LIFE - CYCLE COST ANALYSIS (LCCA) OF ENERGY INTERVENTIONS IN HELLENIC BUILDING STOCK WITH EMPHASIS ON THE REPLACEMENT OF THE HEATING SYSTEM/PRODUCTION OF DOMESTIC HOT WATER

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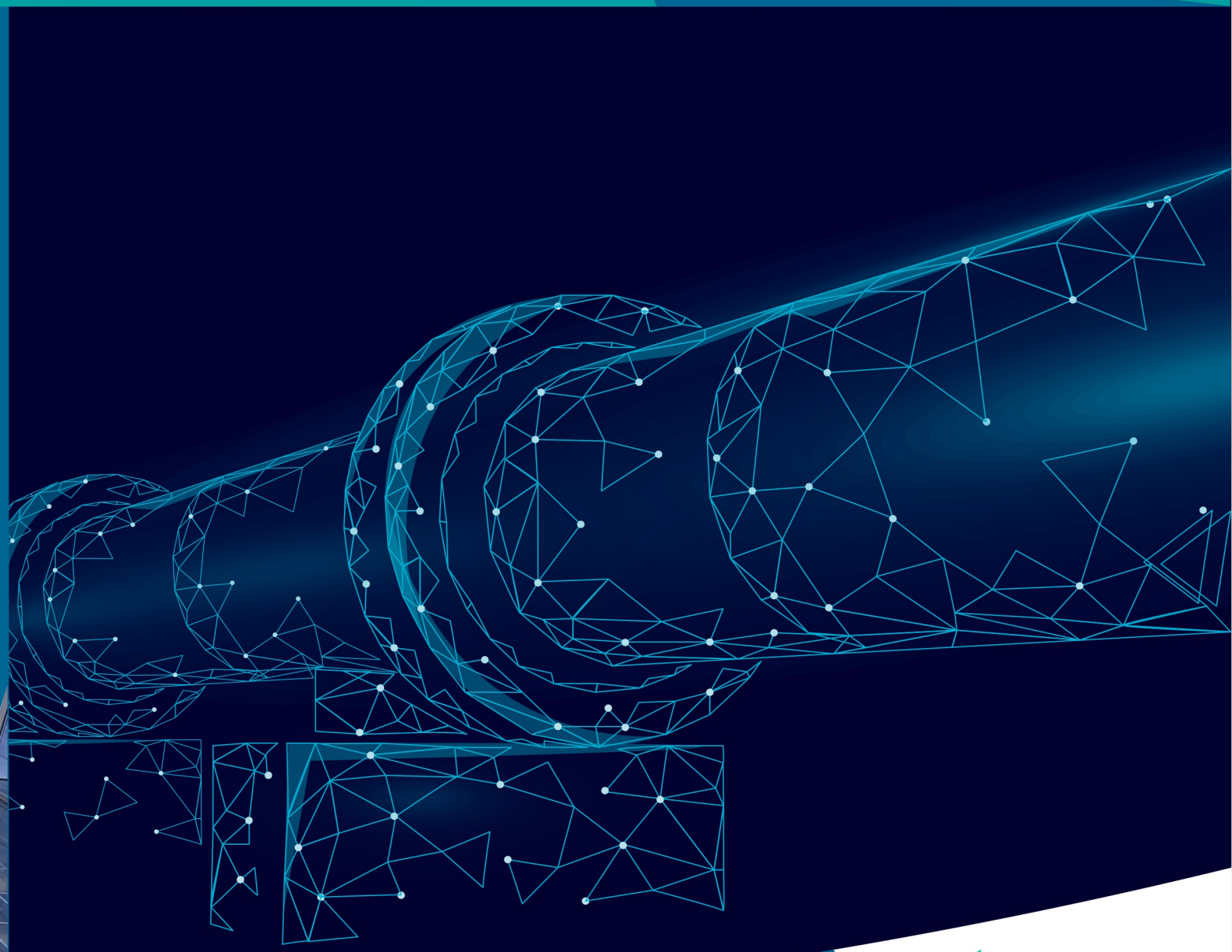

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Techno economical comparison of energy interventions in Hellenic building stock

Contents

Introduction

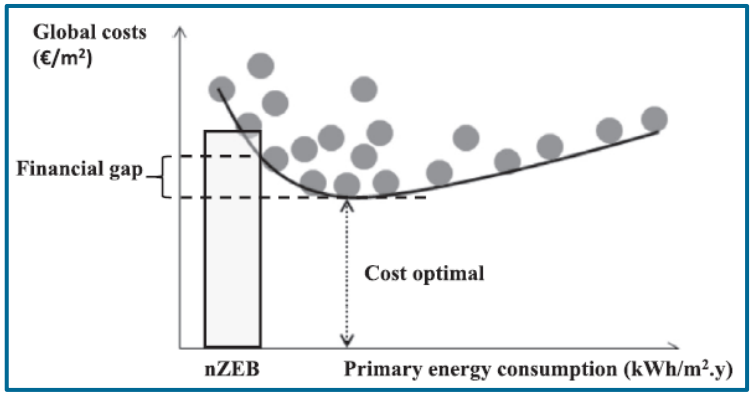
- **EPBD Amendments**
- **2018 → nZEB – near Zero Energy Building**
- **2025 → ZeB – Zero emissions Building**
- **EU buildings energy consumption – reduction targets by 2030 & 2055**

- National building stock renovation **16% by 2030 & 20-22% by 2035**
- All members states: **National Building Renovation Plan by the end of 2025**

Cost effective - Cost optimal assessment

Effective Methodology since 2015 for designing energy retrofit policies

Numerous studies and papers about cost optimal assessment in various countries and typical buildings



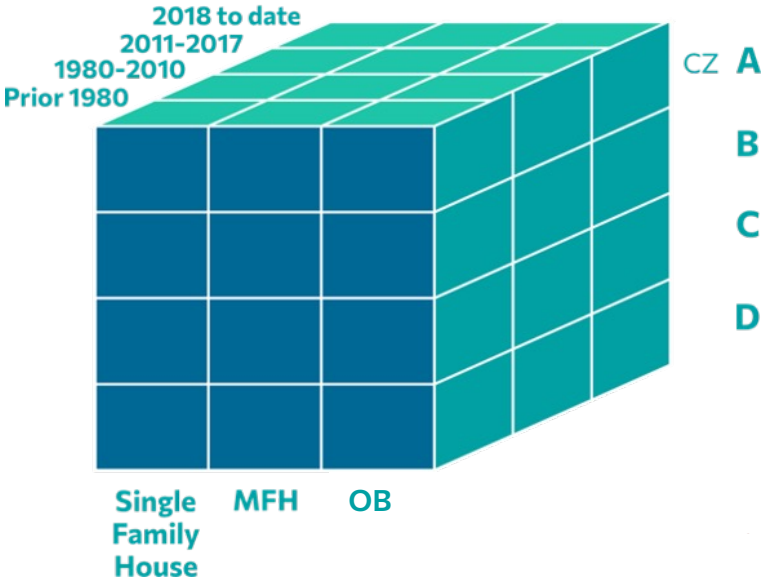
Introduction

Current study

Cost effectiveness – cost optimal assessment based on **Life Cycle Cost (LCC), Depreciated Payback Time (DPP) and Primary Energy Consumption (PEC)** of buildings examined:

- ❑ **3 Typical buildings**
- ❑ Various Intervention Packages **focused on heating and DHW systems**
- ❑ **4 Construction Periods (CPs) for existing buildings**
- ❑ **4 Climate Zones (CZs) of Greece**

MFH multi family house
SFH single family hoyse
OB office building
CZ climate zone



Typical buildings, construction periods and climate zones

Typical buildings

Single family house
Ground floor building over basement

Multi family house
3-storey apartment building

Office building
5-storey office building

Construction Periods

1. Prior to 1980	No insulation
2. 1980 – 2010	Insulation based on first insulation regulation of Greece (1979 - ΚΘΚ)
3. 2011 – 2017	Insulation based on KENAK 2010
4. 2018 to date	Insulation based on KENAK 2017

Climate Zones

1. Climate Zone A	Greek Islands, South Peloponnese
2. Climate Zone B	North Peloponnese, Central Greece incl. Attica
3. Climate Zone C	Central & East Macedonia, Thrace
4. Climate Zone D	West Macedonia and Drama prefecture

Important aspect → The majority (around 50-55%) of the buildings in the country were built before 1980.

