Potentials of Fuel Cells as m-CHP Systems for Domestic Applications in the Framework of Energy Efficient and Sustainable Districts

G. Vourliotakis, D. Giannopoulos and M.A. Founti

Laboratory of Heterogeneous Mixtures and Combustion Systems

School of Mechanical Engineering

National Technical University of Athens, Greece

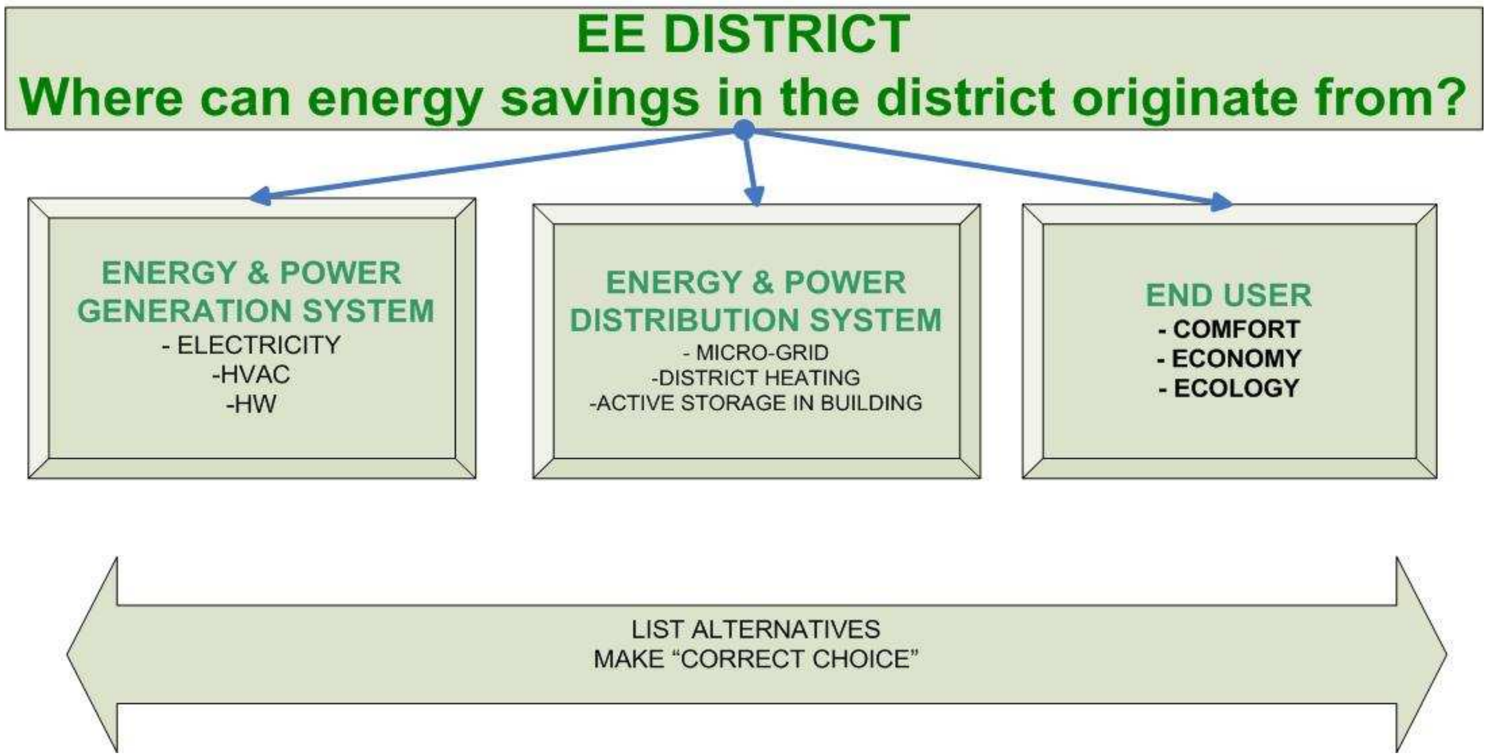
PRESENTATION OUTLINE

- Objectives of the work
- Decentralized Cogeneration of Heat and Power (CHP)
- μ-CHP Technologies
- Solid Oxide Fuel Cells (SOFC)
- Thermal and Electrical Integration of μ-CHP units at district level
- Case Study
- Conclusions

