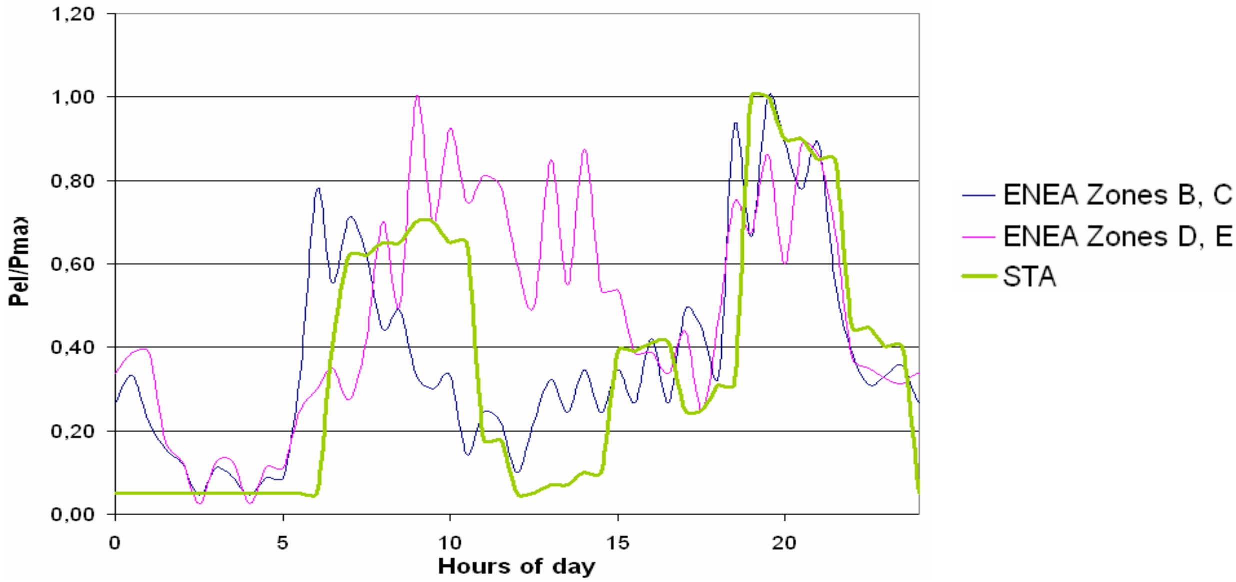

Figure 11: Dimensionless electrical consumption profile for different data set by day of week.

Figure 11 showed that the evening peak load for sub task A profile is similar to climatic zones B and C, instead morning peak load is different for each profiles.

Italian sub task A electrical profile have not been select for ENEA performance assessment study, because these one has been obtained as average of different SFH electrical profiles. Instead Italian electrical profiles, obtained by CESI study, has been made for same average social multi family houses (MFH) studied in ENEA performance assessment study.

3.5.3 Selected electricity and natural gas cost

Electricity costs have been considered adopting a net metering rule with the power company: the user pays the difference of annual delivered grid electricity and annual excess of electricity locally produced and delivered back into the grid. Italian average cost (spring 2007) for electricity and natural gas is given in Table 3:

Natural gas cost for cogeneration plant : $Cost_{NG\_CHP}$	0.372	€/mc
Natural gas cost for traditional plant: $Cost_{NG\_GB}$	0.590	€/mc
Delivered grid electricity cost : $Cost_{El\text{-}Grid}$	0.160	€/kWh

Table 3: Electricity and natural gas cost (Tax free)

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4 PERFORMANCE ASSESSMENT RESULT PRESENTATION

The following simulation results have been achieved through simulations computerized with the TRNSYS software.

Delivered and primary energies have been related to the energy reference floor area (ERFA) of the building. ($MJ/m^2/a$). The energy reference floor area is 2135 m^2. Performance assessment analyses have been made for each of the four climatic zones in relation to the different thermal power capacities of the auxiliary heater and the traditional system according to the heating load of the climatic zone.

4.1 Climatic zone B (Palermo): simulation results

Cogeneration plant:

CGU: ICE 35 kWe
Auxiliary SH: GB 30 kWth
Auxiliary DHW: 10 kWth
EL-GRID: Mix European Electric grid

Traditional Plant:

SH: GB 100 kWth
Auxiliary DHW: 10 kWth
EL-GRID: Mix European Elctric grid

A) Delivered and primary energy

	Cogeneration system	**Traditional system**	
dEel_grid	36.21	45.81	$MJ/m^2/a$
dEel_cgu	26.81	0.00	$MJ/m^2/a$
nEel	45.81	45.81	$MJ/m^2/a$
pE_{SH}	100.14	71.50	$MJ/m^2/a$
pE_{DHW}	77.13	39.32	$MJ/m^2/a$
pE_{NG}	177.28	110.82	$MJ/m^2/a$
pE_{EL_Grid}	79.28	152.72	$MJ/m^2/a$
pE	256.55	263.54	$MJ/m^2/a$

B) Energy analysis

	Cogeneration system	**Traditional system**	
η_{PE}	68.15	53.13	**%**

C) Environmental analysis

	Cogeneration system	**Traditional system**	
CO_2 Total emission	20.38	31.14	**t**

D) Economic analysis

	Cogeneration system	**Traditional system**	
electricity costs	0.0566	0.15	€/kWh_{El}
SH + DHW costs	0.064	0.061	€/kWh_{Th}

E) Simplified approach

PES	0.219
ΔCO_2	0.346

4.2 Climatic zone C (Naples): simulation results

Cogeneration plant:

CGU: ICE 35 kWe

Auxiliary SH: GB 50 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Electric grid

Traditional Plant:

SH: GB 130 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Elctric grid

A) Delivered and primary energy

	Cogeneration system	Traditional system	
dEel_grid	39.14	51.91	$MJ/m^2/a$
dEel_cgu	34.43	0.00	$MJ/m^2/a$
nEel	51.91	51.91	$MJ/m^2/a$
pE_{SH}	146.02	114.21	$MJ/m^2/a$
pE_{DHW}	87.26	44.04	$MJ/m^2/a$
pE_{NG}	233.27	158.25	$MJ/m^2/a$
pE_{EL_Grid}	79.87	173.03	$MJ/m^2/a$
pE	313.15	331.29	$MJ/m^2/a$