Existing heating system / Domestic hot water (DHW) system

Construction Period	Single Family House	Multi Family House	Office building
1. Prior to 1980	Oil boiler / Electric heater	Central Oil boiler / Electric heater	Central Oil boiler
2. 1980 – 2010	Oil boiler / Electric heater	Central Oil boiler / Electric heater	Central Oil boiler
3. 2011 – 2017	Oil boiler or Gas boiler & Solar thermal for DHW	Central Oil or Central Gas boiler & decentralized Solar thermal for DHW	Central Heat Pump
4. 2018 – 2022	Oil boiler or Gas boiler & Solar thermal for DHW	Central Oil or Central Gas boiler & decentralized Solar thermal for DHW	Central Heat Pump

Heating & DHW systems evaluated

New heating system / DHW system

Single Family House	Multi Family House	Office building
Condensing Gas boiler	Central & Decentralized Condensing Gas boiler	Central Condensing Gas boiler (only for periods 1 & 2)
High Temperature Heat Pump	Central High Temperature Heat Pump	Central Medium Temperature Heat Pump
Medium Temperature Heat Pump	Decentralized Medium Temperature Heat Pump	Central Hybrid system
Hybrid system	Central Hybrid system	VRF system

Other interventions

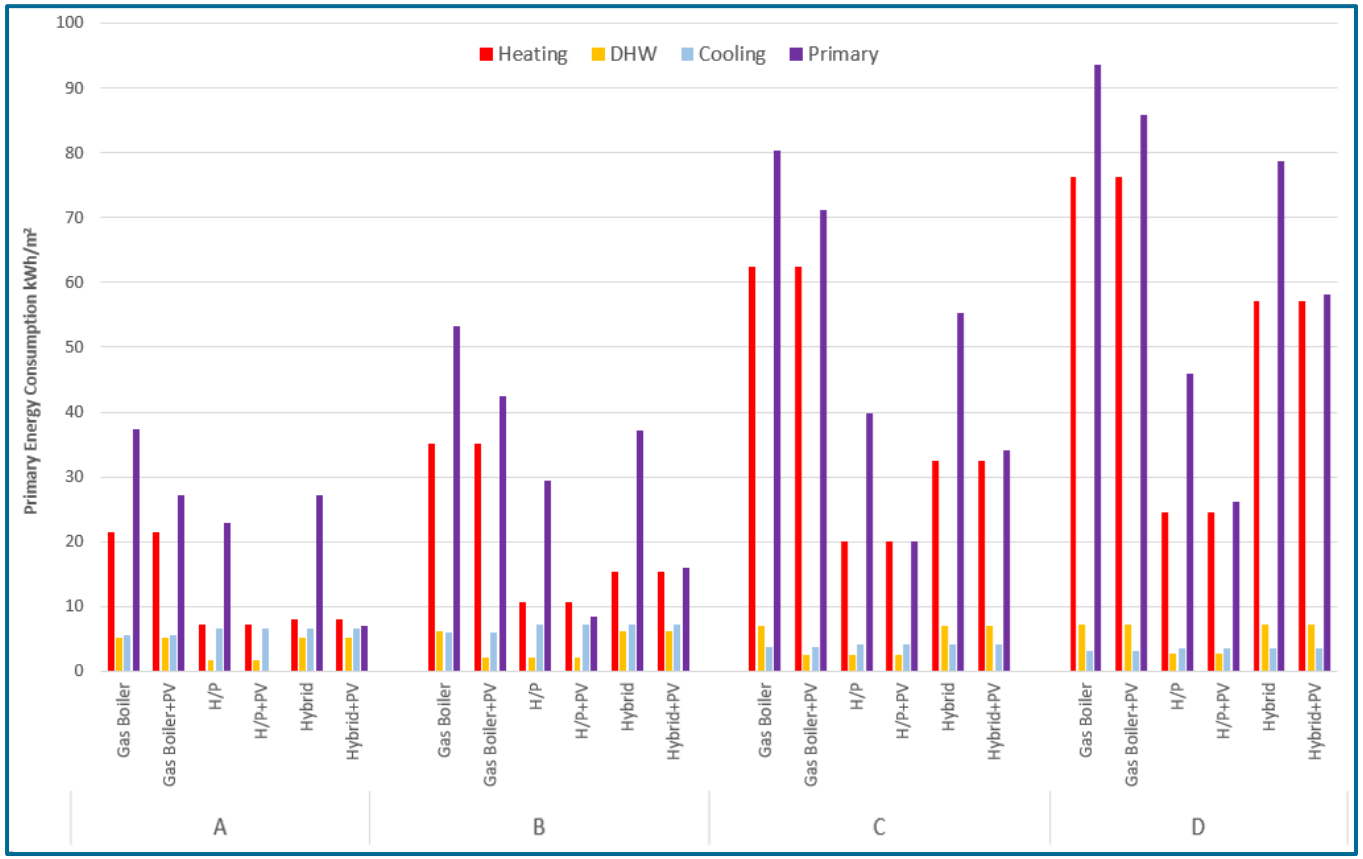
Cooling system – New split units	Cooling system – New split units	Cooling system – New chiller
Insulation & Windows replacement	Insulation & Windows replacement	Insulation & Windows replacement
Solar thermal system for DHW	Solar thermal system for DHW	Ventilation system (AHU) upgrade
PV system (net billing)	PV system (net billing)	Lighting upgrade with LED
		PV system (net billing)

Total simulated scenarios

Construction Period	Single Family House	Multi Family House	Office building
1. Prior to 1980	224	288	96
2. 1980 – 2010	224	288	176
3. 2011 – 2017	56	72	72
4. 2018 – 2022	56	72	72
Sum	560	720	416

Energy Consumption Results – Single Family House (SFH) example

Single Family House - 1980 Ind. Climate Zone B	Heating	Cooling	DHW	PEC kWh/m²
	Consumption kWh/m²			
Existing (No Insulation)	384.1	29.6	22.2	508.2
New Gas Boiler + Solar collector + Insulation	35.2	6	6.2	53.3
New Gas Boiler + Solar collector + Insulation + PV	35.2	6	2	42.5
New H/P (Med T) Solar collector + Insulation	10.7	7.1	2	29.4
New H/P (Med T) Solar collector + Insulation + PV	10.7	7.1	2	8.4
New Hybrid System Solar collector + Insulation	15.3	7.1	6.2	37.1
New Hybrid System Solar collector + Insulation + PV	15.3	7.1	6.2	15.9



Energy Prices Assumptions

Indicative energy prices

FUEL PRICES private perspective (incl. VAT)		
Gas (Home)	0.103	€/kW.hr
Gas (Central)	0.097	€/kW.hr
Gas (Business)	0.106	€/kW.hr
Electricity (Γ1)	0.285	€/kW.hr
Electricity (Γ22)	0.305	€/kW.hr
Heating Oil	0.125	€/kW.hr

FUEL PRICES macroeconomic view (excl. VAT)		
Gas (Home)	0.093	€/kW.hr
Gas (Central)	0.087	€/kW.hr
Gas (Business)	0.090	€/kW.hr
Electricity (Γ1)	0.255	€/kW.hr
Electricity (Γ22)	0.271	€/kW.hr
Heating Oil	0.075	€/kW.hr

Innovation aspect → Energy prices for electricity and natural gas are derived directly from the simulated primary energy consumption of each scenario.

Financial rates of basic economic evaluation

Energy price development → Increase of 2.8 % per year

Discount Rate 7% for Private evaluation / (3 % for Macroeconomic evaluation)

Investment Cost Assumptions

➢ **New system purchase & installation cost at an existing building based on the Pgen of the building.**

Central Gas Boiler		
kW	Purchase & Installation (€)	Connection fees* (€)
12	2,598	245.5
20	3,751	245.5
35	4,904	245.5
50	8,246	334.8
100	16,504	334.8
200	23,349	334.8
400	31,248	334.8

Cost includes:
- certified condensing gas boiler (installed at existing hot water piping network)
- circulation inverter pump
- Gas piping
- labour cost

* Only for climate zones B & C

Heat Pump (low temp – 55° C)		
kW	Purchase & Installation (€)	Electrical upgrade cost (€)
8	7,148	400
12	10,000	400
20	12,003	400
35	20,602	400
50	34,199	400
100	58,450	560
200	98,813	560
400	181,198	560

Cost includes:
- H/P installed (at existing hot water piping network)
- circulation inverter pump
- labour cost

Does not include new fan coils, cost of which is 279€ / kWth (VAT incl.)