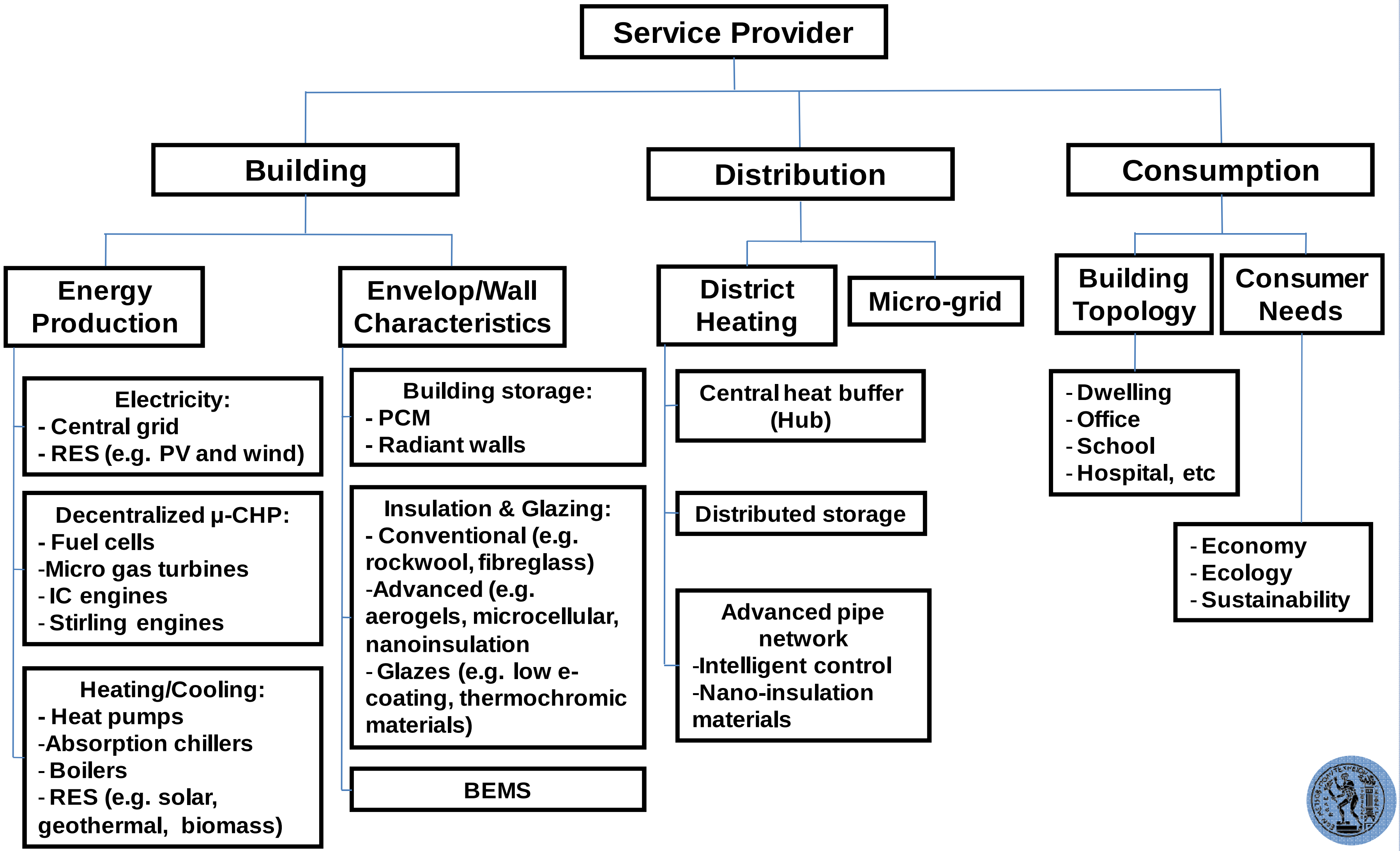
OBJECTIVES

Main Objectives:

- To introduce an innovative energy production and distribution concept for sustainable and energy efficient refurbished and/or new districts.
- To estimate the associated primary energy savings.

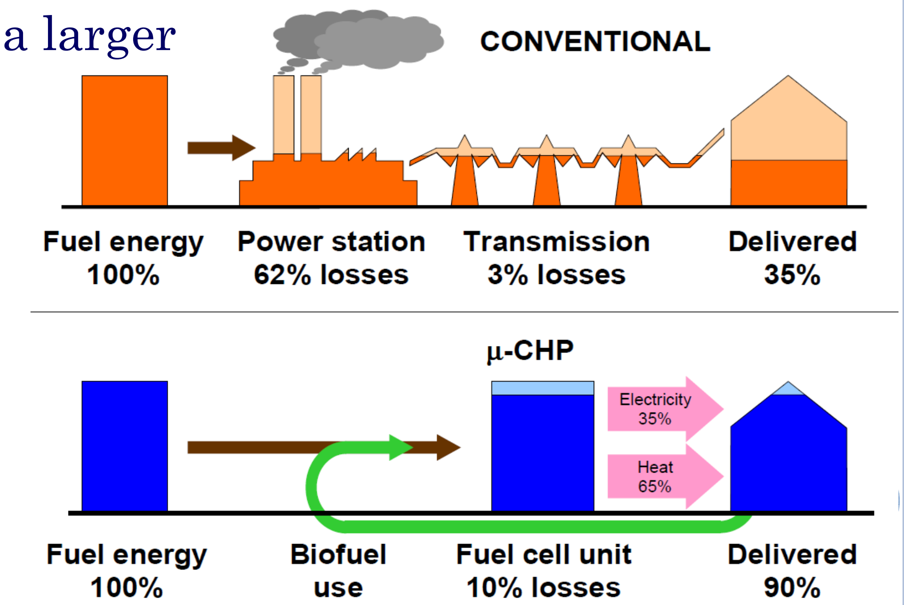


ENERGY SYSTEMS & TECHNOLOGIES



DECENTRALIZED CHP

- Savings in losses over the long transmission and distribution lines.
- Enhanced energy efficiency.
- Reduced pollutant emissions.
- Lower installation cost.
- Locally produced (bio-) fuels utilization.
- Local voltage regulation.
- Ability to add a small unit instead of a larger one during peak load conditions.



MICRO-CHP TECHNOLOGIES

	μ-CHP System				
	SOFC		Stirling engine	I.C. Engine	Micro-turbine
Manufacturer	(Literature data)		Stirling Systems	Senertec	Capstone
η_{el}^{CHP} (%)	25%	35%	20%	27%	26%
η_{th}^{CHP} (%)	65%	55%	70%	61%	59%
Power to Heat Ratio (PHR)	0.38	0.64	0.29	0.44	0.44
Nominal thermal output $\dot{Q}_{th}^{CHP}$ (kW_{th})	5.2	3.1	4.67	12.4	67.8
Nominal electric output $\dot{W}_{el}^{CHP}$ (kW_{el})	2.0		1.33	5.5	30.0

The SOFC System

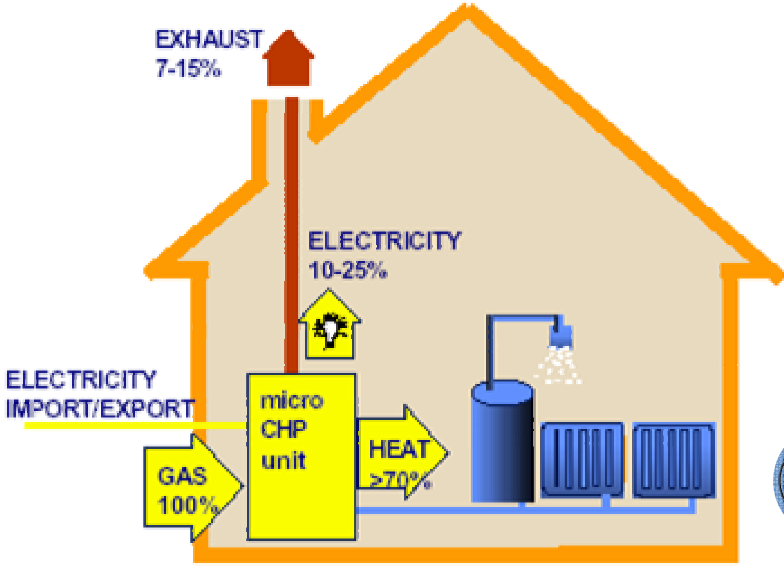
• Solid-oxide fuel cells have the potential of very high efficiencies at relatively high operating temperatures (650 – 1000 ºC).

• SOFCs can be used both for direct electricity generation and combined heat and power applications.

• SOFCs are fuel flexible and can operate on hydrocarbon or reformed-hydrocarbon fuels.

