Potential of fuel cells as micro-CHP systems for domestic applications

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NTUA - PV seminar

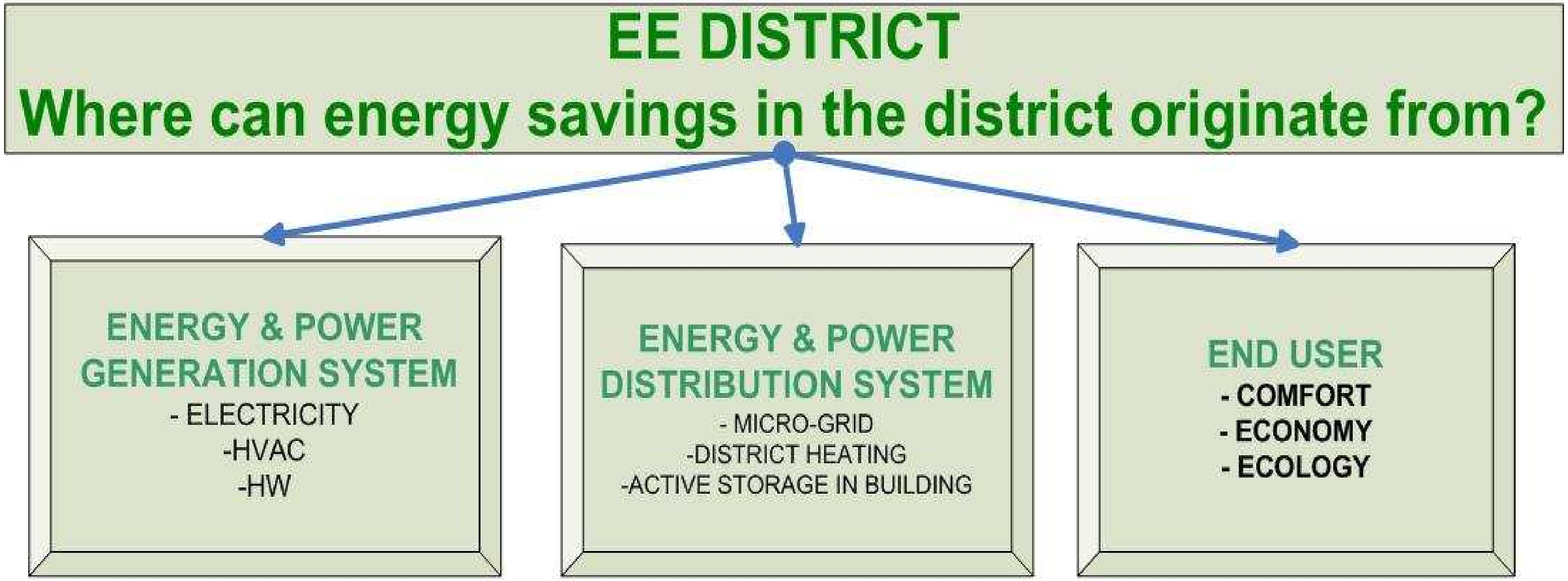
PRESENTATION OUTLINE

- Overall objective
- Decentralized Cogeneration of Heat and Power (CHP)
- micro-CHP technologies
- SOFC fuel cells
- Thermal and electrical network of micro-CHP units
- Case study
- Conclusions

OBJECTIVE

ENERGY EFFICIENT / AUTONOMUS DISTRICT

Innovative scheme (thermal network) for energy production and management in refurbished and/or new energy efficient and sustainable districts.



EE DISTRICT

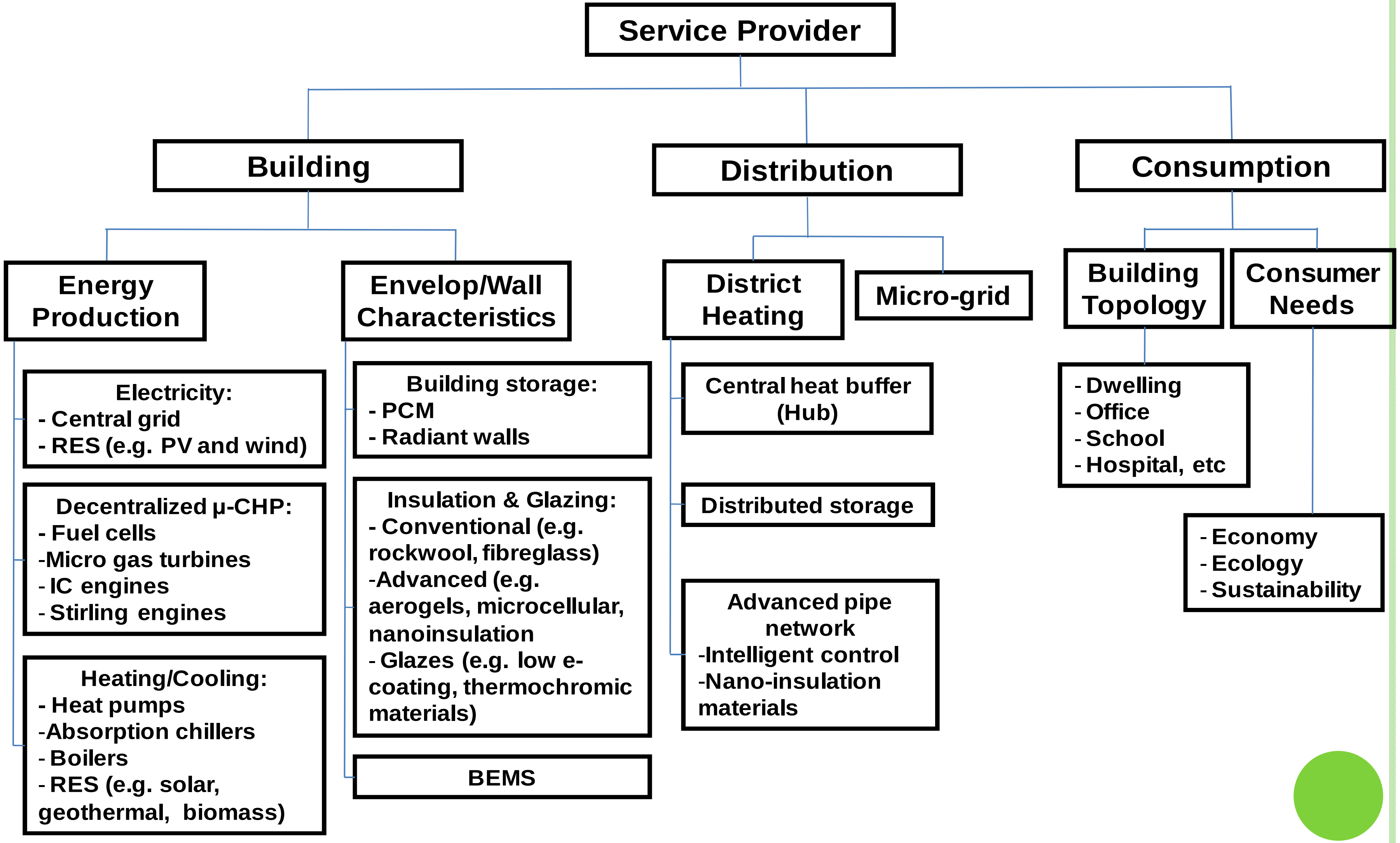
Where can energy savings in the district originate from?