Heat Pump (High temp – 70° C)		
kW	Purchase & Installation (€)	Electrical upgrade cost (€)
8	10,800	400
12	11,048	400
20	12,698	400
35	23,951	400
50	42,501	400
100	74,699	560
200	139,824	560
400	259,601	560

Cost includes:
- H/P installed (at existing hot water piping network & terminals)
- circulation inverter pump
- labour cost

Note: All prices include VAT

➢ **Hybrid System pricing is the sum of a gas boiler and a HP with 70% of the heating design capacity.**
For CP3 & CP4 if there is an existing gas boiler or HP then it is combined with a new HP or boiler respectively.

Primary energy and emissions factors

Evolution of primary energy conversion & CO_2 emission factor for electricity by year intervals 2022-2050 (based on revised NECP - Dec 2024)

	2022	2025	2030	2035	2040	2045	2050
Primary energy conversion factor for electricity	1.79	1.49	1.20	1.07	1.05	1.03	1.03
CO_2 emission factor for electricity (kg_{CO2}/kWh)	0.398	0.327	0.063	0.025	0.017	0.009	0.010

Considered EU ETS carbon prices (€/tnCO2) by year interval

EU ETS carbon price		
Time Period	Value	Unit
2023-2025	86	€/tn_{CO2}
2026-2030	100	€/tn_{CO2}
2031-2050	182	€/tn_{CO2}

Methodological Approach

Single Family House (SFH)	Multi Family House (MFH)	Office building

Economic calculations for every simulated scenario – alternative technologies evaluation

Financial analysis:

- Life Cycle Cost – LCC in €/m^2
- Depreciated payback period – PbP in years

Graphs

- LCC & PbP vs Primary Energy Consumption (PEC)

- Cost optimal region frequency graphs

Further Economic results for intervention packages (IPs) include:

- Initial investment cost
- Operation and Maintenance cost (O&M)
- Total energy cost
- Greenhouse emissions cost
- Residual value & Disposal cost
- **Global cost - LCC**