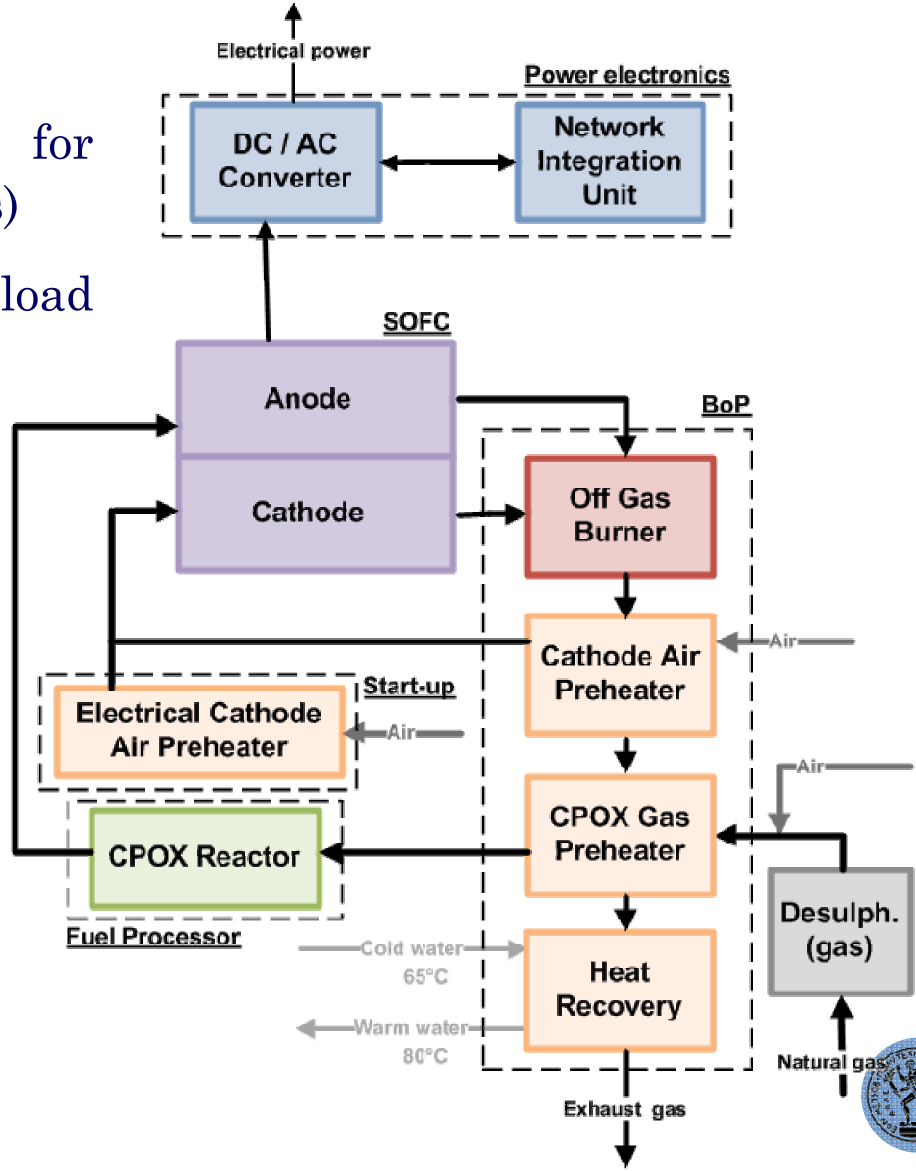
CHP250 SOFC Power System for Ontario Power Generation (2292 cells, 225 kWe @ efficiency > 45%, 250 kWe max)

Domestic applications: micro-CHP (electricity for lights and appliances, heat for central heating and hot water)



SOFC BASED MICRO-CHP

- High operating temperatures
- Versatile CPOX fuel processor for reforming of Natural gas (or Biogas)
- High efficiency in partial load conditions
- Suitable power heat ratio
- Tri-genaration capabilities