ENERGY & POWER GENERATION SYSTEM
- ELECTRICITY
-HVAC
-HW

ENERGY & POWER DISTRIBUTION SYSTEM
- MICRO-GRID
-DISTRICT HEATING
-ACTIVE STORAGE IN BUILDING

END USER
- COMFORT
- ECONOMY
- ECOLOGY

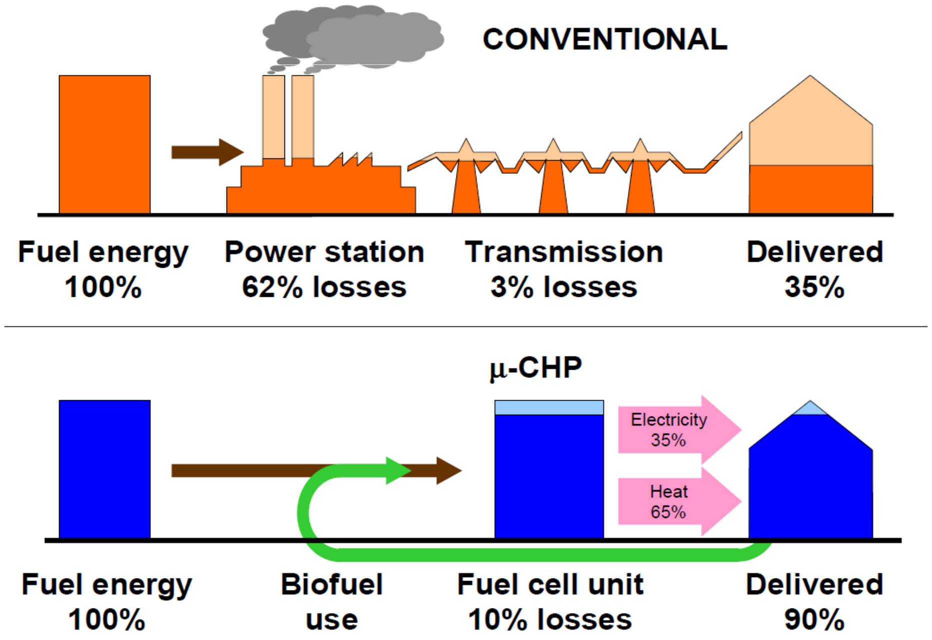
TECHNOLOGIES AND SYSTEMS FOR IMPROVED ENERGY USE



- **Service Provider**
  - **Building**
    - **Energy Production**
      - Electricity:
        - Central grid
        - RES (e.g. PV and wind)
      - Decentralized μ-CHP:
        - Fuel cells
        - Micro gas turbines
        - IC engines
        - Stirling engines
      - Heating/Cooling:
        - Heat pumps
        - Absorption chillers
        - Boilers
        - RES (e.g. solar, geothermal, biomass)
    - **Envelop/Wall Characteristics**
      - Building storage:
        - PCM
        - Radiant walls
      - Insulation & Glazing:
        - Conventional (e.g. rockwool, fibreglass)
        - Advanced (e.g. aerogels, microcellular, nanoinsulation
        - Glazes (e.g. low e-coating, thermochromic materials)
      - BEMS
  - **Distribution**
    - **District Heating**
      - Central heat buffer (Hub)
      - Distributed storage
      - Advanced pipe network
        - Intelligent control
        - Nano-insulation materials
    - **Micro-grid**
  - **Consumption**
    - **Building Topology**
      - Dwelling
      - Office
      - School
      - Hospital, etc
    - **Consumer Needs**
      - Economy
      - Ecology
      - Sustainability

DECENTRALIZED CHP

- No central grid use - No transmission losses
- High energy efficiency
- Reduced pollutant emissions
- Reduced capital cost
- Potential use of locally produced bio-fuels
- Local voltage regulation



CONVENTIONAL

Fuel energy 100%

Power station 62% losses

Transmission 3% losses

Delivered 35%

µ-CHP

Electricity 35%

Heat 65%

Fuel energy 100%

Biofuel use

Fuel cell unit 10% losses

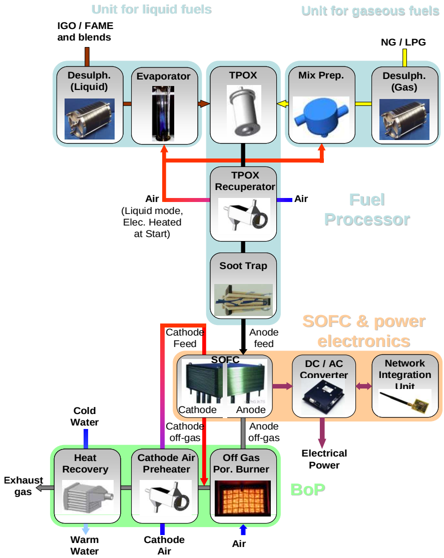
Delivered 90%

MICRO-CHP TECHNOLOGIES

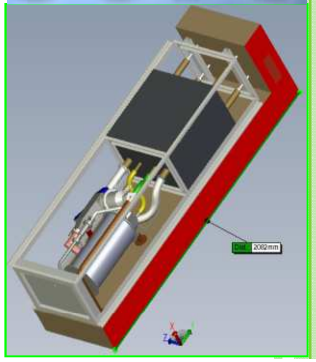
	Reference technical performance of microCHP technologies				
	Solid Oxide Fuel Cell (SOFC)		**Stirling Engine**	**I.C. Engine**	**Micro-turbine**
Manufacturer	FlameSOFC EU funded research project		Stirling Systems (ex Solo)	Senertec	Capstone
η_{CHP_el} (%)	25%	35%	20%	27%	26%
η_{CHP_th} (%)	65%	55%	70%	61%	59%
Power to Heat Ratio (PHR)	0.38	0.64	0.29	0.44	0.44
Thermal output (nominal) $\dot{Q}_{CHP\_th}$ (kW_{th})	5.2	3.1	4.67	12.4	67.8
Electric output (nominal) $\dot{W}_{CHP\_el}$ (kW_{el})	2.0		1.33	5.5	30.0