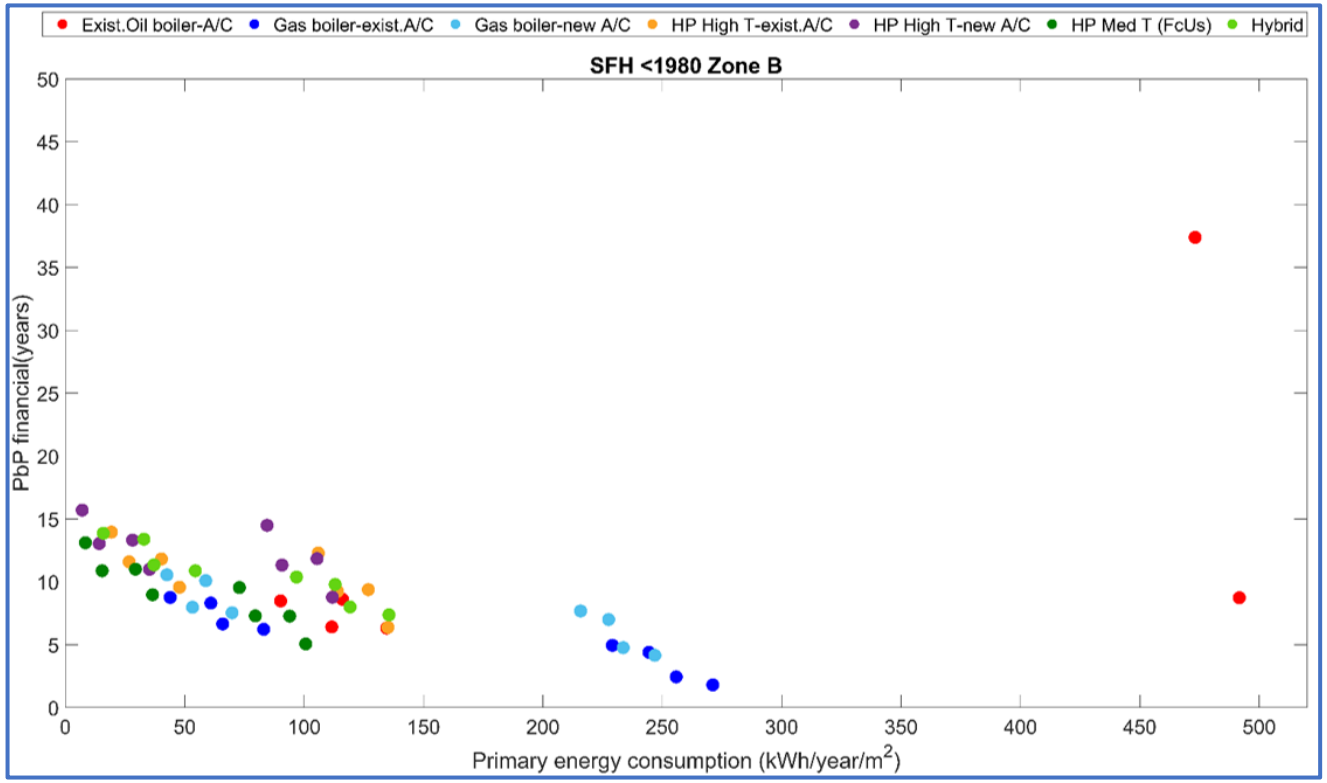
Methodological Approach

Energy Simulation Results

Economic Analysis Results

LCC vs PEC

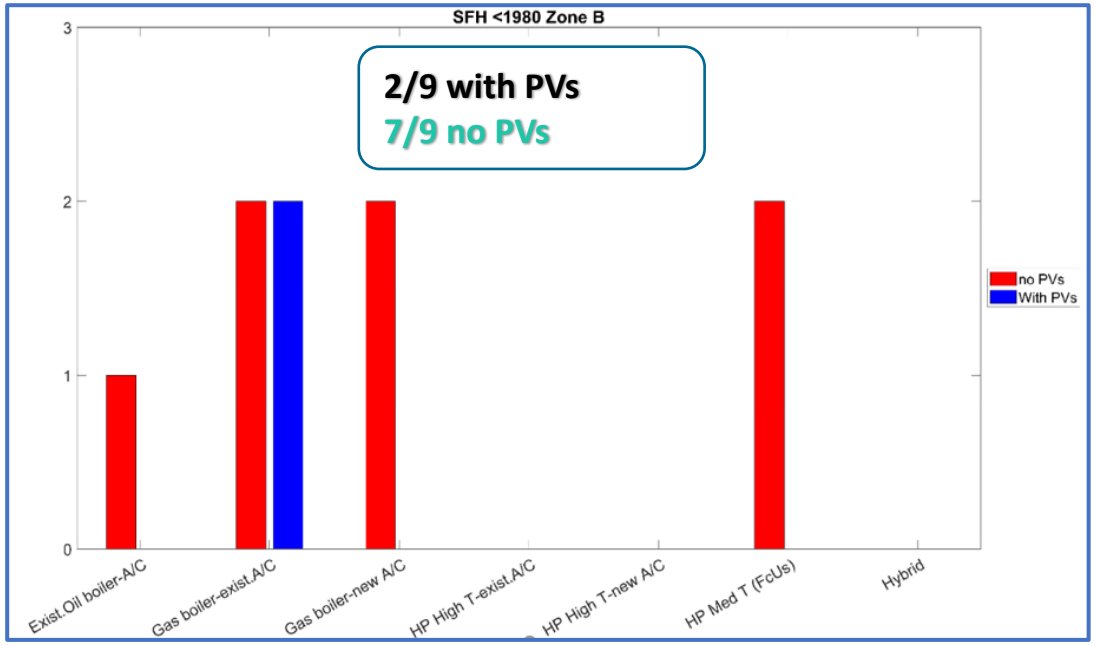
PbP vs PEC

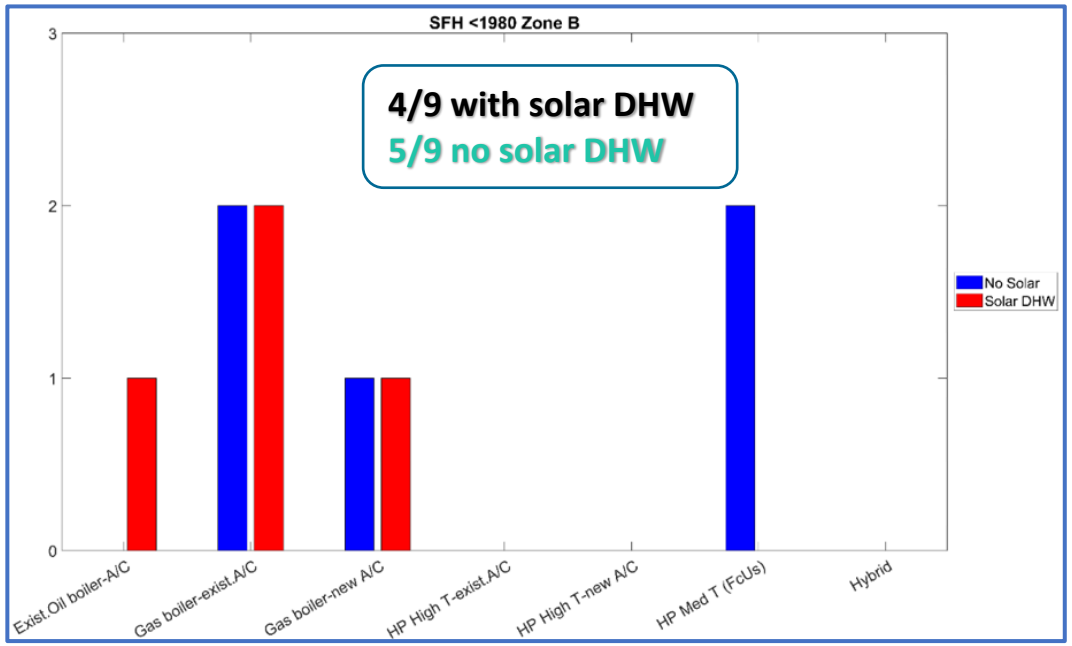


Cost optimal region: LCC Range = Min LCC+10%(Max LCC – Min LCC)
PEC Range = 1.5 x Min PEC

Economic Analysis Results

Supporting tool of Frequency graphs: Showing no. and type of scenarios within Cost Optimal Region