B) Energy analysis

	Cogeneration system	Traditional system	
η_{PE}	71.70	56.41	%

C) Environmental analysis

	Cogeneration system	Traditional system	
CO_2 Total emission	25.65	40.38	t

D) Economic analysis

	Cogeneration system	Traditional system	
electricity costs	0.0489	0.15	€/kWh_{El}
SH + DHW costs	0.064	0.061	€/kWh_{Th}

E) Simplified approach

PES	0.213
ΔCO_2	0.365

4.3 Climatic zone D (Rome): simulation results

Cogeneration plant:

CGU: ICE 35 kWe

Auxiliary SH: GB 55 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Elctric grid

Traditional Plant

SH: GB 140 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Elctric grid

A) Delivered and primary energy

	Cogeneration system	Traditional system	
dEel_grid	46.32	64.14	$MJ/m^2/a$
dEel_cgu	50.77	0.00	$MJ/m^2/a$
nEel	64.14	64.14	$MJ/m^2/a$
pE_{SH}	221.35	170.19	$MJ/m^2/a$
pE_{DHW}	103.81	52.46	$MJ/m^2/a$
pE_{NG}	325.16	222.65	$MJ/m^2/a$
pE_{EL_Grid}	83.88	213.80	$MJ/m^2/a$
pE	409.04	436.45	$MJ/m^2/a$

B) Energy analysis

	Cogeneration system	Traditional system	
ηPE	75.75	58.43	%

C) Environmental analysis

	Cogeneration system	Traditional system	
CO_2 Total emission	33.32	54.13	t

D) Economic analysis

	Cogeneration system	Traditional system	
electricity costs	0.0389	0.15	$€/kWh_{El}$
SH + DHW costs	0.065	0.061	$€/kWh_{Th}$

E) Simplified approach

PES	0.229
ΔCO_2	0.384

4.4 Climatic zone E (Biella): simulation results

Cogeneration plant:

CGU: ICE 35 kWe

Auxiliary SH: GB 80 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Elctric grid

Traditional Plant

SH: GB 160 kWth

Auxiliary DHW: 10 kWth

EL-GRID: Mix European Elctric grid

A) Delivered and primary energy

	Cogeneration system	Traditional system	
dEel_grid	42.32	70.37	MJ/m^2/a
dEel_cgu	84.13	0.00	MJ/m^2/a
nEel	70.37	51.13	MJ/m^2/a
pE_{SH}	448.27	364.43	MJ/m^2/a
pE_{DHW}	112.26	56.81	MJ/m^2/a
pE_{NG}	560.53	421.24	MJ/m^2/a
$pE_{EL\ Grid}$	35.96	234.56	MJ/m^2/a
pE	596.48	655.80	MJ/m^2/a

B) Energy analysis

	Cogeneration system	Traditional system	
ηPE	86.36	66.48	%

C) Environmental analysis

	Cogeneration system	Traditional system	
CO_2 Total emission	52.27	86.99	t

D) Economic analysis

	Cogeneration system	Traditional system	
electricity costs	0.0128	0.15	€/kWh_{El}
SH + DHW costs	0.065	0.061	€/kWh_{Th}

E) Simplified approach

PES	0.33
ΔCO_2	0.29

5 COMPARISON CASES

5.1 Relative performance

In order to draw conclusions, results in terms of performance assessment criteria P for selected CHP configuration is presented as well as in form of a relative performance in relation to a given reference case for each climatic zone.

Relative performance criteria in terms of NRPE (Non-renewable primary energy) demand reduction (Ppe) and CO_2 total emission reduction (P_{CO2}) for heating period have been expressed as percentage:

$$P_{pe} = \frac{pE_{CHP} - pE_{ref}}{pE_{ref}} \; \%$$

$$P_{CO2} = \frac{CO2_{CHP} - CO2_{ref}}{CO2_{ref}} \; \%$$

Where:

- pE_{CHP}: is primary energy for natural gas consumed by CHP system
- pE_{ref} : is primary energy for natural gas consumed by reference system
- CO_{2CHP}: Amount of CO_2 emitted during the simulation period the cogen system
- CO_{2ref}: Amount of CO_2 emitted during the simulation period the reference system