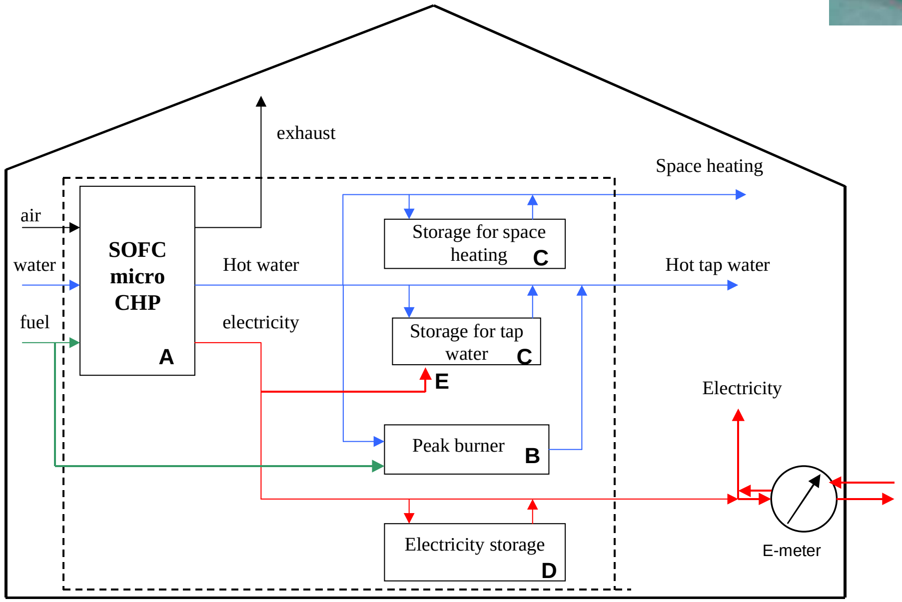
SOFC MICRO-CHP SYSTEMS

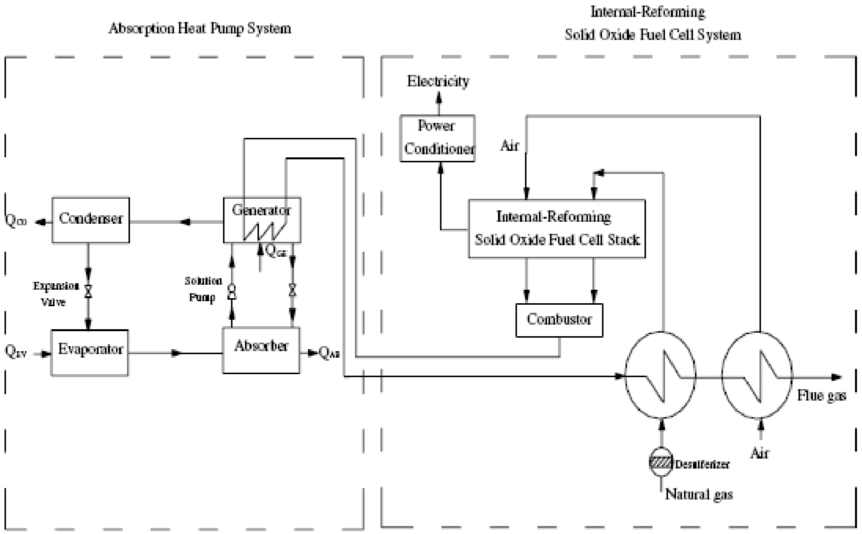
- High operational temperatures
- Fuel flexibility
- High efficiency at partial load operation
- Combination with cooling systems (e.g. sorption chillers)