1/9 existing boiler
6/9 gas boiler
2/9 HP med T

Economic Analysis Results

Single Family House

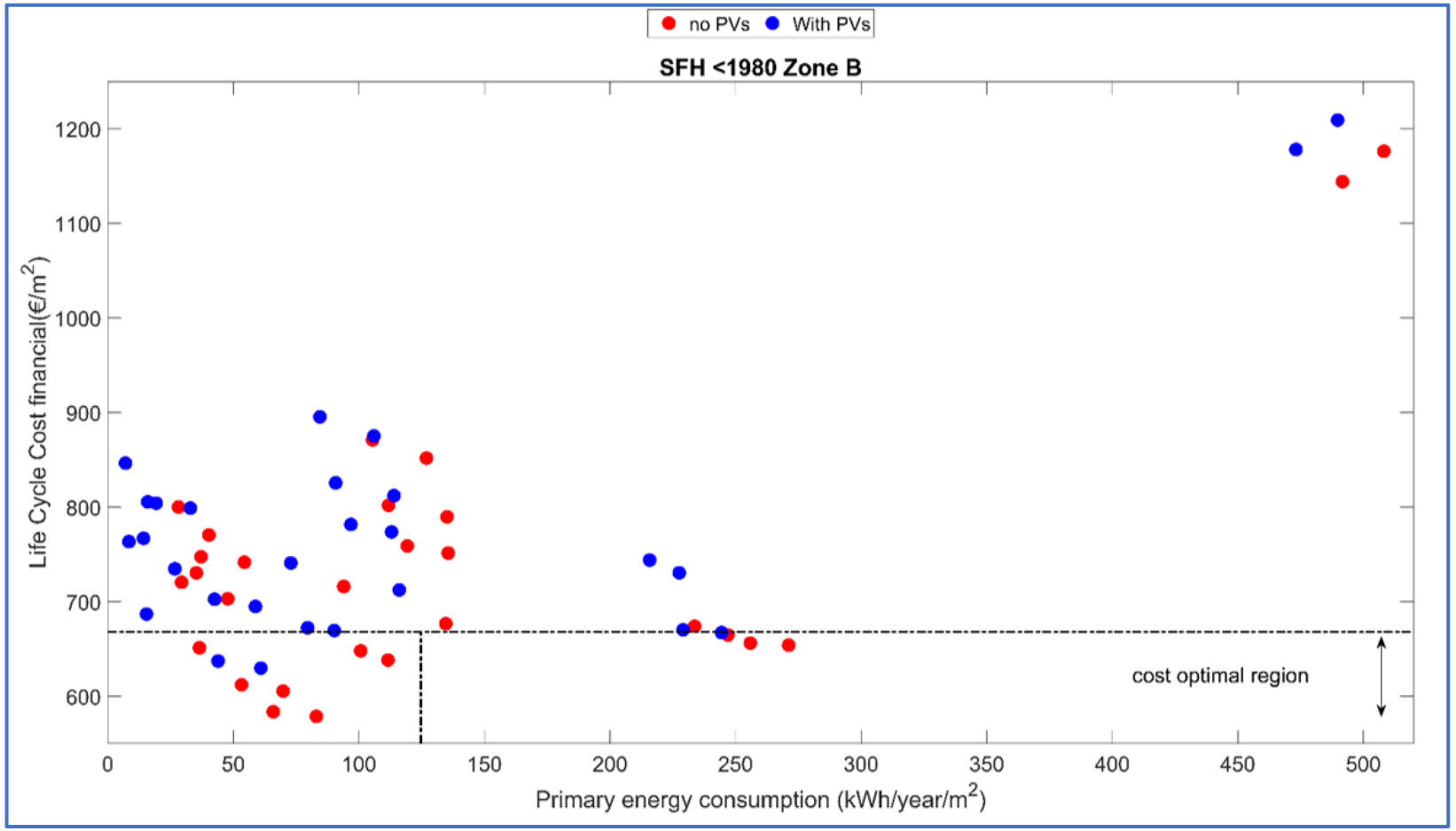
Constr. Period 1: pre-1980

Climatic Zone B

Heating/Cooling systems graph

PV/no PV graph

LCC vs PEC



Economic Analysis Results

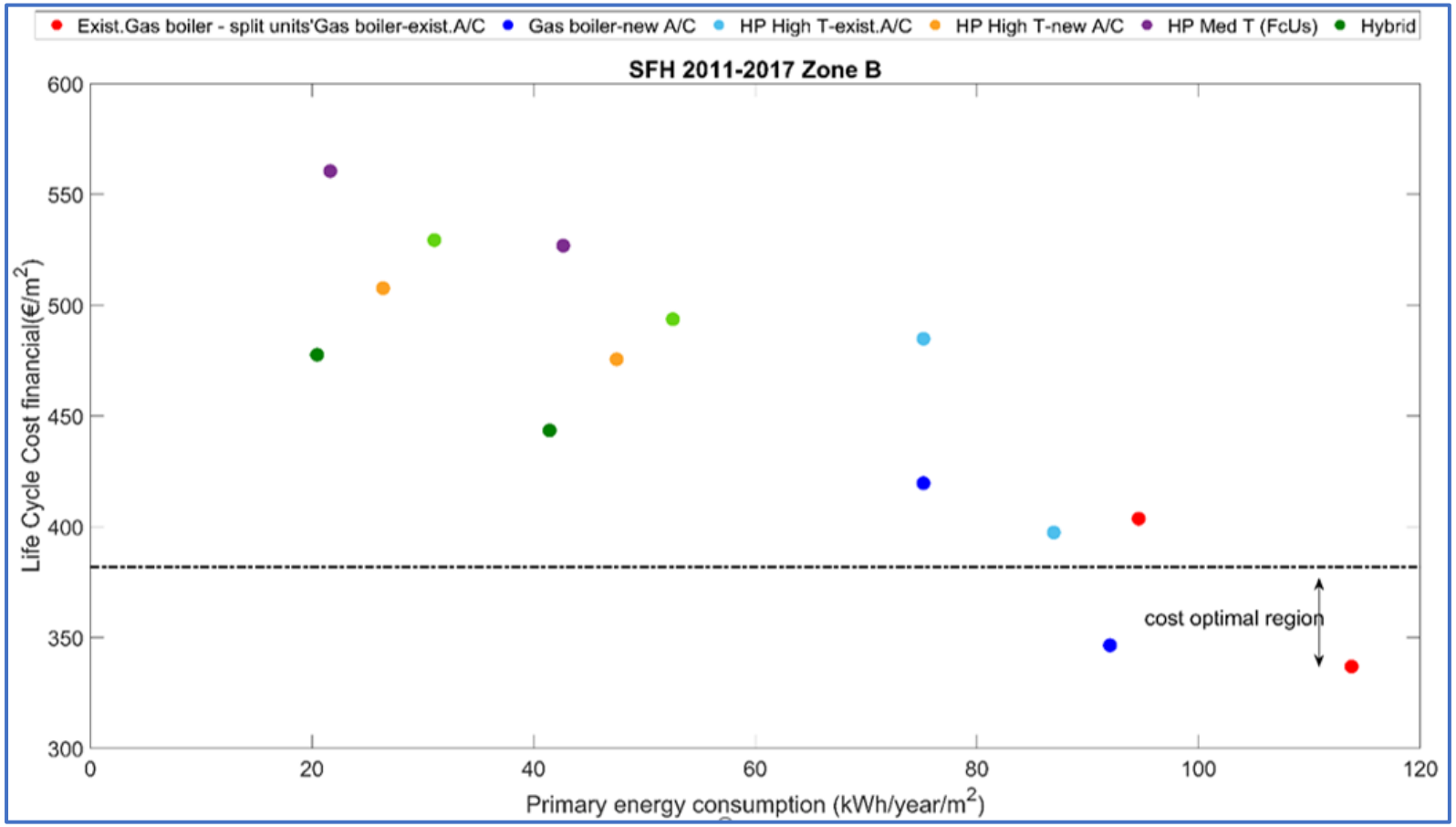
Single Family House

Constr. Period 3: 2011-2017

Climatic Zone B

Heating/Cooling systems graph

LCC vs PEC



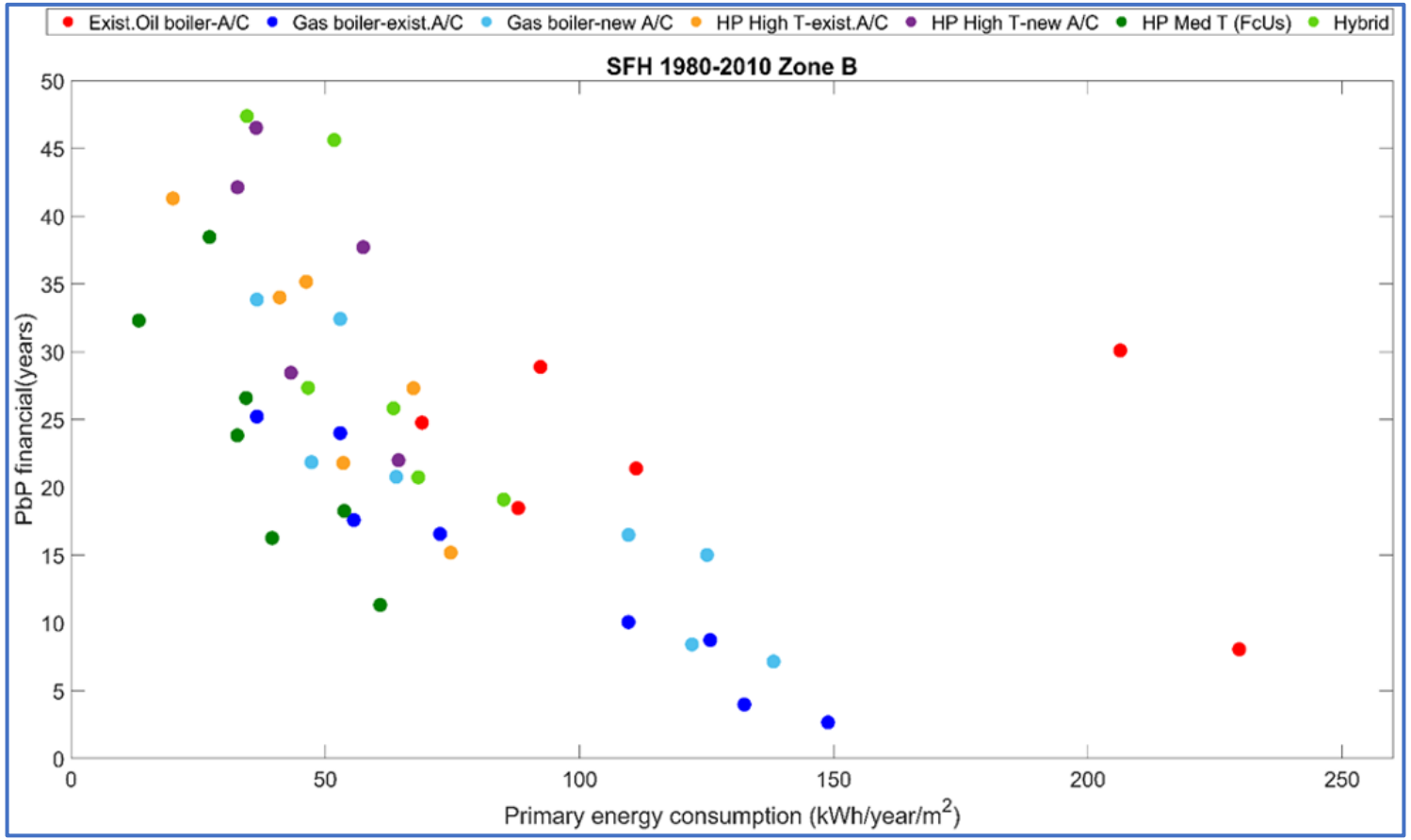
Economic Analysis Results

Single Family House

Constr. Period 2: 1980-2010

Climatic Zone B

PbP vs PEC



Economic Analysis Results

Multi Family House

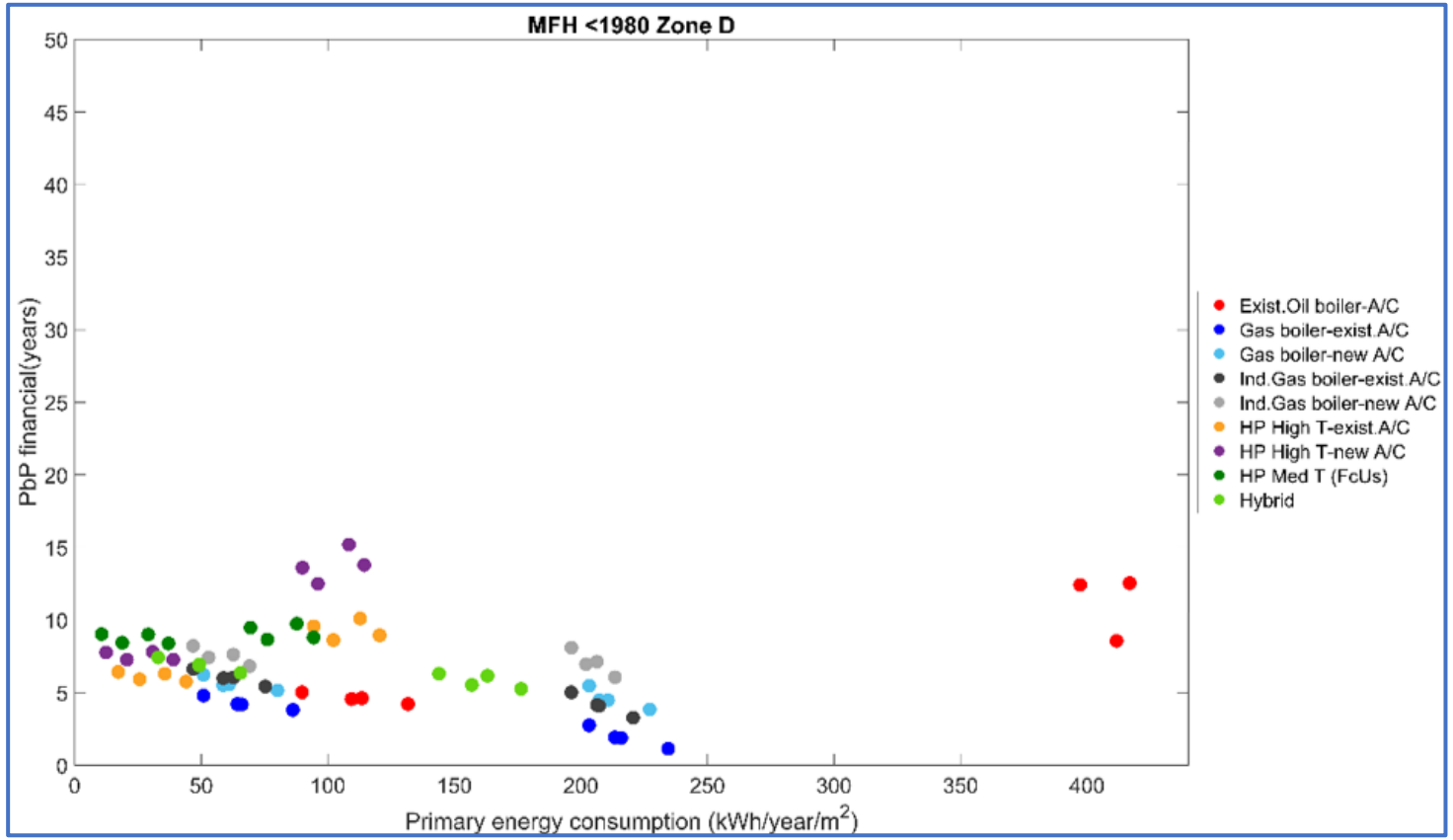
Constr. Period 1: pre-1980

Climatic Zone D

A
B
C
D

PbP

LCC vs PbP



Basic Conclusions on Multi Family House

Constr. Period 1: pre-1980

- All technologies included in retrofitting measure packages can achieve very low PEC (< 50 kWh/m2).
- **Natural gas packages** achieve **lowest LCC** (€/m2) and **lower PbP** while Heat Pump packages achieve **lowest PEC** (kWh/m2).
- Going from the mildest to the coldest climate zone LCC increases for the same technologies while;
- **Central systems** have half or even less LCC than individual (autonomous) ones.
- Net billing PV systems have a **positive impact** (in contrast with SFH cases).

Constr. Period 2: 1980-2010

- **Natural gas packages achieve lowest LCC** (€/m2) and **lower PbP** while Heat Pump packages achieve **lowest PEC** (kWh/m2).
- **Central VS Individual LCC gap is reduced** due to separate heating piping network → Ind. Gas boiler systems have less LCC than P1.
- Generally similar to previous period with less positive impact of passive measures & larger **financial gap**.

Constr. Period 3: 2011-2017

- Apart from climate zone A & D (where existing system is oil boiler) no scenarios with reasonable PbP exist.

Constr. Period 4: 2018-2023

- As general remark, no interventions are financially feasible (exceptions in existing oil boiler cases)

LCC, PEC & DPP Performance table

Multi Family House

Best Interventions Packages for LCC, PEC & DPP for all periods and climate zones for MFH