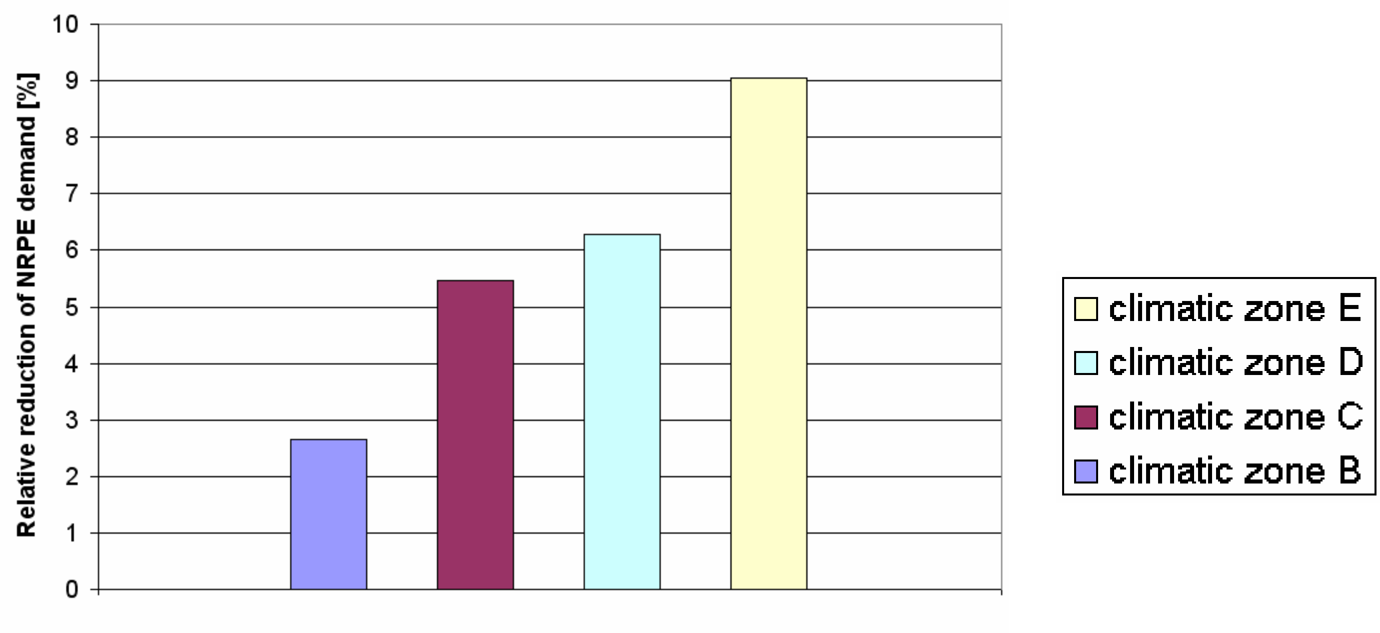

Figure 12: Percentage of NRPE demand reduction by CHP system in relation to reference traditional system: standard gas boiler system (for SH and DHW) and electricity generation mix.

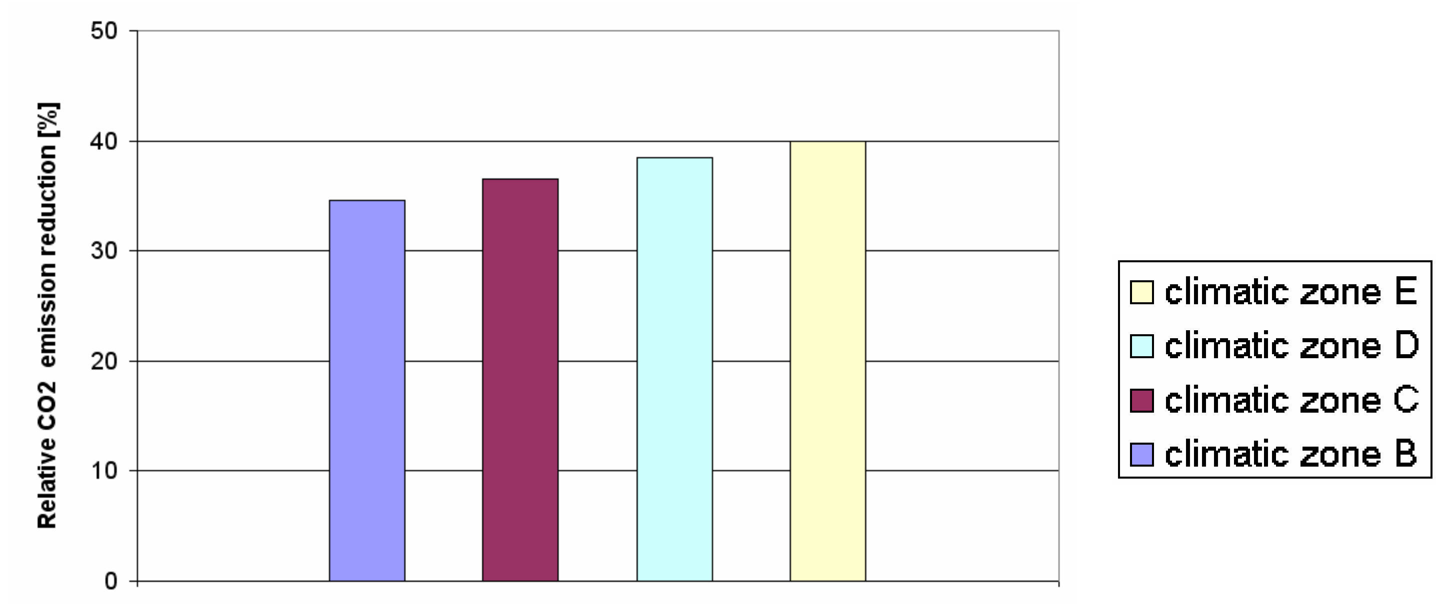

Figure 13: **Percentage of CO2 emission reduction by CHP system in relation to reference traditional system: standard gas boiler system (for SH and DHW) and electricity generation mix.**

5.2 Simplified approach

As defined to paragraph 2.5, comparison between PES and Δ CO_2 for each climatic zone below is showed:

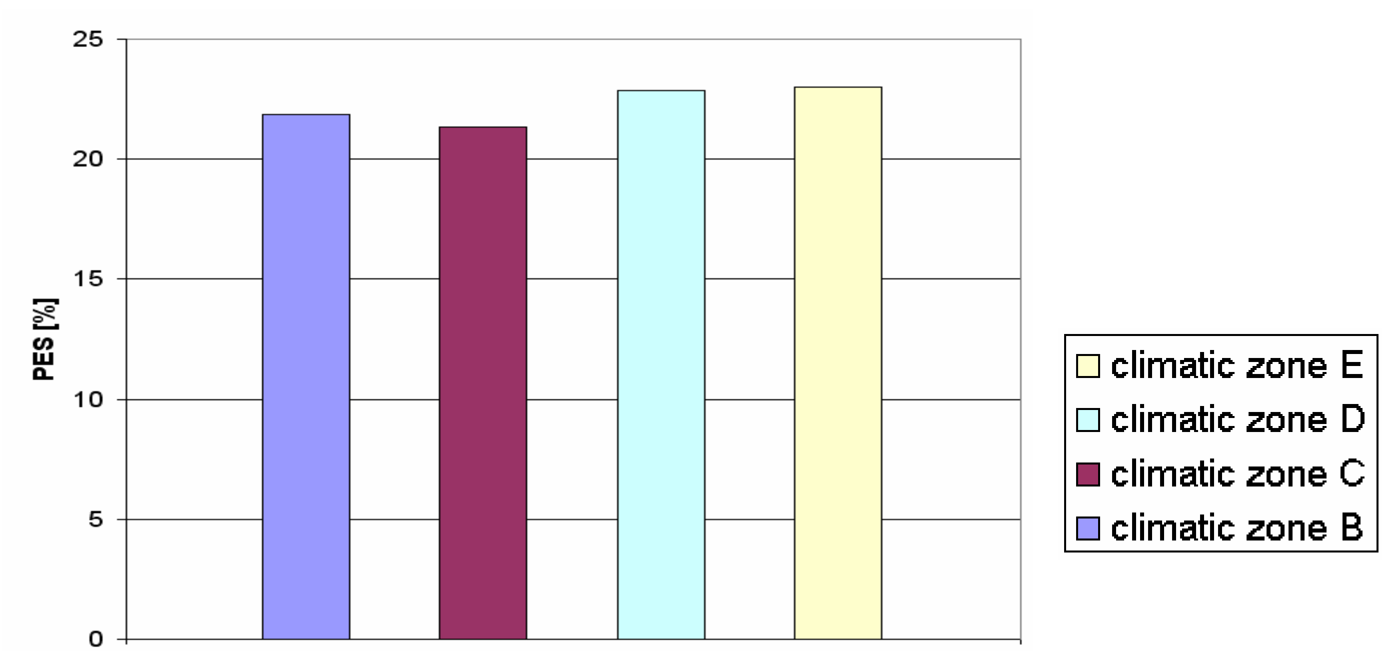

Figure 13: Simplified approach: primary energy reduction (PES)

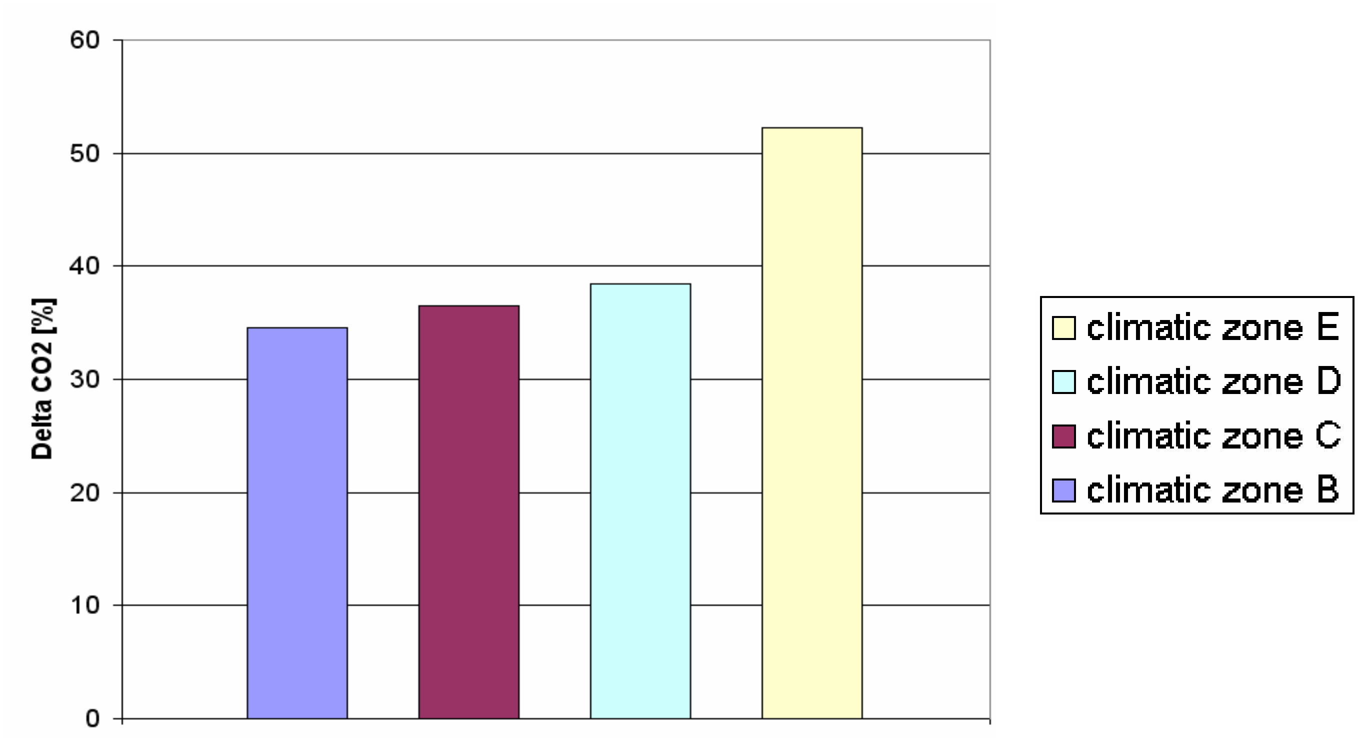

Figure 14: Simplified approach: CO_2 emission reduction

5.3 Average CGU total efficiency

The total efficiency of CGU is calculated for each time step as the sum of electric and thermal efficiency at nominal power and at part load as indicated to par. 3.1. The average total CGU efficiency during simulation period for each Italian climatic zone is shown below:

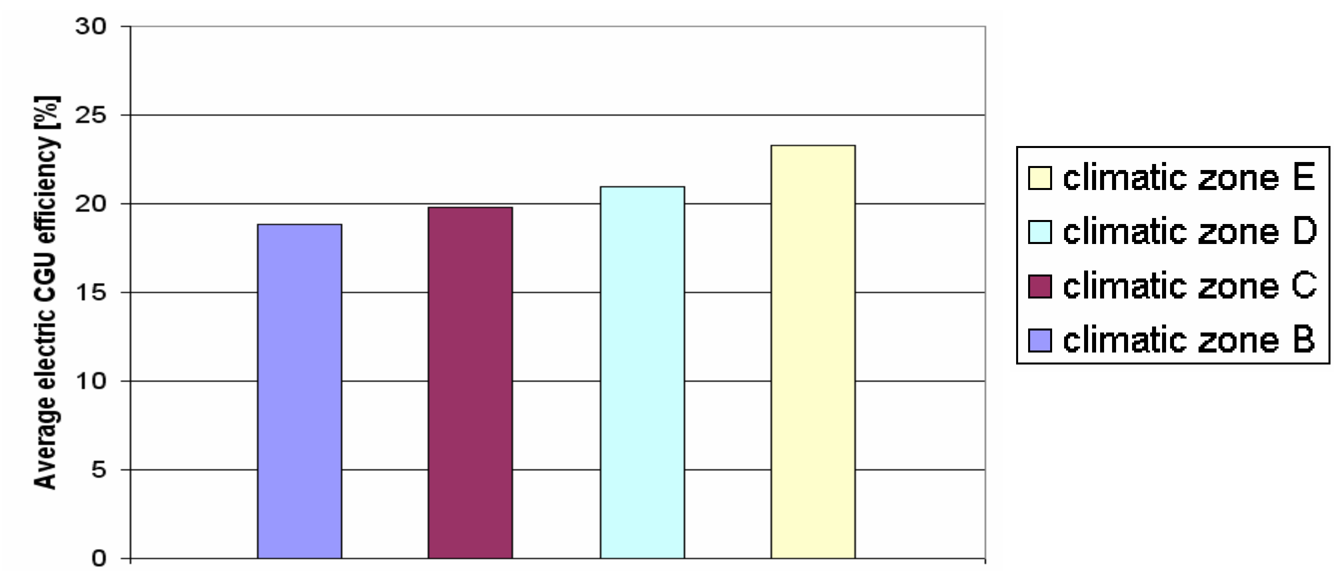

Figure 15 : Average CGU efficiency during simulation period for each climatic zone

5.4 Comparison with new building

Performance assessment analysis defined in par.2 has been done also for new buildings built after 2006 Following plants configuration has been considered for each climatic zone :

Climatic zone B	
Cogeneration plant:	Traditional Plant:
CGU: ICE 35 kWe	
Auxiliary SH: 5kWth	Space Heating: Gas Burner: 80 kWth
Auxiliary DHW: 10 kWth	Auxiliary DHW: 10 kWth

Climatic zone C	
Cogeneration plant:	Traditional Plant:
CGU: ICE 35 kWe	
Auxiliary SH: 10 kWth	Space Heating: Gas Burner: 90 kWth
Auxiliary DHW: 10 kWth	Auxiliary DHW: 10 kWth

Climatic zone D	
Cogeneration plant:	Traditional Plant:
CGU: ICE 35 kWe	
Auxiliary SH: 15 kWth	Space Heating: Gas Burner: 100 kWth
Auxiliary DHW: 10 kWth	Auxiliary DHW: 10 kWth

Climatic zone E	
Cogeneration plant:	Traditional Plant:
CGU: ICE 35 kWe	
Auxiliary SH: 50 kWth	Space Heating: Gas Burner: 110 kWth
Auxiliary DHW: 10 kWth	Auxiliary DHW: 10 kWth

In order to evaluate the efficiency of the cogeneration plant also for new buildings with better insulation, the performance of the CHP for the actual building stock is compared to the performance of the CHP for new buildings as follows:

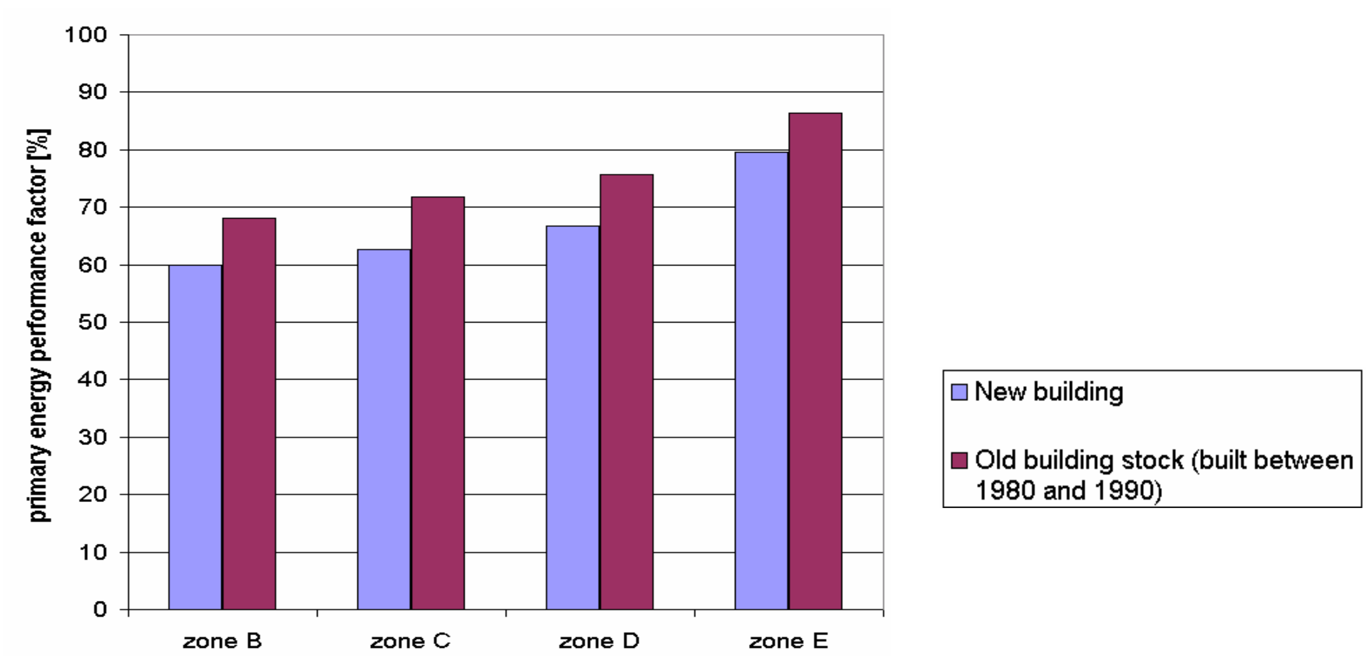

Figure 16 : Primary energy performance factor actual buildings stock and new buildings