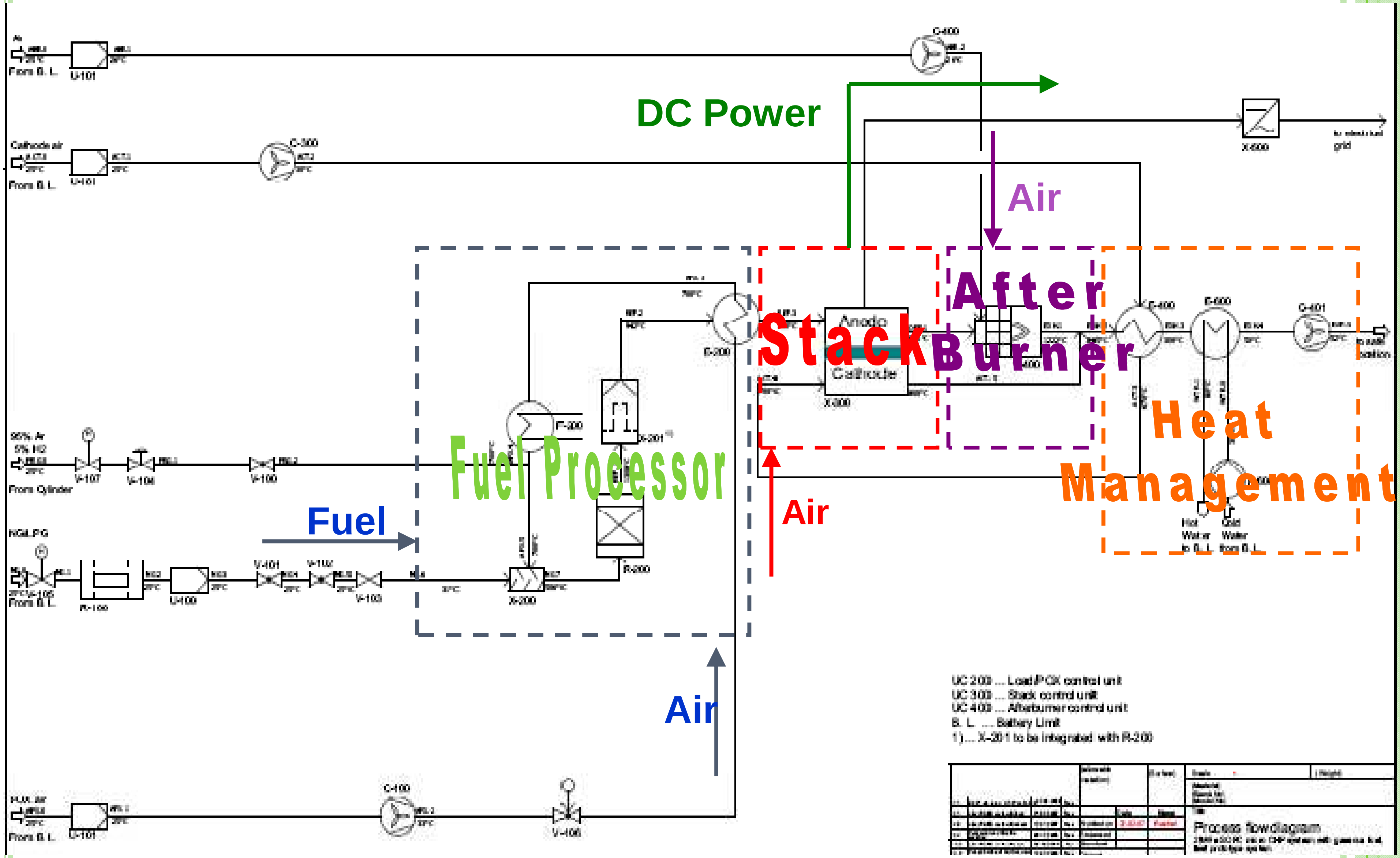
Flame SOFC







FLOWSHEET OF AN SOFC MICRO-CHP SYSTEM



UC 200 ... Load/POX control unit
UC 300 ... Stack control unit
UC 400 ... Afterburner control unit
B. L. ... Battery Limit
1)... X-201 to be integrated with R-200

SOFC MICRO-CHP DOMESTIC MARKET

Hexis Galileo 1000 N
1.0 kWel, 2 kWth
ηel > 30 % (SR, NG)

STAXERA and EBZ
2 x 1.0 kWel
ηel: 50 % @ uf = 75 % (SR, NG)

SOFC MICRO-CHP DOMESTIC MARKET

Vaillant system

1 kWel and 1,8 kWth (CPOX, NG)

ηel: 30% (net AC, NG LHV), ηth: 55%

CFCL system – BlueGen

2 kWel (SR, NG)

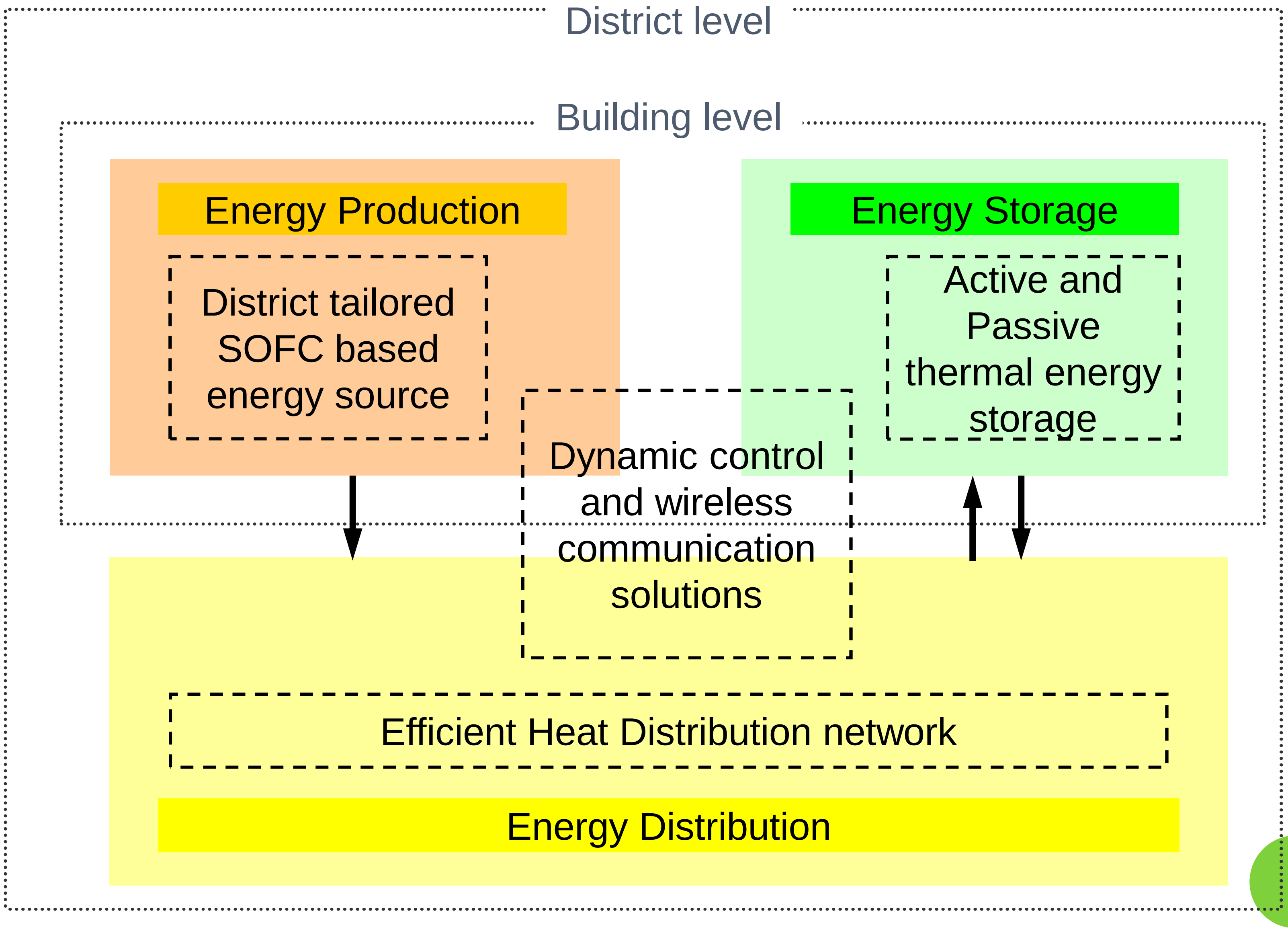
ηel: 60%, HPR < 0.5

THERMAL AND ELECTRICAL STORAGE

- <u>Load Balance</u>
  - Thermal
    - Building: building materials (Phase Change Materials - PCM)
    - District: smart thermal grid
  - Electrical
    - Building: μ-grid, flywheels, batteries
    - District: smart-grid (ESCO)