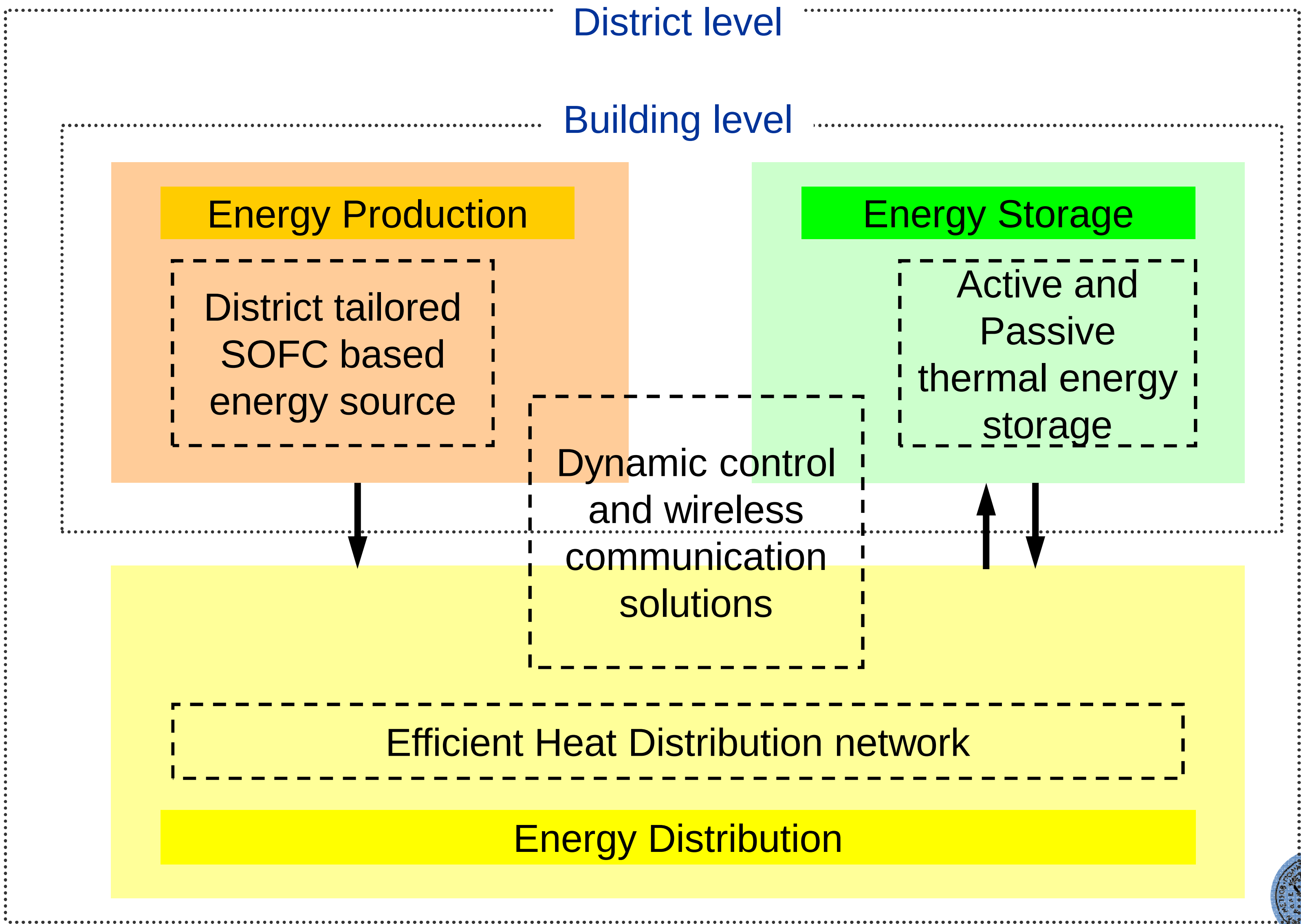


Thermal and Electrical Storage

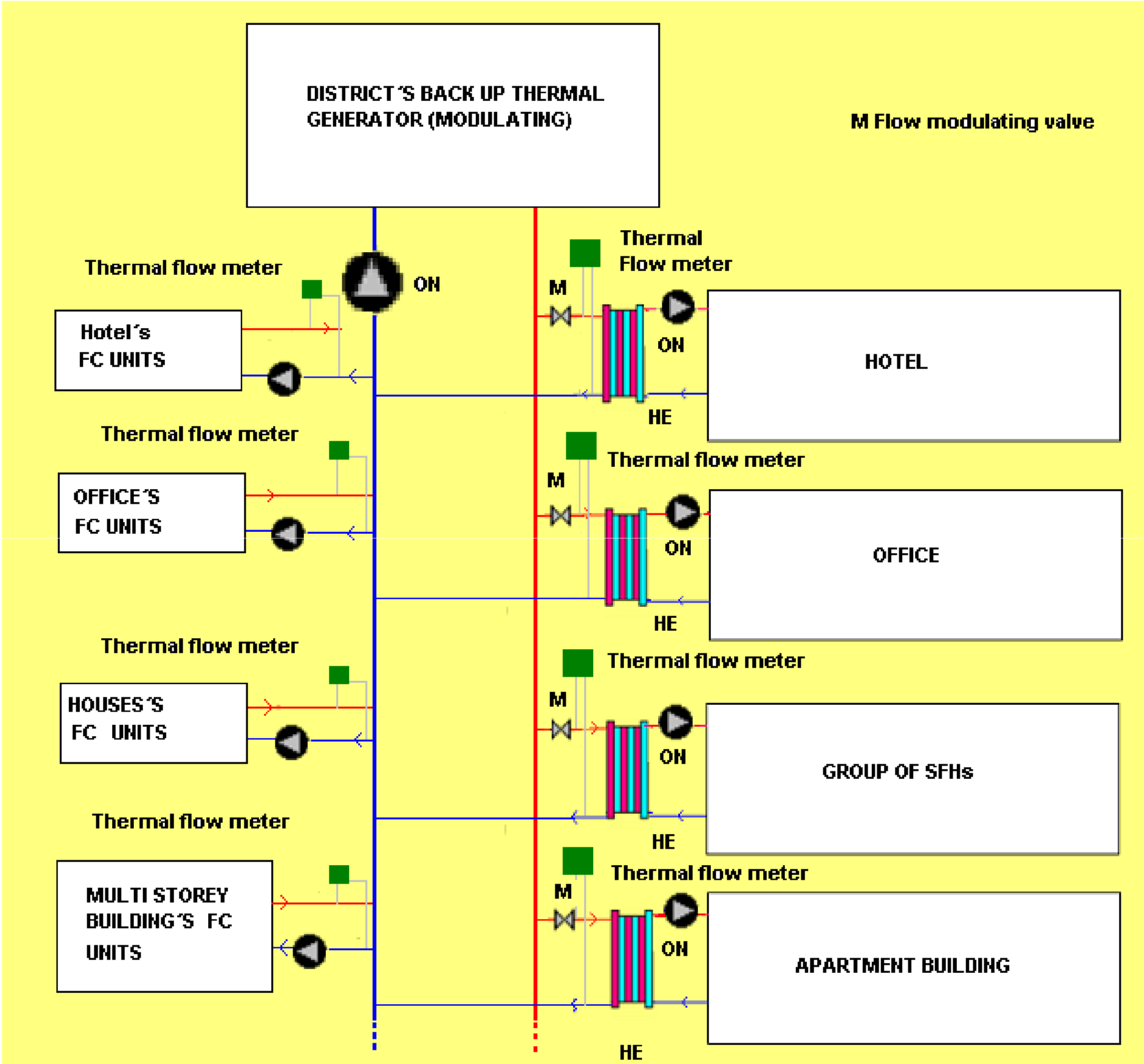
- <u>Load balance</u>
  - Thermal
    - Building: Building elements (PCMs)
    - Districts: “Smart” thermal netwroks
  - Electrical
    - Buildings: μ-grid, flywheels, battaries
    - Districts: smart-grid (ESCO)

- <u>Surplus energy storage for future use</u>
  - Thermal
    - Building: Building elements (PCMs)
    - District: Heat Buffer pipe network for dynamic load exchange
  - Electrical
    - Building: batteries
    - District: smart-grid (ESCO)

INTEGRATION

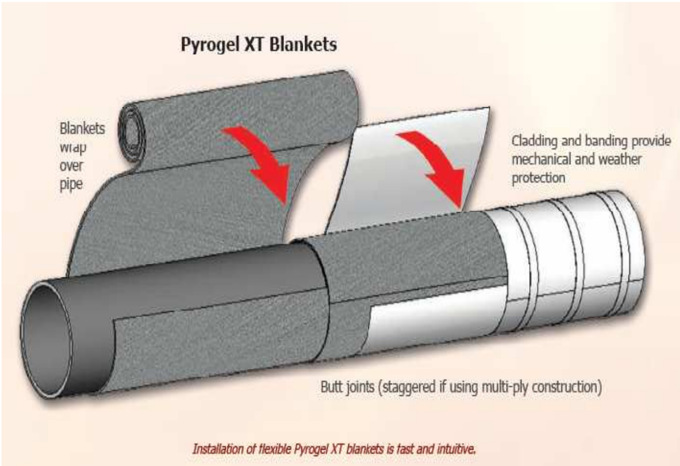


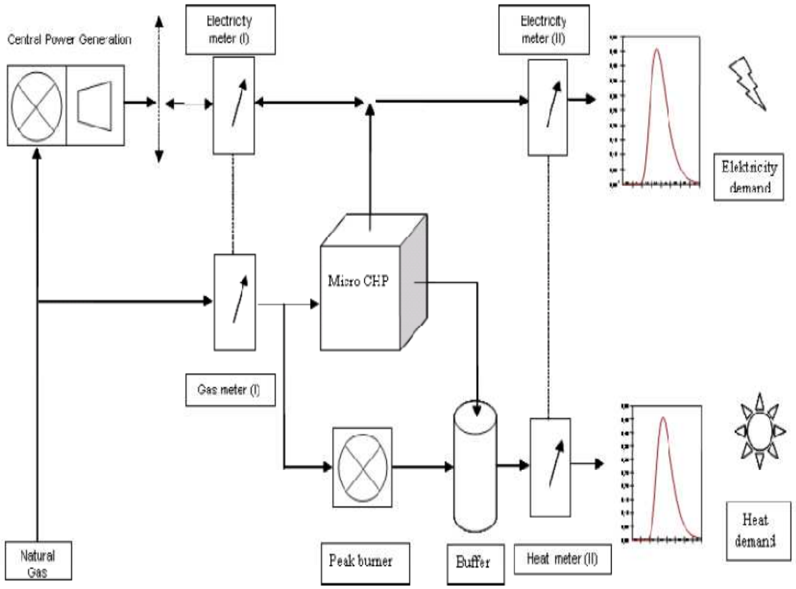
INTEGRATION



Thermal and Electrical Integration

- Advanced pipe insulating materials featuring «aerogels».
- Thermal losses minimization.
- Central heat buffer system.