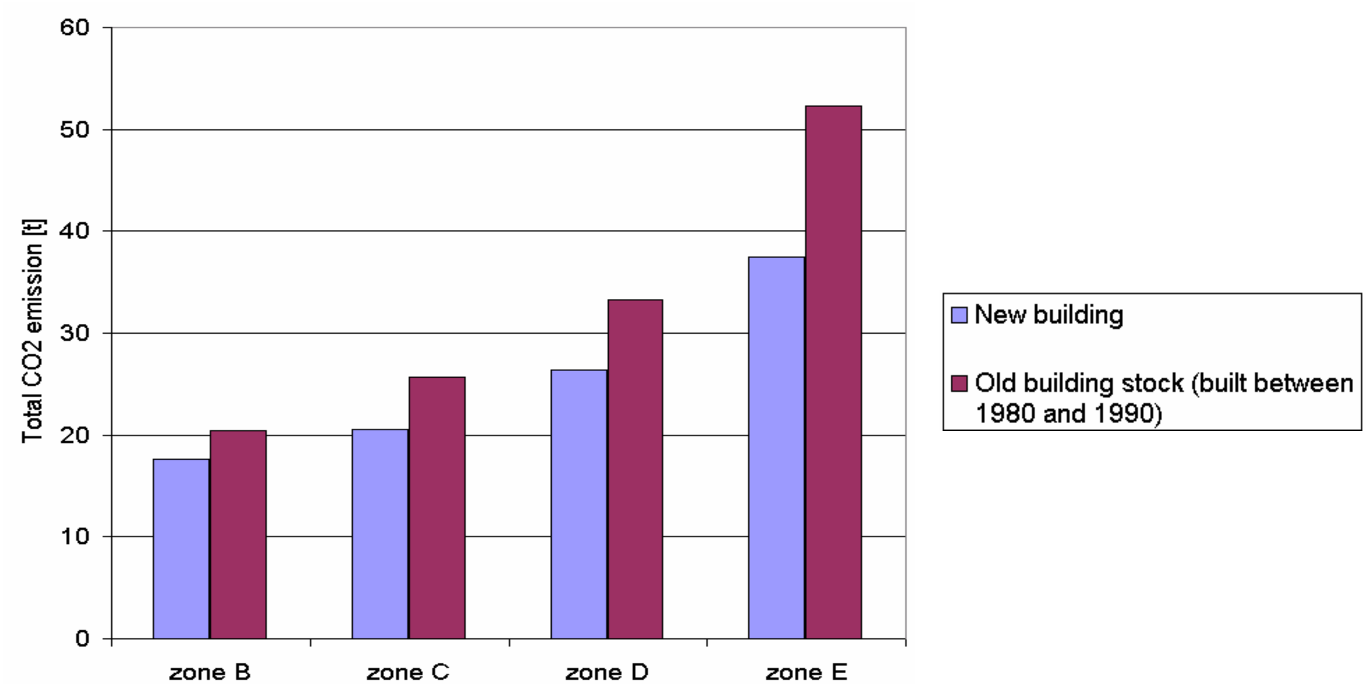

Figure 17 : Total CO_2 emission for actual buildings stock and new buildings

Relative performance criteria in terms of NRPE (Ppe) as defined to par. 5.1 for actual buildings stock is compared to new buildings as following :