- <u>Excess energy production for future use</u>
  - Thermal
    - District: Heat Buffer and pipe network for dynamic heat load control
    - Building: building materials (PCM)
  - Electrical
    - District: smart-grid (ESCO)
    - Building: batteries, capacitors

INTEGRATION CONCEPT



District level

Building level

Energy Production

District tailored SOFC based energy source

Energy Storage

Active and Passive thermal energy storage

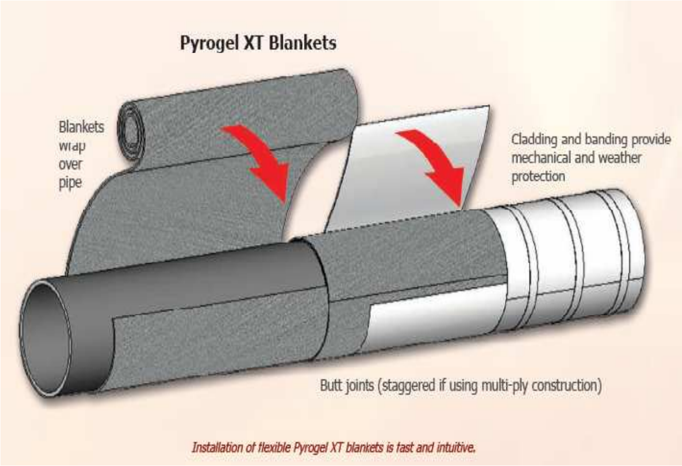
Dynamic control and wireless communication solutions

Efficient Heat Distribution network

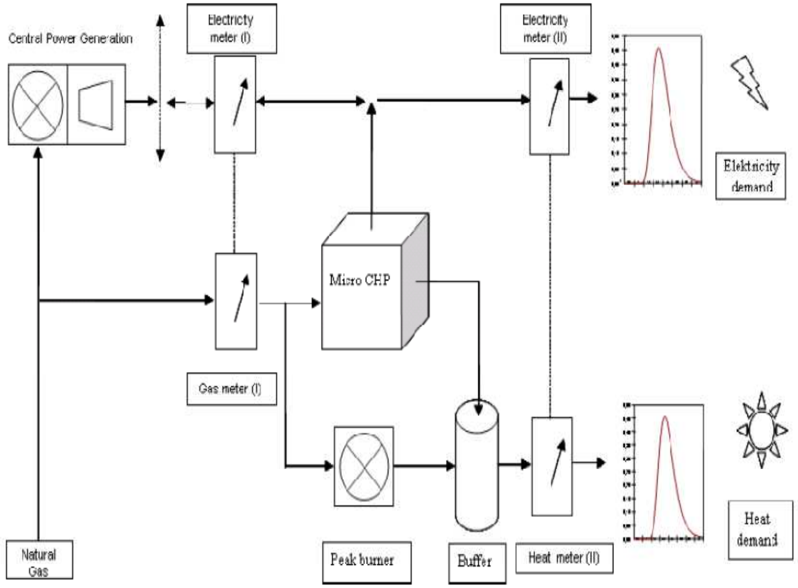
Energy Distribution

THERMAL AND ELECTRICAL INTEGRATION

- Advanced pipe materials with “aerogel”
- Thermal losses minimization
- Central heat buffer system



Installation of flexible Pyrogel XT blankets is fast and intuitive.



- Thermally and electrically driven system
- Advance control models and optimized overall operation strategy
- “Virtual Power Plant” realization
- District needs/targets

CASE STUDY

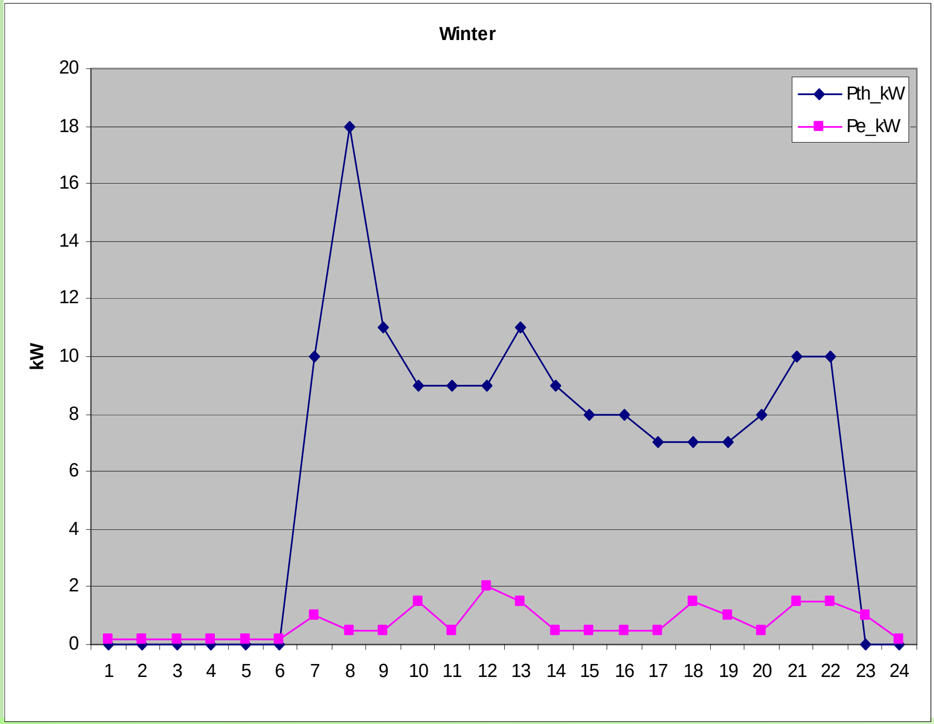
Annual primary energy savings (1)