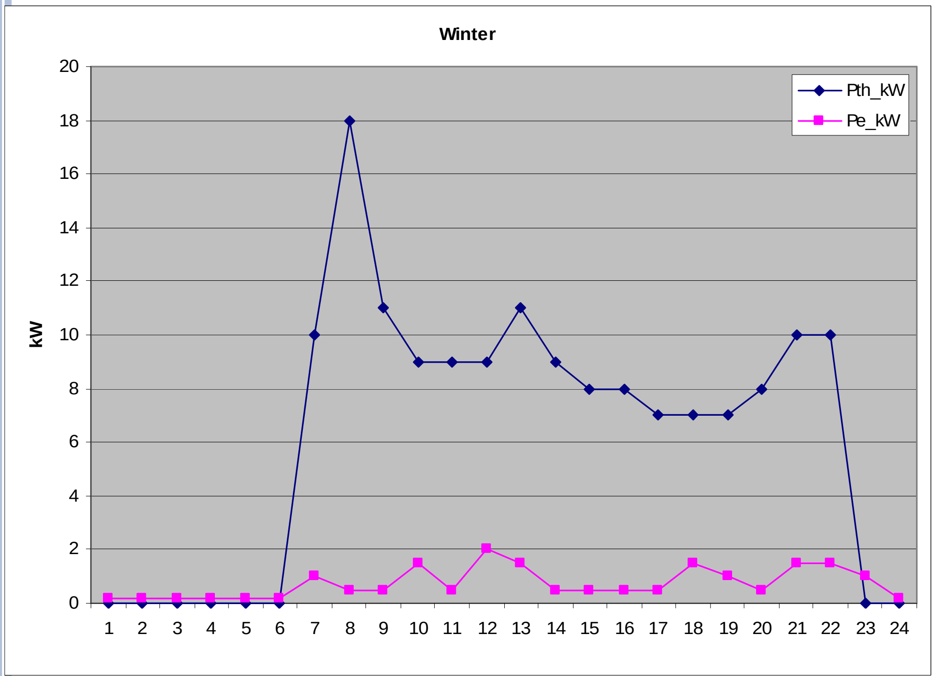


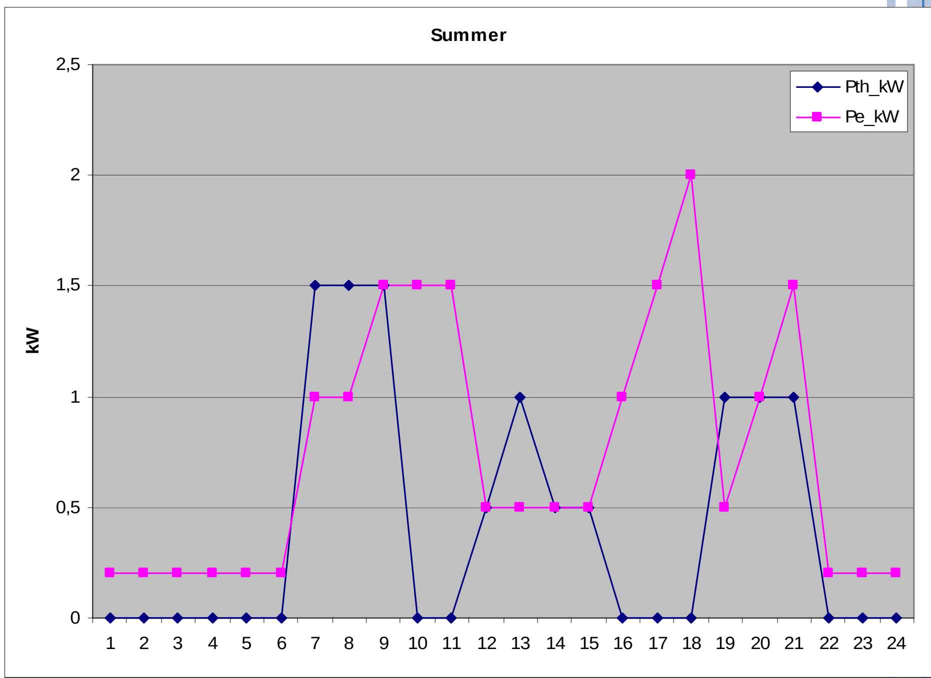
- "thermally driven" or "electrically driven" operation.
- Advanced control models and operating strategies.
- Virtual Power Plant configuration
- Overall district's needs and goal.

Case Study - Annual primary energy saving (1)

Energy Demand

- Domestic hourly heat and power load profiles from literature (Peacock and Newborough, 2006)
- Typical winter and summer days