Constructions periods – Multi - Family House

	Lowest LCC				Lowest PEC				Lowest DPP			
CP/Cl.Z	A	B	C	D	A	B	C	D	A	B	C	D
CP1 Before 1980	New Central Gas Boiler/exist. A/C No Insulation / Insulation PV No Solar DHW				New Central or Ind. HP Insulation PV Solar DHW				New Central Gas Boiler exist. A/C No Insulation No PV No Solar DHW			
CP2 1980-2010	New Central Gas Boiler/exist. A/C No Insulation PV No Solar DHW				New Central or Ind. HP Insulation PV Solar DHW				New Central Gas Boiler exist. A/C No Insulation No PV No Solar DHW			
CP3 & CP4 2011 - today (exist. Solar DHW)	New Central Gas Boiler exist. A/C No PV	exist. Central Gas Boiler / exist. A/C No PV	New Central Gas Boiler exist. A/C No PV		Central or Ind. HP PV				New Central Gas Boiler exist. A/C No PV	exist. Gas Boiler exist. A/C No PV	New Central Gas Boiler exist. A/C No PV	

General Conclusions

- All technologies in all typical buildings can reduce PEC at nZEB levels with or without synergies of other measures depending on each case

RESIDENTIAL:

- Lower LCCs and PbP is mostly achieved with condensing gas boilers & lower PECs with HPs
- Insulation is economically viable only in CP1
- PV systems is not cost effective in SFH while the opposite stands for MFH
- CP3 & CP4 cases → Only when existing oil boiler (cl. Zones A & B) is replaced by a condensing gas boiler.

OFFICE:

- All technologies result in similar LCCs especially in CP1 & CP2.
- Significant impact is made by the PV and the LED interventions in all CPs
- Heat Pumps result in the Lowest LCCs
- VRFs give the lowest PEC

Overall, there is no single, universally optimal energy technology solution. Instead, choices should be based on rational, context-specific criteria such as the use, location, age, and scale of a building—as these factors significantly affect outcomes in terms of energy efficiency, LCC, and DPP, beyond any ideological considerations.

Thank You For Your Attention!

S. Karellas, Professor NTUA

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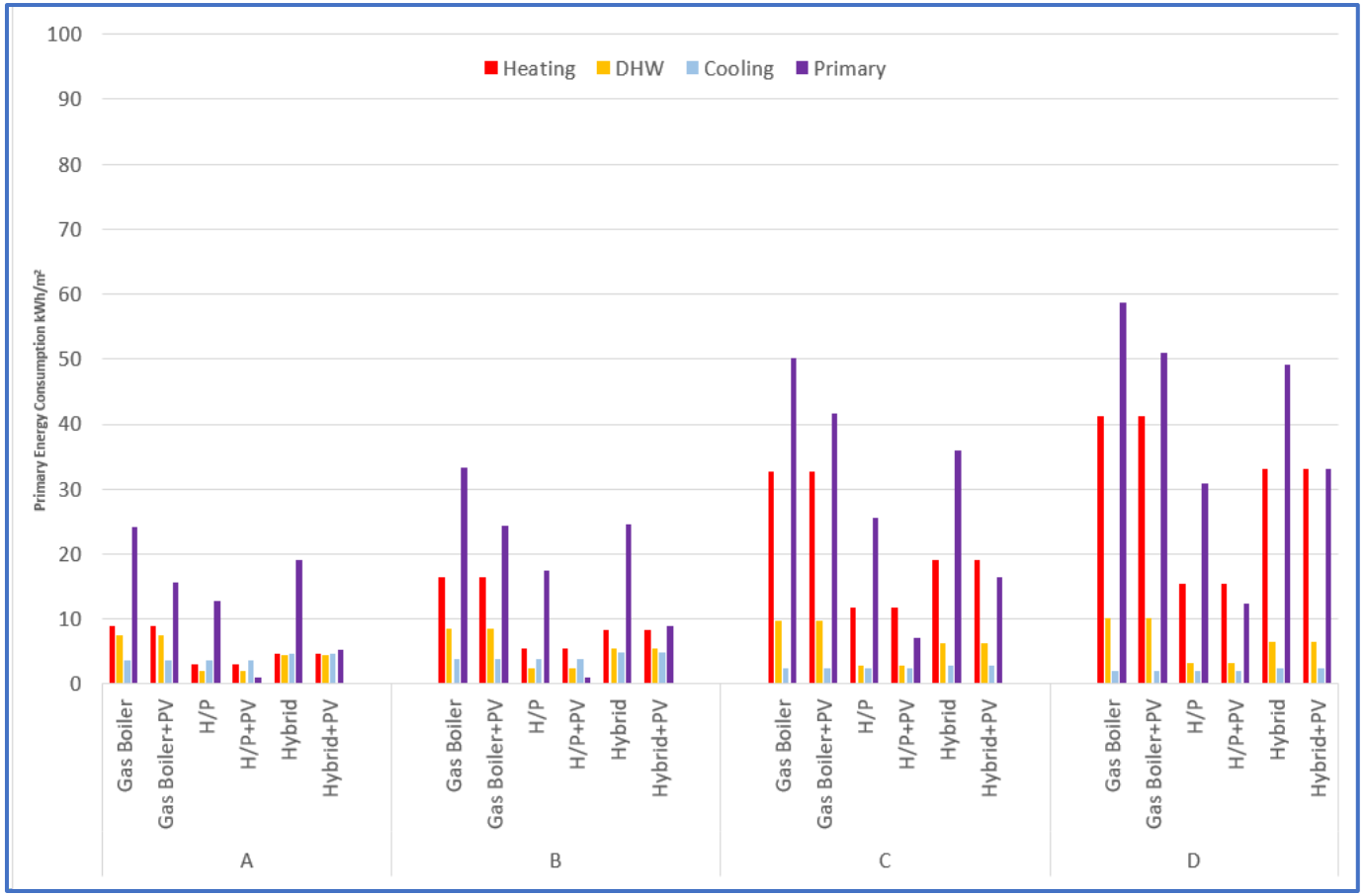
Annex