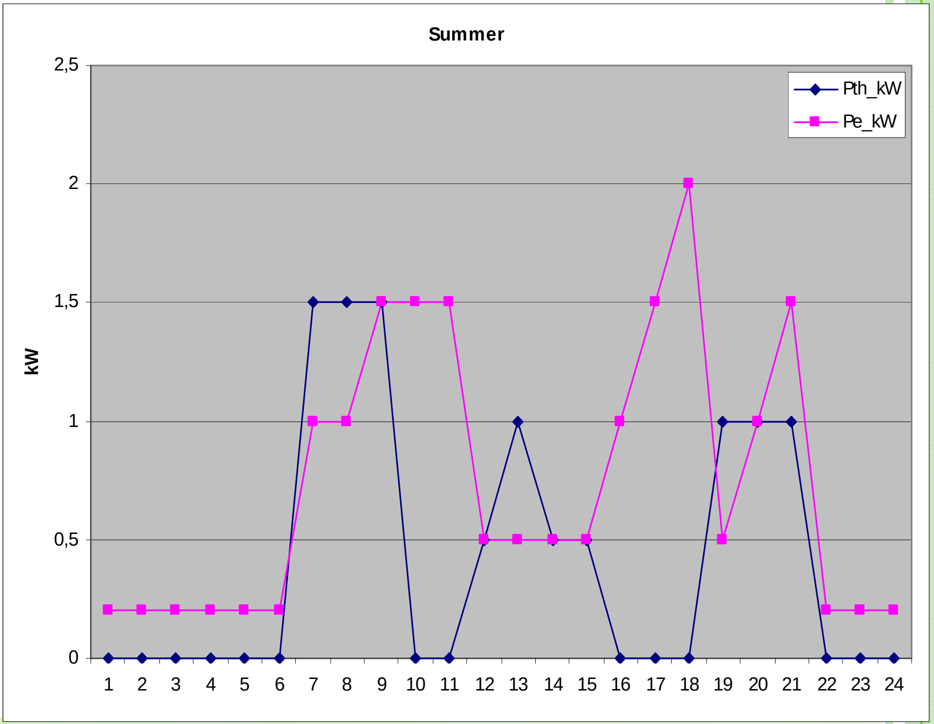
Energy demand

- Domestic hourly heat and power load profiles from literature

(Peacock and Newborough, 2006)

- Typical summer and winter days

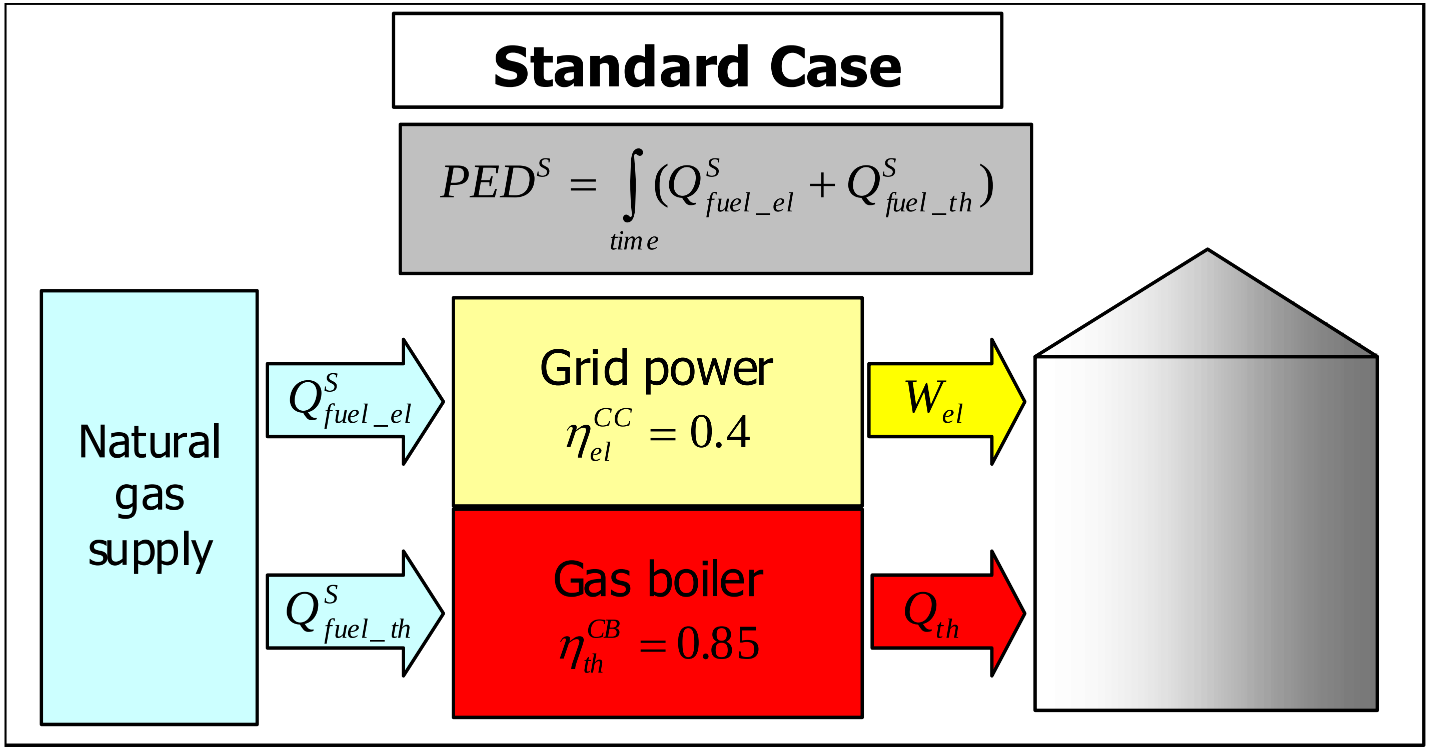




Annual primary energy savings (2)

Energy supply – Standard Case

- Separate heat and electricity production for n dwellings
- W_{el} (kW): Electricity demand – Q_{th} (kW): Heat demand
- $APED^S$: Annual Primary Energy Demand for Standard Case



Standard Case

$$PED^S = \int_{time} (Q^S_{fuel\_el} + Q^S_{fuel\_th})$$

Natural gas supply

$Q^S_{fuel\_el}$

Grid power

$\eta^{CC}_{el} = 0.4$

W_{el}

$Q^S_{fuel\_th}$

Gas boiler

$\eta^{CB}_{th} = 0.85$

Q_{th}

Annual primary energy savings (3)