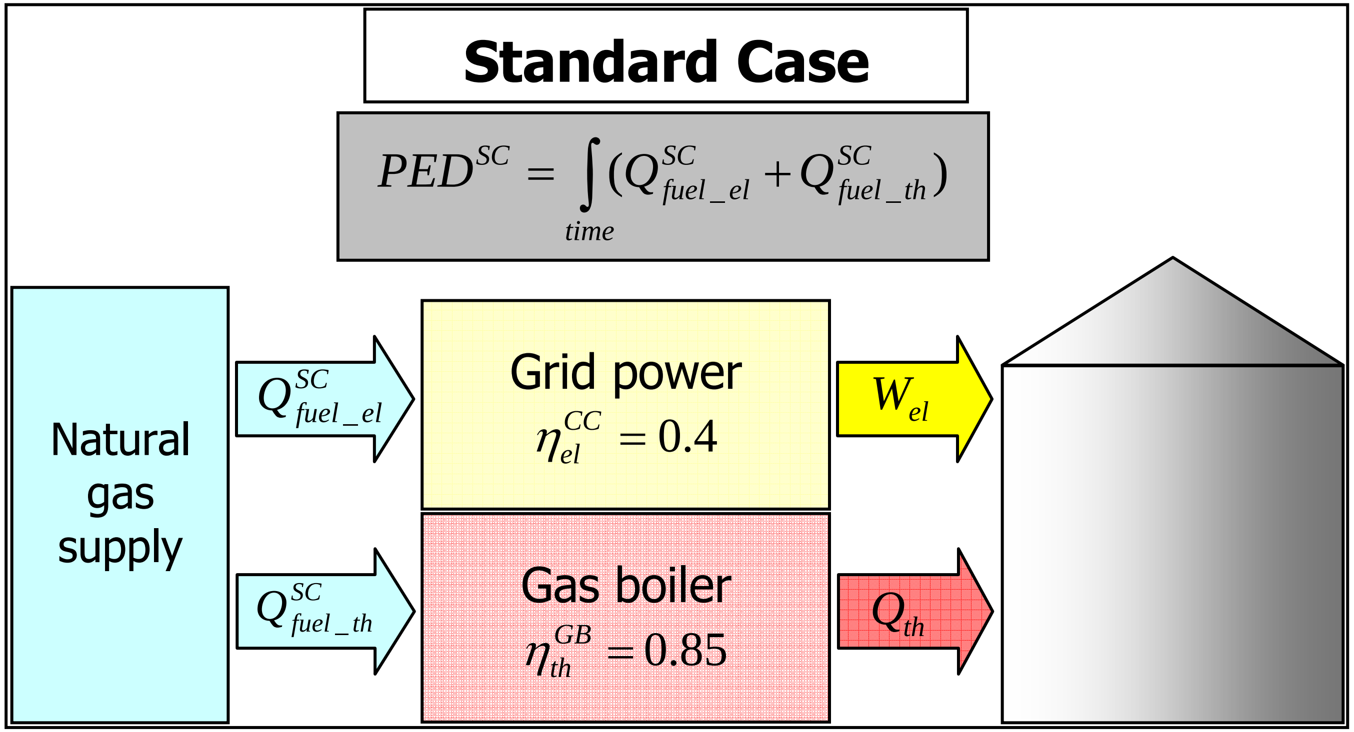




Case Study - Annual primary energy saving (2)

Energy Supply – Standard Case

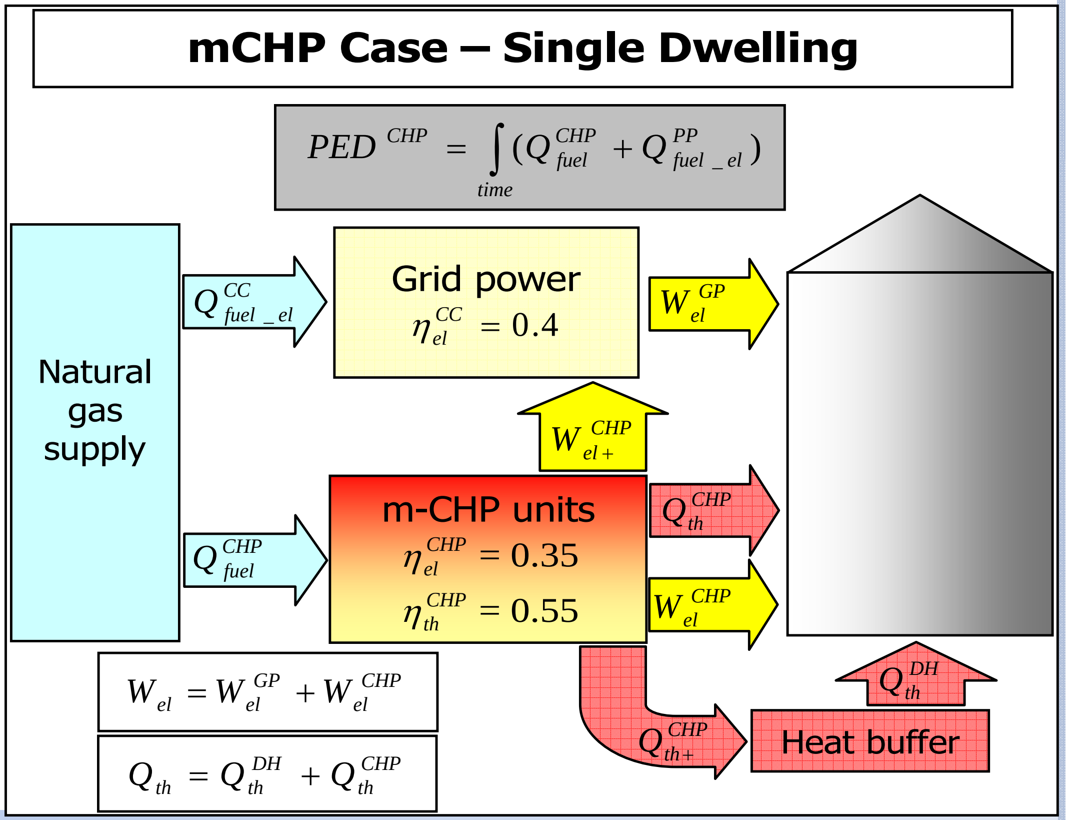
- Separate heat and electricity production for n dwellings
- Wel (kW): Electricity demand – Qth (kW): Heat demand
- $APED_S$: Annual Primary Energy Demand for Standard Case



Case Study - Annual Primary Energy Saving (3)

Energy Supply – Micro-CHP case

- Independent, self sufficient heat network of n dwellings
- Micro-CHP: SOFC units with η_{CHP}=90%, η_{el}=25-35% , W_{elCHP}=2-2.8 kW
- Central heat buffer: Less FC units needed, more working time for each
- $APED_{CHP}$: Annual Primary Energy Demand for the integrated District Case



- Same energy demand with Standard Case covered:
- Power: CHP ± Grid
- Heat: CHP ± Heat buffer