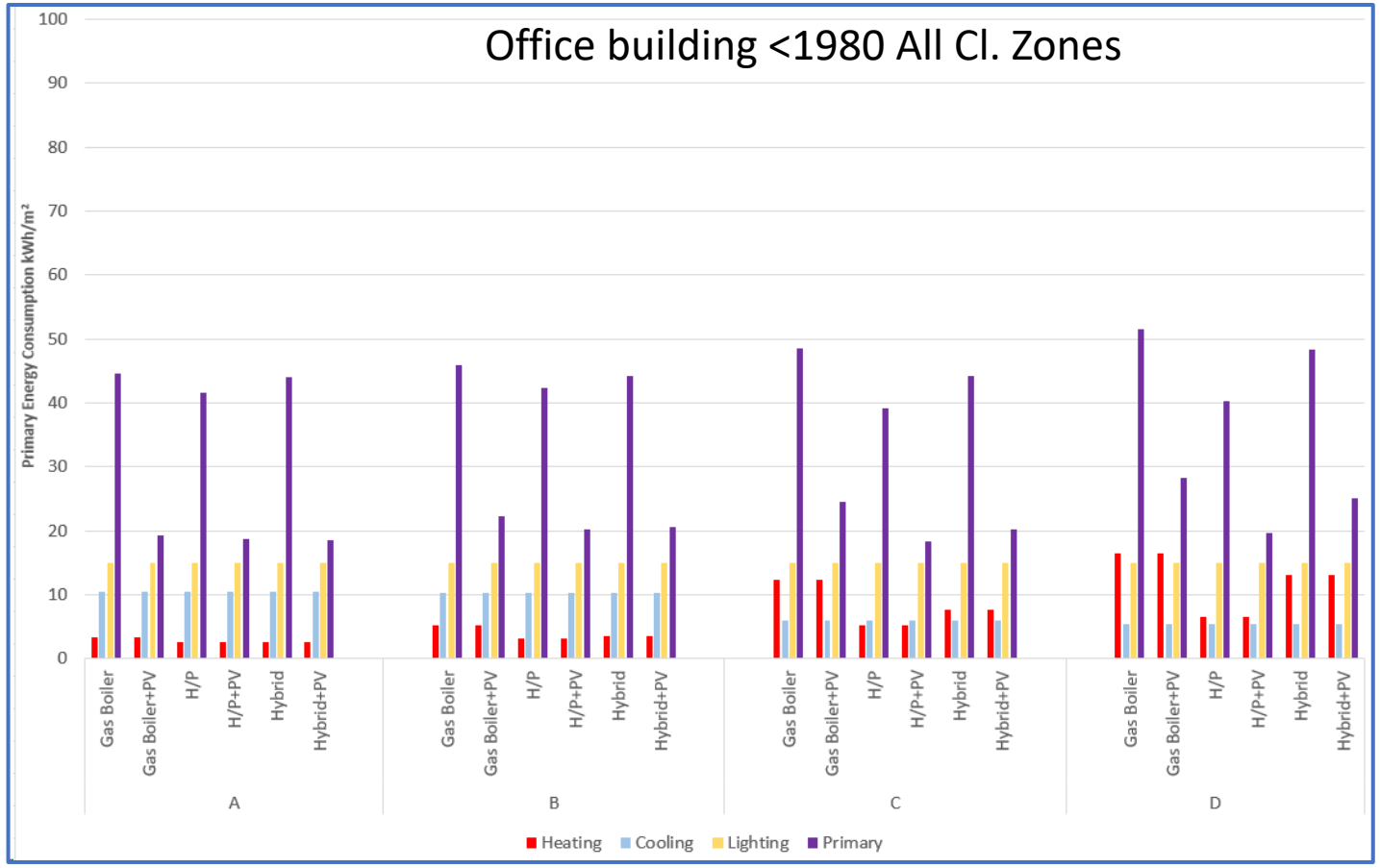
Energy Consumption Results - MFH

Multi Family House - 1980 Ind. Climate Zone C	Heating	Cooling	DHW	PEC kWh/m²
	Consumption kWh/m²			
Existing (No Insulation)	302.5	9.8	20.4	381.9
New Gas Boiler + Solar collectors + Insulation	32.7	2.5	9.7	50.2
New Gas Boiler + Solar collectors + Insulation + PV	32.7	2.5	9.7	41.7
New H/P (High T) Solar collector + Insulation	11.8	2.5	2.9	25.6
New H/P (High T) Solar collectors + Insulation + PV	11.8	2.5	2.9	7
New Hybrid System Solar collectors + Insulation	19	2.9	6.2	35.9
New Hybrid System Solar collectors + Insulation + PV	19	2.9	6.2	16.4



Energy Consumption Results - Offices

Office building - 1980 Ind. Climate Zone B	Consumption kWh/m² Heating	Cooling	Lighting	PEC kWh/m²
Existing (No Insulation)	75.4	52.8	15	241.1
New Gas Boiler + Insulation	5.3	10.3	15	45.9
New Gas Boiler + Insulation + PV	5.3	10.3	15	22.2
New H/P + Insulation	3.1	10.3	15	42.3
New H/P Insulation + PV	3.1	10.3	15	20.2
New Hybrid System + Insulation	3.6	10.3	15	44.2
New Hybrid System Insulation + PV	3.6	10.3	15	20.6



Basic Conclusions on Single Family House

Single Family House

Constr. Period 1: pre-1980

- All technologies included in retrofitting measure packages can achieve low PEC (even below 50 kWh/m2).
- Natural gas packages achieve **lowest LCC** (€/m2) and **lower PbP** while Heat Pump packages achieve **lowest PEC** (kWh/m2).
- Going from the mildest to the coldest climate zone LCC increases for the same technologies.
- Net billing PV systems increases LCC and PbP in the majority of scenarios that is included.

Constr. Period 2: 1980-2010

- Natural gas packages achieve **lowest LCC** (€/m2) and **lower PbP** while Heat Pump packages achieve **lowest PEC** (kWh/m2).
- Generally similar to previous period with less positive impact of passive measures & larger **financial gap**.

Constr. Period 3: 2011-2017

- Apart from climate zone A & D (where existing system is oil boiler) no scenarios with reasonable PbP exist.

Constr. Period 4: 2018-2023

- As general remark, no interventions are financially feasible.