Energy supply – Standard Case

- Independent, self sufficient heat network of ***n*** dwellings
- Micro-CHP: SOFC units, η_{CHP}=90%, η_{el}=25-35% , W_{el}^{CHP} = 2 kW
- Central heat buffer: Less FC units needed, more working time for each
- APED^{CHP}: Annual Primary Energy Demand for CHP Case

Same energy demand with Standard Case covered:

❖ Power.: CHP ± Grid

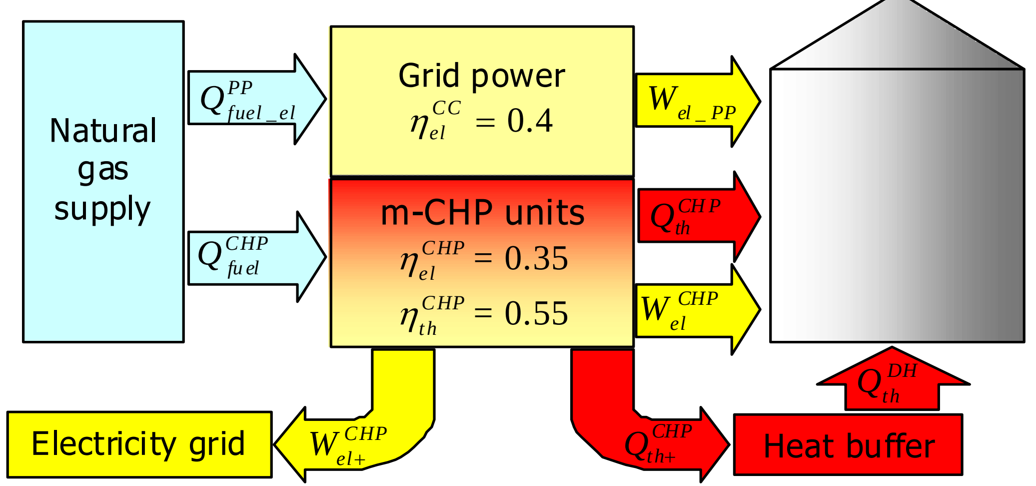
❖ Heat: CHP ± Heat buffer

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

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

Micro-CHP case – single dwelling

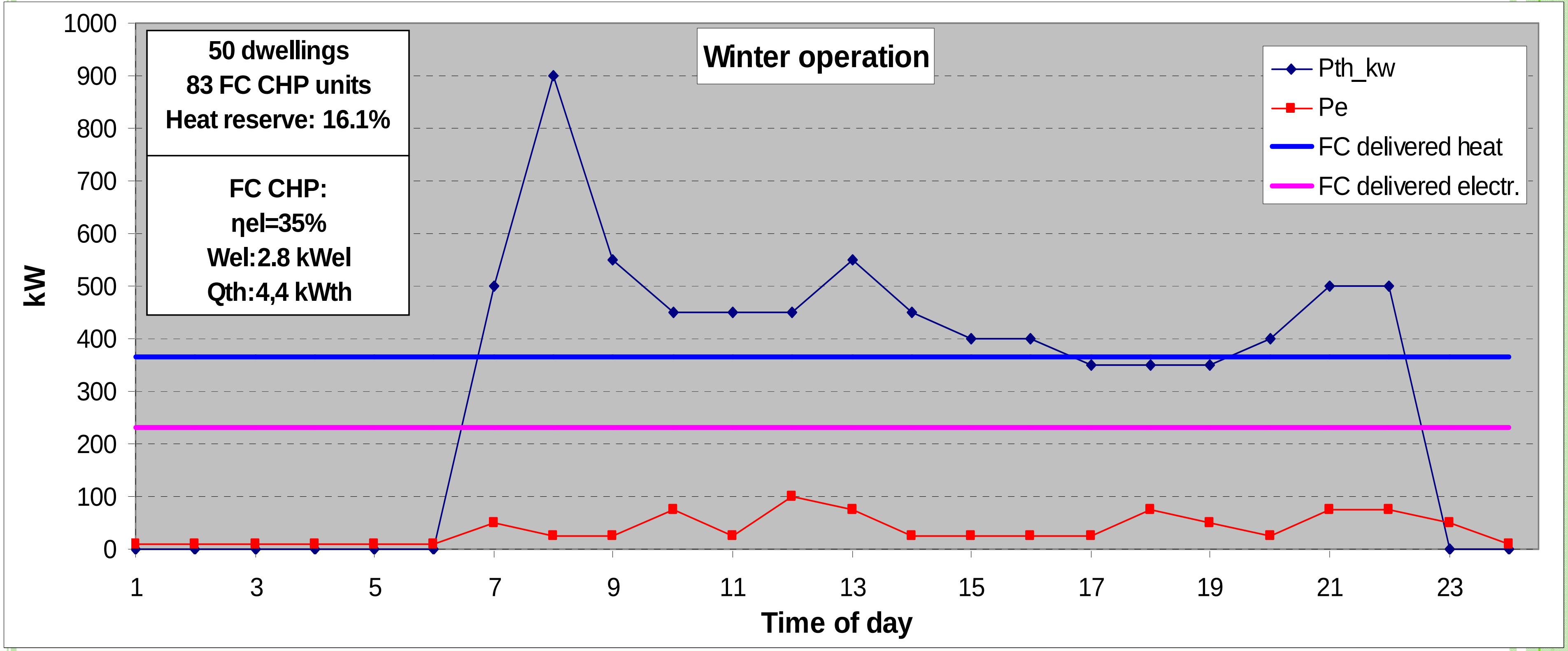
$$PED^{CHP} = \int_{time} (Q_{fuel}^{CHP} + Q_{fuel\_el}^{PP})$$



Annual primary energy savings (4)

Operation of microCHP "swarm"