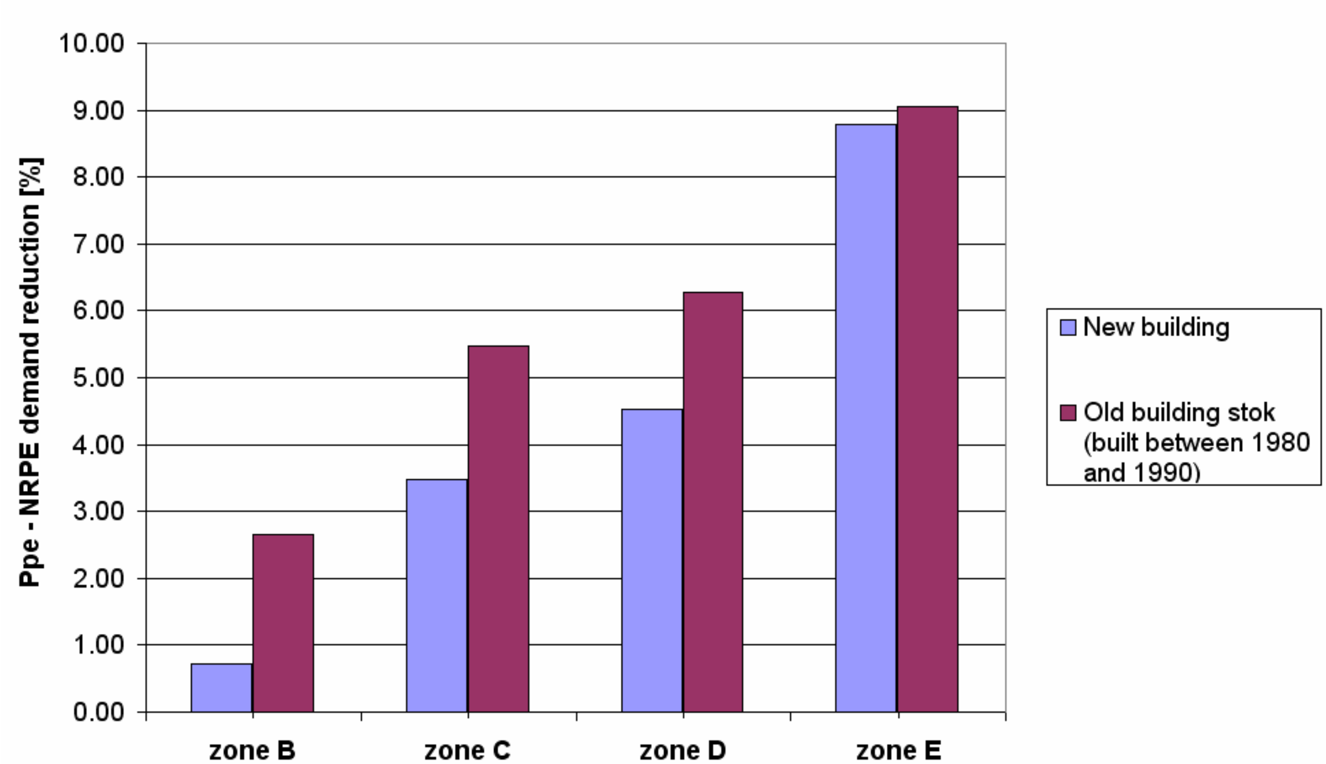

Figure 18 : NRPE demand reduction for actual buildings stocks and new buildings

6 CONCLUSION

The simulations showed that ICE cogeneration system analyzed in this study could provide considerable contribution in reducing building CO_2 emissions in residential multi-family buildings for all Italian climate areas.

The percentage of CO_2 and PE reduction is higher in cold climates (climate zone E, Biella) than in warmer areas (climate zone B, Palermo), nevertheless the PES index is almost constant around 20%.

One reason for these promising results concerning reduction potential could be the bad energetic quality of the reference building stock adopted in this study, representing the actual social building stock in Italy.

Considering the liberalisation of the electricity market, and the respective transport and exchange of electricity between countries and industrial centres, primary energy factor for European mix (pef=3.25), according to UCTE, has been used in the performance assessment study.

Using average primary energy factor for Italian electricity mix (pef = 2.7), in performance assessment study the advantages of the cogeneration system decrease in comparison to the traditional system.

New buildings have a substantially different performance in terms of NRPE reduction in warmer areas; CHP gives more primary energy reduction in the social buildings with bad energy level than in the new buildings. This fact is due to difference (in terms of time shifting) of electric load demand compared to heating demand profiles.

That means also that in case of well retrofitted buildings an improvement of the building envelope performance may considerably reduce the potential for micro cogeneration applications. On the other hand, because in many cases building envelope retrofit is difficult to realize, the adoption of micro cogeneration technologies could be considered as a possible promising additional measure in order to achieve substantial primary energy and CO_2 emissions reduction.

To use condensing gas boiler in social housing building stock could not achieve high primary energy and CO_2 emissions reduction because distribution system for space heating with radiators and high temperature of heating water (70 – 80 °C) reduce energy efficiency of condensing gas boiler to traditional gas boiler.

The electricity costs with cogeneration plant are lower in colder areas, where the system works longer during heating period so it generates more electric energy, reducing delivered grid electricity and increasing exported electricity to the grid.

Unitary thermal costs for space heating and DHW with cogeneration system are almost equal in each climatic zone. This cost depends on thermal efficiency to convert primary energy (natural gas) to delivered thermal energy: as showed in fig. 3 and 4, thermal CGU part load performance, based on generated electric power, are almost constant throughout the working interval.

7. REFERENCE

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8. APPENDIX

8.1 TRNSYS

TRNSYS is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc.

The source code of the kernel as well as the component models is delivered to the end users. This simplifies extending existing models to make them fit the user's specific needs. The DLL-based architecture allows users and third-party developers to easily add custom component models, using all common programming languages (C, C++, PASCAL, FORTRAN, etc.). In addition, TRNSYS can be easily connected to many other applications, for pre- or post-processing or through interactive calls during the simulation (e.g. Microsoft Excel, Matlab, COMIS, etc.). TRNSYS applications include: • Solar systems (solar thermal and PV) • Low energy buildings and HVAC systems with advanced design features (natural ventilation, slab heating/cooling, double façade, etc.) • Renewable energy systems • Cogeneration, fuel cells • etc.

A TRNSYS project is typically setup by connecting components graphically in the Simulation Studio. Each Type of component is described by a mathematical model in the TRNSYS simulation engine and has a set of matching Proforma's in the Simulation Studio The proforma has a black-box description of a component: inputs, outputs, parameters, etc. TRNSYS components are often referred to as Types (e.g. Type 1 is the solar collector). The Multizone building model is known as Type 56. The Simulation Studio generates a text input file for the TRNSYS simulation engine. That input file is referred to as the deck file.

In this study version TRNSYS version 16.01 is used

TRNSYS model used:

Type 154: Internal Combustion Engine Cogeneration Device: This model is based on the combustion engine based CHP model specification, developed and documented by IEA Annex 42 [Beausoleil, Kelly 2007] and implemented into the TRNSYS code by Empa, using Fortran, based on the implementation made for ESP-r, see IEA Annex 42 Sunmmary report [Beausoleil (ed), 2007].

Type 4: Thermal storage tank: The thermal performance of a fluid-filled sensible energy storage tank, subject to thermal stratification, is modelled by assuming that the tank consists of N (N <= 100) fully-mixed equal volume segments. The degree of stratification is determined by the value of N. If N is equal to 1, the storage tank is modelled as a fully-mixed tank and no stratification effects are possible. This instance of Type 4 models a stratified tank having fixed inlet positions defined within the code. Fluid entering the hot side of the tank is added to the tank node below the first auxiliary heater. Fluid entering the cold side of the tank enters the bottom node. The node sizes in this instance need not be equal. Temperature deadband on heater thermostats are available. This instance further assumes that losses from each tank node are equal and does not compute losses to the gas flue of the auxiliary heater.

Type 11: Tee piece: This component model a tee piece in which two inlet liquid streams are mixed together into a single liquid outlet stream.