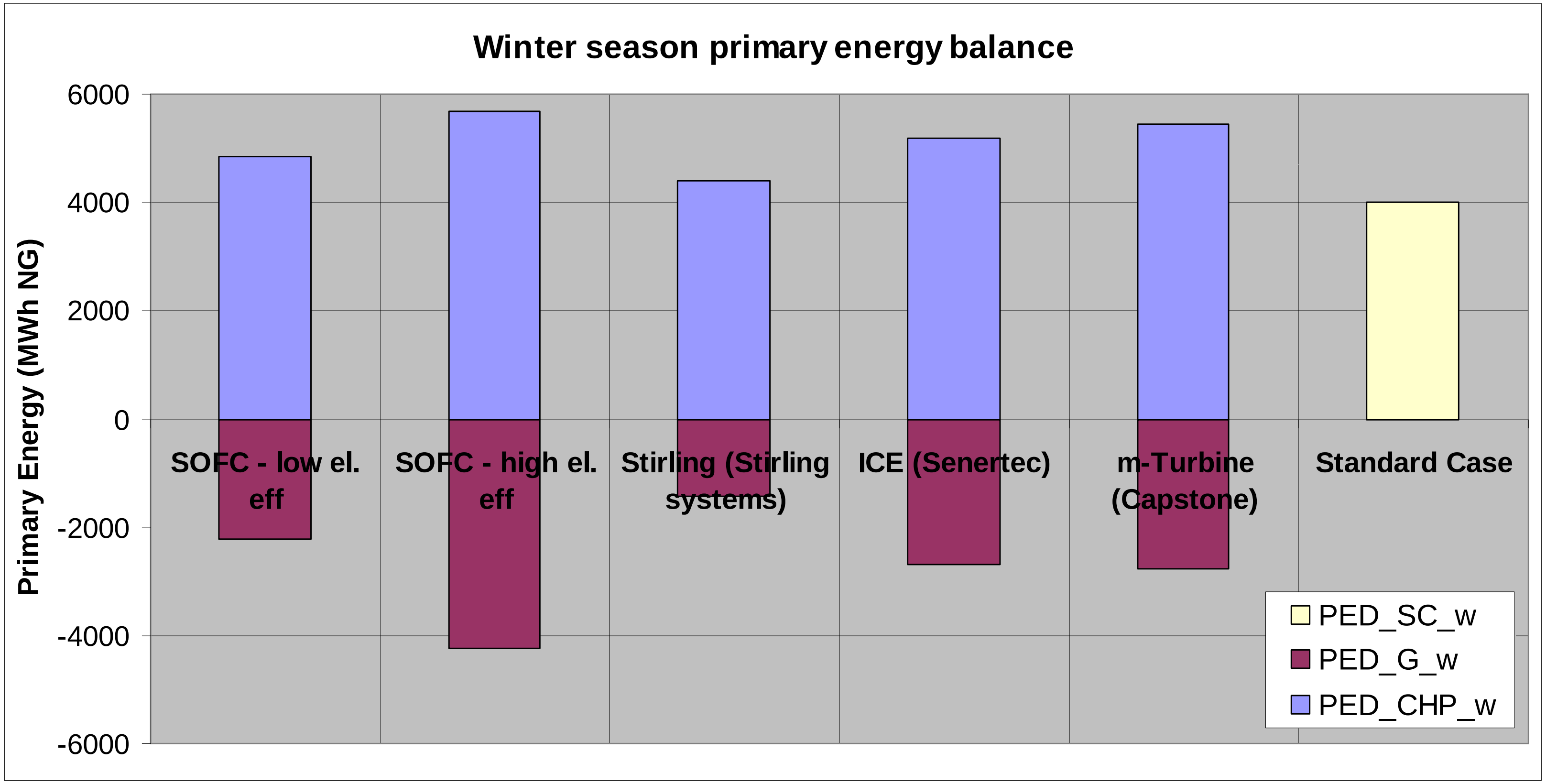
$$W_{el} = W_{el\_PP} + W_{el}^{CHP}$$

$$Q_{th} = Q_{th}^{DH} + Q_{th}^{CHP}$$

Case Study - Annual primary energy saving (4)

Operation of microCHP "swarm"

- Annual load: 6 months winter, 6 months summer.
- Number of FC microCHP units : Covering @ steady full capacity the annual thermal ENERGY load of n dwellings

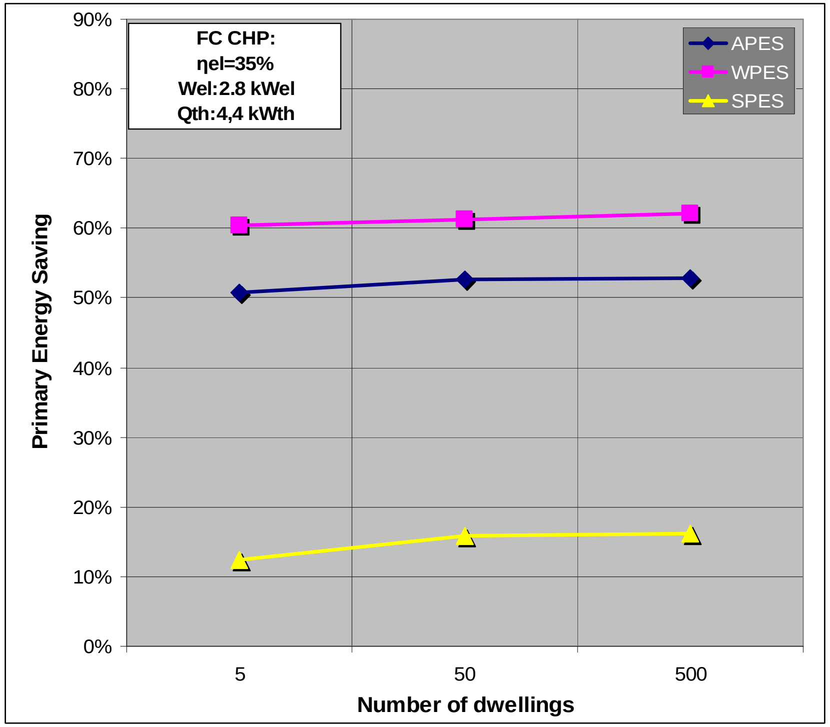


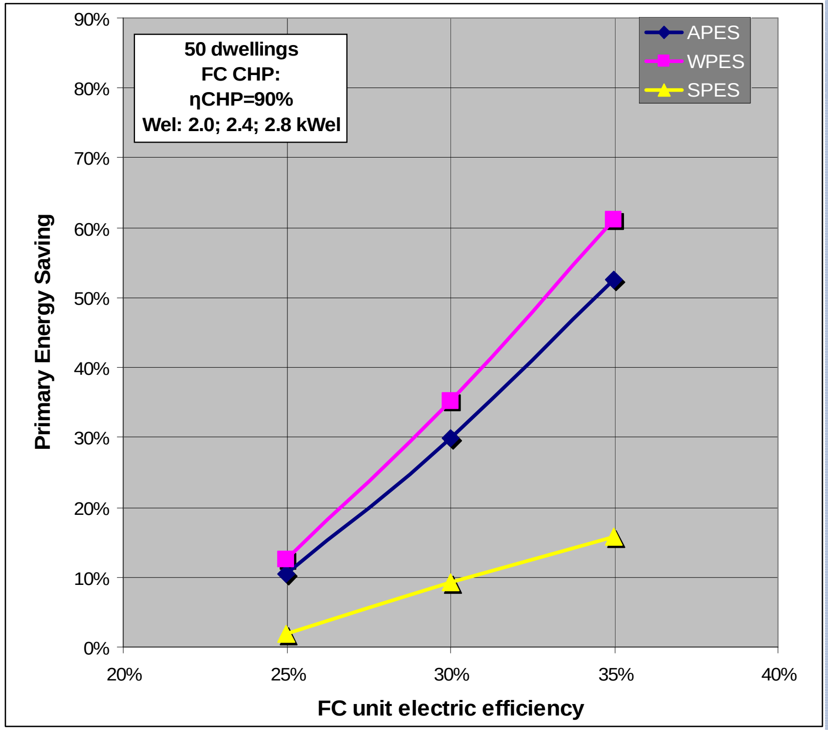
CASE STUDY - ANNUAL PRIMARY ENERGY SAVING (5)