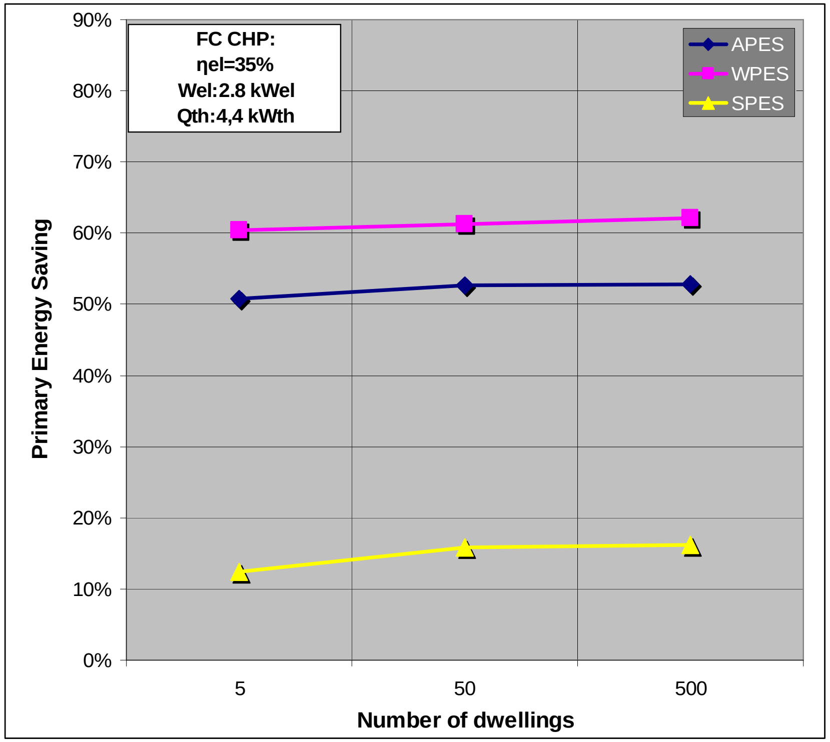
- Annual load: 6 months winter, 6 months summer.
- Number of FC microCHP units : Covering @ steady full capacity the annual thermal ENERGY load of n dwellings

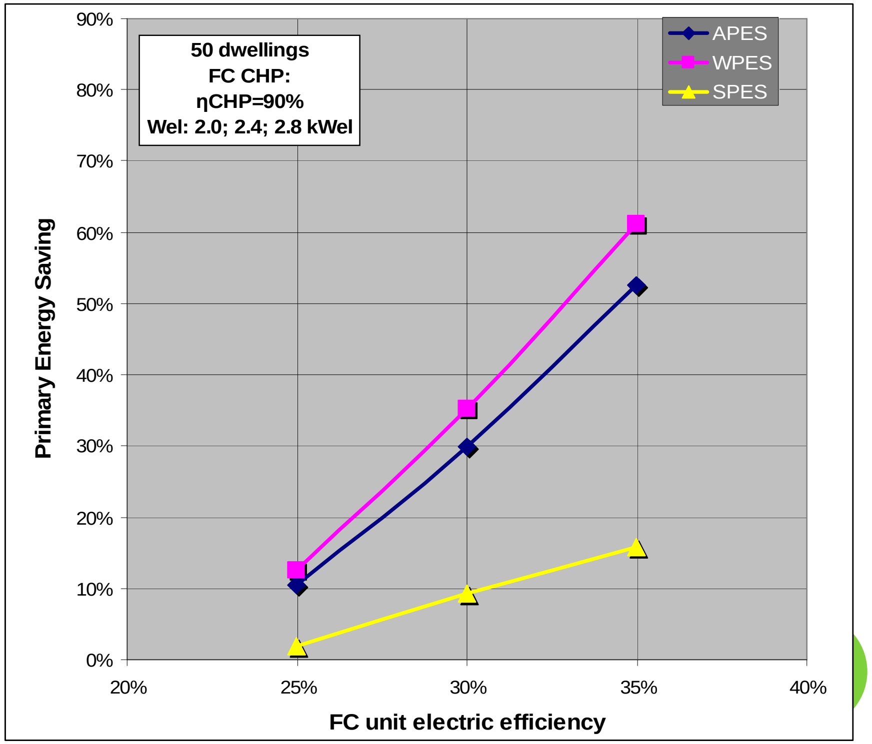


Annual primary energy savings (5) – Results

- ❖ $APED^S$ = 50.16 MWh (NG energy) per dwelling
- ❖ APES = $(APED^S – APED^{CHP})/APED^S$: Annual Primary Energy Saving
- ❖ WPES: Winter PES, SPES: Summer PES

Parameters: # dwellings, η_{el} of micro-CHP





CONCLUSIONS

		Energy and emissions performance of microCHP technologies					Conventional Case	
		SOFC		Stirling Engine	I.C. Engine	Micro-turbine		
		η_{CHP_el} 25%	35%					
Primary Energy Demand (PED) – CHP, Winter	MWh NG/year	4838.4	5697.7	4393.1	5181.2	5460.8	Annual PED due to electric load	1606.5
Primary Energy Demand (PED) – CHP, Summer		345.6	389.6	316.8	351.3	496.4		
Primary Energy saved due to electricity exports to grid - Winter		2218.5	4248.9	1440.3	2699.1	2758.5	Annual PED due to thermal load	3409.4
Primary Energy required for electricity imports from grid - Summer		585.0	455.4	642.6	563.4	477.0		
Annual PED		**3550.5**	**2293.8**	**4012.2**	**3396.7**	**3675.7**	**5015.9**	
Energy Demand Reduction Potential	%	**29.2%**	**54.3%**	**20.0%**	**32.3%**	**26.7%**	-	
Annual CO_2 emissions	CO_2 tonnes /year	**720.8**	**465.6**	**814.5**	**689.5**	**746.2**	**1018.2**	
Reduction of annual CO_2 emissions		**297.4**	**552.6**	**203.7**	**328.7**	**272.0**	-	

- Energy saving of the order of 55%.
- 3,5GWh consumption reduction (reference of 100 dwellings).
- CO_2 emission reduction: 550 tn/y

CONCLUSIONS

- Thermally driven or electricity driven CHP system operation.
- The same systems are utilized for both local demand cover and excess energy storage for future use at district level (reduction of capital cost).
- Need for advanced control interfaces, dynamic control and operating optimization .
- Interaction between the consumer and the ESCO – new business models.
- Interaction between active building materials and the energy unit.
- Energy saving of the order of 55%.

SEVENTH FRAMEWORK
PROGRAMME

FC-DISTRICT

New μ-CHP network technologies for energy efficient and sustainable districts

FP7 - EeB.NMP.2010-2 New technologies for energy efficiency at district level

Thank you for your attention!