Type 23: PID controller: The PID controller calculates the control signal (u) required to maintain the controlled variable (y) at the setpoint (ySet). Its control signal is proportional to the tracking error, as well as to the integral and the derivative of that tracking error. It is based on state-of-the-art discrete algorithms for PID controllers and implements anti windup for the integrator.

Type 56: Multy zone Building: This component models the thermal behaviour of a building having up to 25 thermal zones. The building description is read by this component from a set of external files having the extensions *.bui, *.bld, and *.trn. The files can be generated based on user supplied information by running the preprocessor program called TRNBuild (known as Prebid in TRNSYS versions prior to the release of v. 16.0). This instance of Type56 generates its own set of monthly and hourly summary output files.

8.2 Italian buildings stock

The age of Italian building stock is showed in following table, where amount of Multi family dwellings and individual dwellings is indicated for period of construction:

Year: 2001	Housing stock		Individual dwellings		Multi-family dwellings	
Period of construction	Total	Social Housing	Total	Social Housing	Total	Social Housing
< 1945	6.598.536	123.525	2.392.523		4.206.013	
1945 - 1955	4.333.882	113.700	992.693		3.341.189	
1956 - 1965	5.707.383	172.569	1.090.224		4.617.159	
1966 - 1975	5.142.940	222.204	1.154.008		3.988.932	
1976 - 1985	3.324.794	181.957	796.196		2.528.598	

1986 - 2001	2.161.345	120.490	796.196		1.365.149	
> 2001	1.200.000	93.840	na		na	
Source: ISTAT NATIONAL CENSUS 2001 AND ANCE (for >2001)for social housing Federcasa						

Residential building types in terms of construction data and material of the supporting structure are showed in the following table:

Construction data	Type of material			
	Supporting masonry	Reinforced concrete	Other	Total
Before 1919	2.026.538	0	123.721	2.150.259
1919 - 1945	1.183.869	83.413	116.533	1.383.815
1946 - 1961	1.166.107	288.784	204.938	1.659.829
1962 - 1971	1.056.383	591.702	319.872	1.967.957
1972 - 1981	823.523	789.163	370.520	1.983.206
1982 - 1991	418.914	620.698	250.890	1.290.502
After 1991	228.648	394.445	167.934	791.027
Total	**6.903.982**	**2.768.205**	**1.554.408**	**11.226.595**

8.3 Geographic site parameters

Monthly average values of total horizontal radiation and temperature used in performance assessment analysis are indicated in following tables (Font. UNI 10349 Italian Code, ENEA climatic file)

	Zona B (Palermo)	
	Total Horizontal Radiation [kJ/h*mq]	Temperature [C°]
January	7700	11.1
February	11100	11.5
March	15700	12.8
April	20800	15.1
May	25200	18.2
June	27900	21.9
July	27900	26.6
August	25200	25
September	19600	23.1
October	13500	19.6
November	9300	16
December	6900	12.7

	Zona C (Naples)	
	Total Horizontal Radiation [kJ/h*mq]	Temperature [C°]
January	6800	10.3
February	9500	10.7
March	14000	12.4

April	18000	15.8
May	21900	19.9
June	23800	23
July	23700	26.1
August	20800	26.1
September	16100	23.3
October	11800	19.4
November	7800	15.4
December	6100	11.3

	Zona D (Rome)	
	Total Horizontal Radiation [kJ/h*mq]	Temperature [C°]
January	6300	7.5
February	9200	8.6
March	13700	11.1
April	18900	14.1
May	23600	18.1
June	25700	22.1
July	27000	28.9
August	23300	24.6
September	17600	21.6
October	12200	16.8
November	7300	12.1
December	5400	8.8

	Zona E (Biella)	
	Total Horizontal Radiation [kJ/h*mq]	Temperature [C°]
January	4200	0.2
February	7100	2.9
March	11800	7.7
April	16700	12.5
May	20100	17.2
June	21900	21.7
July	24400	23.8
August	21600	22.8
September	14100	18.7
October	8400	12.7
November	4800	6.5
December	3500	1.8

8.4 Calibration of CHP model inputs to model 154

CHP Nominal condition		
Primary Energy Input [*1]	124	kW
Electric Power output [2]	35	kW
Thermal Power Output [3]	78	kW
Electrical Efficiency	28.2	%
Thermal Efficieny	62.9	%
Total efficiency[1,2,3]	91.1	%
Feeding	NG	
Outlet water temperature (max) [4]	85	°C
Intlet water temperature (max) [4]	70	°C
Nominal Outlet Heating Water flowrate	4.4	mc/h
Weight	1540	kg
Rotation speed	1500	rpm

Calibration notes

* LHV = 17.3 MJ/Nmc

1. According to DIN ISO 3046 and DIN 6271reported to standard condition and nominal rotation speed
2. According to VDE 0530 REM/IEC 34.1, power factor =1
3. Tolerance 8%
4. With water flow rate 9,7 mc/h, and outlet temperature tolerance 3%

Internal Combustioc Engine technical dates		
Nominal Power (1500 rpm) [7]	38	kW
Capacity	4400	cm3
Cycle	four time	
pressure rate	9,5 :1	
Average Pressure	7	bar
combustible consuption	13.6	Nm3/h
weight	355	kg

Calibration notes

7. According to DIN ISO 3046 and DIN 6271reported to standard condition and nominal rotation speed

Asyncronous electrical generator technical dates		
Nominal Power	35	kW
Voltage	400	V
Current	61	A
power factor	0,8-1	
frequency	50	Hz
rotation speed	1500	rpm
Ambient temperature (max)	50	°C
Efficiency		
100% load	90.5	%
75% load	90.2	%
50% load	88.5	%
25% load	81.9	%
weight	284	kg

CHP partload condition				
	%	**100**	**75**	**50**
Power mechanics	kW	35	25	15,6
Inlet Power	kW	108	87	65
Thermal output				
Water cooling + oil	kW	38	30	32
Exhaust gas at 120 °C	kW	26	23	17
Exhaust gas				
Exhaust gas temperature	°C	545	530	510
Exhaust gas flow rate	kg/h	275	206	138