Results

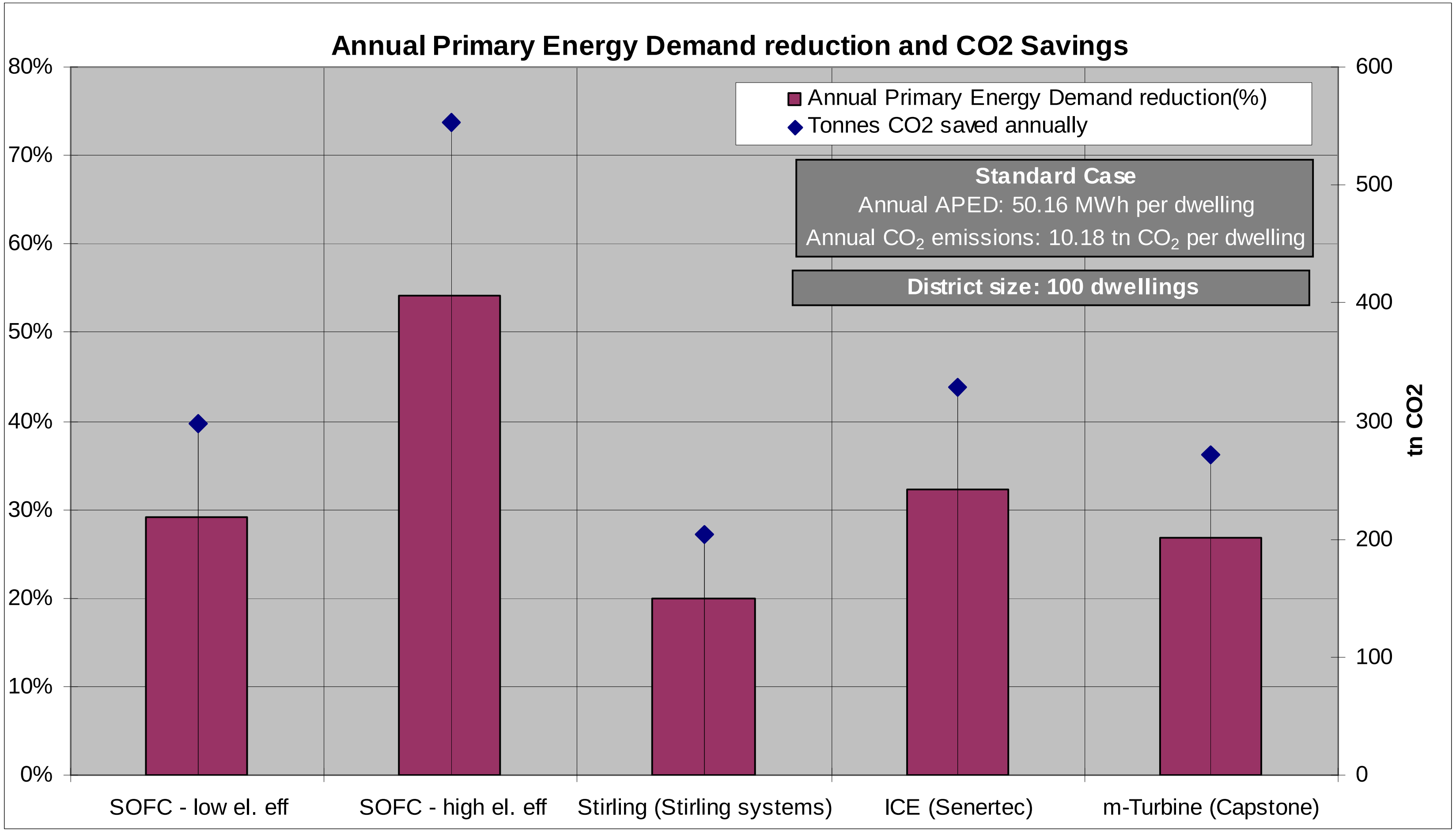
- APEDS = 50.16 MWh (NG energy) per dwelling
- APES = (APEDS – APEDCHP)/APEDS : Annual Primary Energy Saving
- WPES: Winter PES, SPES: Summer PES

Parameters: # of dwellings connected, ηel of FC





CASE STUDY - ANNUAL PRIMARY ENERGY SAVING (6)



- Energy savings up to 55%.
- 3,5 GWh reduced consumption (assumed 100 dwellings).
- Maximum reduction of CO_2 emissions: 550 tn/y

CONCLUSIONS

- Concept applicability: new or refurbished "districts" featuring "complementary" load profiles.
- The PHR of μ-CHP SOFC systems makes them ideal for domestic applications.
- An optimized control system is a prerequisite for heat load balancing within district boundaries.
- Key elements for concept implementation: low energy buildings (insulation), improved low temperature district heating pipe network (insulation, diameter, temp. levels), local and/or central heat buffer, real time control strategies.
- Advanced operational and business models allow the interaction between consumers and ESCOs
- Building and energy system integration results in higher overall efficiency.
- Primary energy savings of the order of 55 %.

THE FC-DISTRICT PROJECT

Project co-funded by EC. Grant no 260105

www.fc-district.eu

Thank you for your attention!

The work has been performed in the framework of the EU founded FC-DISTRICT project: New μ-CHP network Technologies for energy efficient and sustainable districts (Grand No. 260105).

SOFC BASED MICRO-CHP

Specification of SOFC based co-generation system	
General	Gas appliance for single-family homes and district heating environments for providing demand-flexible electricity and heat
Fuel input	Natural gas (H-gas and L-gas), biogas
Nom. max capacity	1.5 kW_{el} / 2.75 kW_{th} at 30% net electrical efficiency
Modulation	1:2
Emissions	NOx < 60 mg/kWh, CO < 50 mg/kWh at 0% O_2 (Blue Angel)
Dimensions	L x W x H: 1000 x 800 x 1800 mm^3

EBZ GmbH Fuel Cells
Phone: +49(0)351/47939-16
Fax: +49(0)351/47939-18
Email: sales@ebz-dresden.de
Postal: Marschnerstrasse 26, 01307 Dresden, Germany
Visitors: Seifhennersdorfer Straße 16, 01099 Dresden, Germany
Web: www.ebz-fc.de

CASE STUDY – RESULTS SUMMARY

		m-CHP systems					Standard Case	
		SOFC		Stirling engine	I.C. engine	Micro-turbine		
		η_{el}^{CHP} 25%	η_{el}^{CHP} 35%					
PED^{CHP_w}	MWh_{NG}/ (winter or summer)	4838.4	5697.7	4393.1	5181.2	5460.8	PED^{SC_el}	1606.5
PED^{CHP_s}		345.6	389.6	316.8	351.3	496.4		
PED^{G_w}		2218.5	4248.9	1440.3	2699.1	2758.5	PED^{SC_th}	3409.4
PED^{G_s}		-585.0	-455.4	-642.6	-563.4	-477		
APED	MWh_{NG}/ year	3550.5	2293.8	4012.2	3396.7	3675.7	5015.9	
Annual reduction potential	%	29.2%	54.3%	20.0%	32.3%	26.7%	-	
Annual CO_2 emissions	Tonnes CO_2/year	720.8	465.6	814.5	689.5	746.2	1018.2	
Annual CO_2 emissions reduction		297.4	552.6	203.7	328.7	272.0	-	

- Energy savings of the order of 55%.
- 3,5 GWh reduced consumption (assumed 100 dwellings).
- Reduce in CO_2 emissions: 550 tn/y