LCC, PEC & DPP Performance table

Single Family House | **Best Interventions Packages for LCC, PEC & DPP for all periods and climate zones for SFH**

		Lowest LCC				Lowest PEC				Lowest DPP			
	CP/Cl.Z	A	B	C	D	A	B	C	D	A	B	C	D
Single-Family House	CP1	New Gas Boiler/exist. A/C Insulation No PV No Solar DHW				HP Med Insulation PV Solar DHW				HP Med No Insulation No PV No solar DHW		New Gas Boiler exist. A/C Insulation No PV No Solar DHW	
	CP2	New Gas Boiler/exist. A/C No Insulation No PV No Solar DHW				HP Med Insulation PV Solar DHW				New Gas Boiler exist. A/C No Insulation No PV No Solar DHW			
	CP3 (exist. Solar DHW)	New Gas Boiler exist. A/C No PV	exist. Gas Boiler exist. A/C No PV	New Gas Boiler exist. A/C No PV		HP Med PV				New Gas Boiler exist. A/C No PV	exist. Gas Boiler exist. A/C No PV		New Gas Boiler exist. A/C No PV
	CP4 (exist. Solar DHW)	New Gas Boiler exist. A/C No PV	exist. Gas Boiler exist. A/C No PV		New Gas Boiler exist. A/C No PV	HP Med PV				exist. Oil/Gas Boiler exist. A/C No PV			New Gas Boiler exist. A/C No PV

Economic Analysis Results

Multi Family House

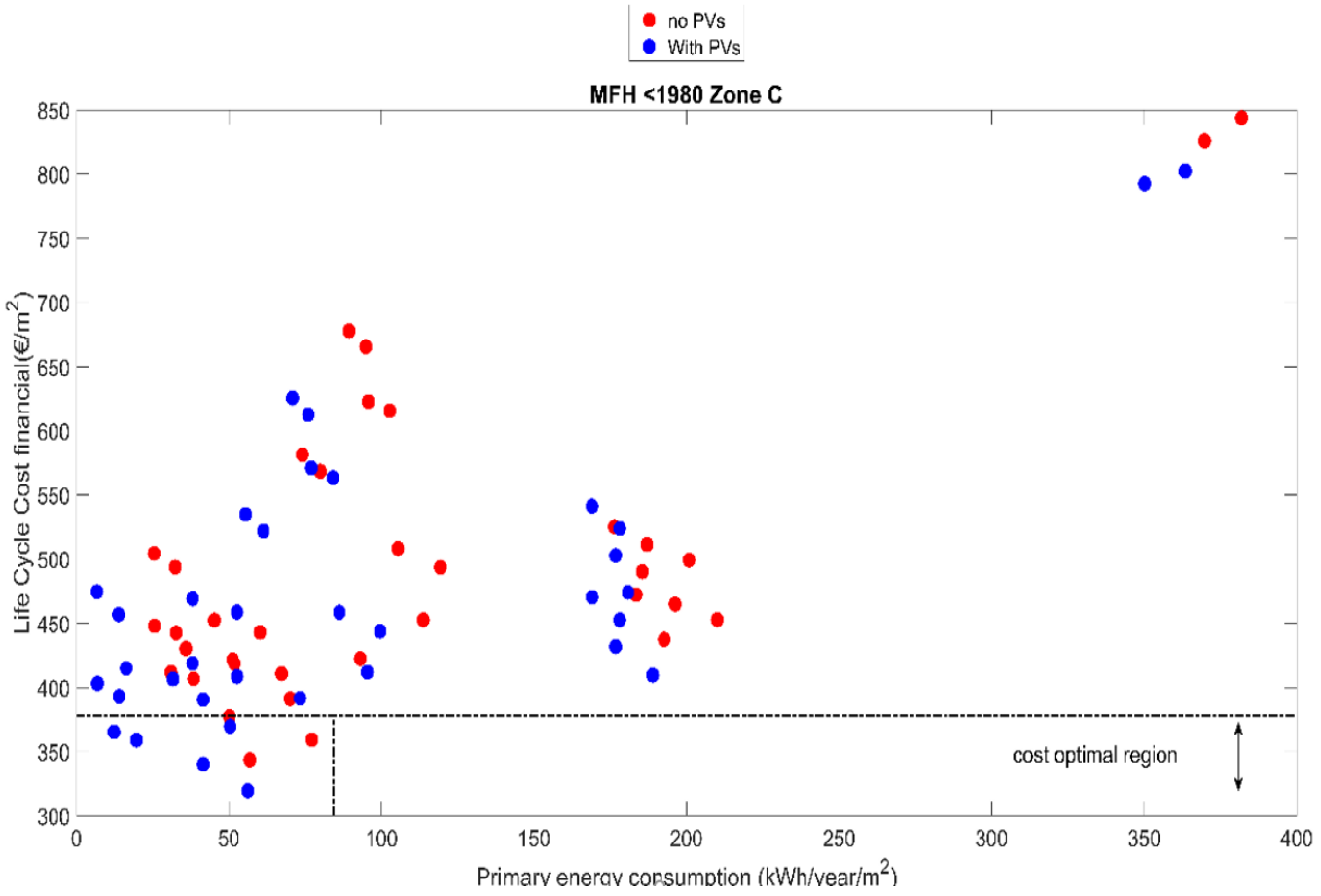
Constr. Period 1: pre-1980

Climatic Zone C

Heating/Cooling systems graph

PV/no PV graph

LCC vs PEC



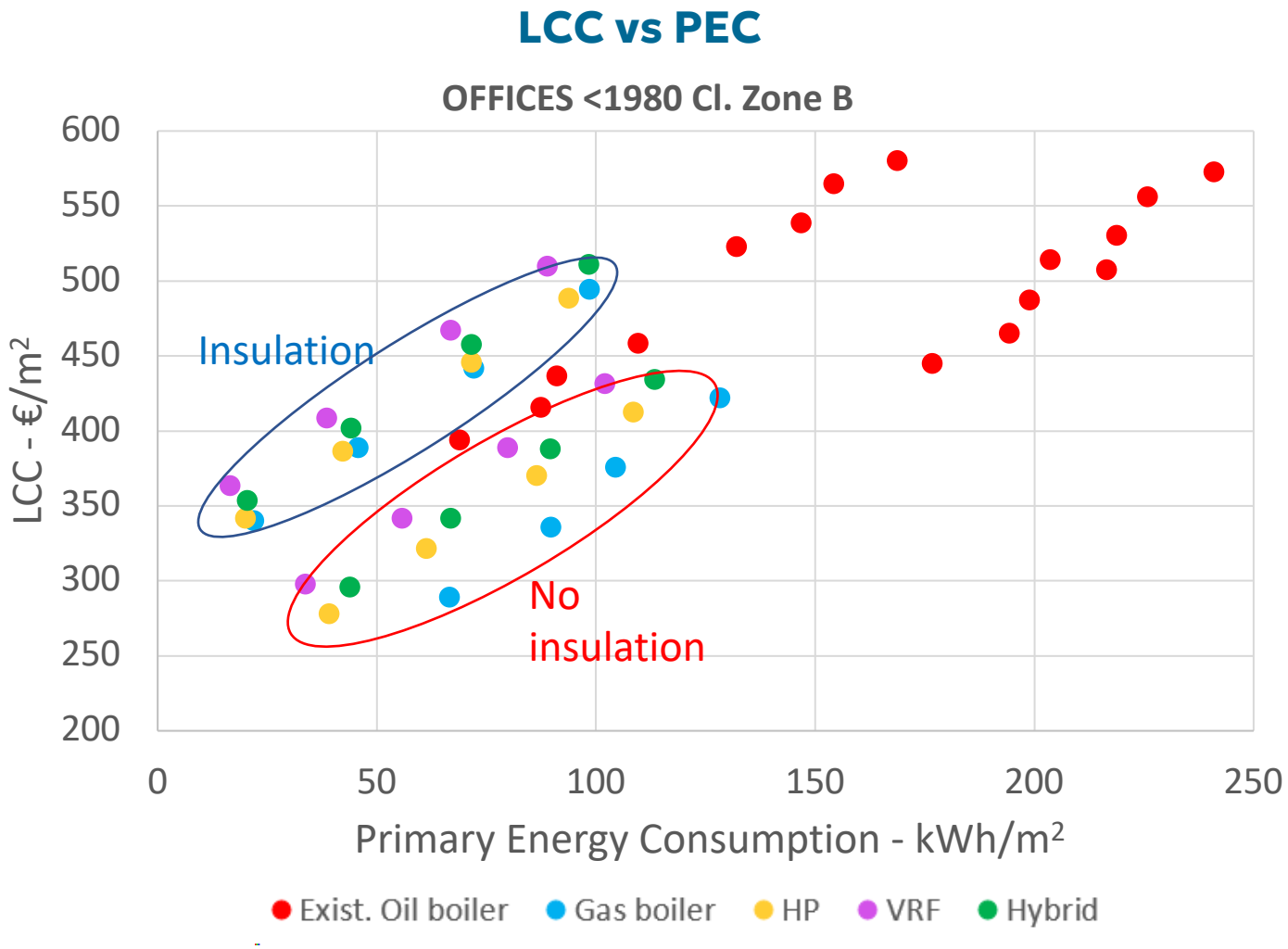
Economic Analysis Results

Office building

Constr. Period 1: pre-1980

Climatic Zone B

Heating/Cooling systems graph



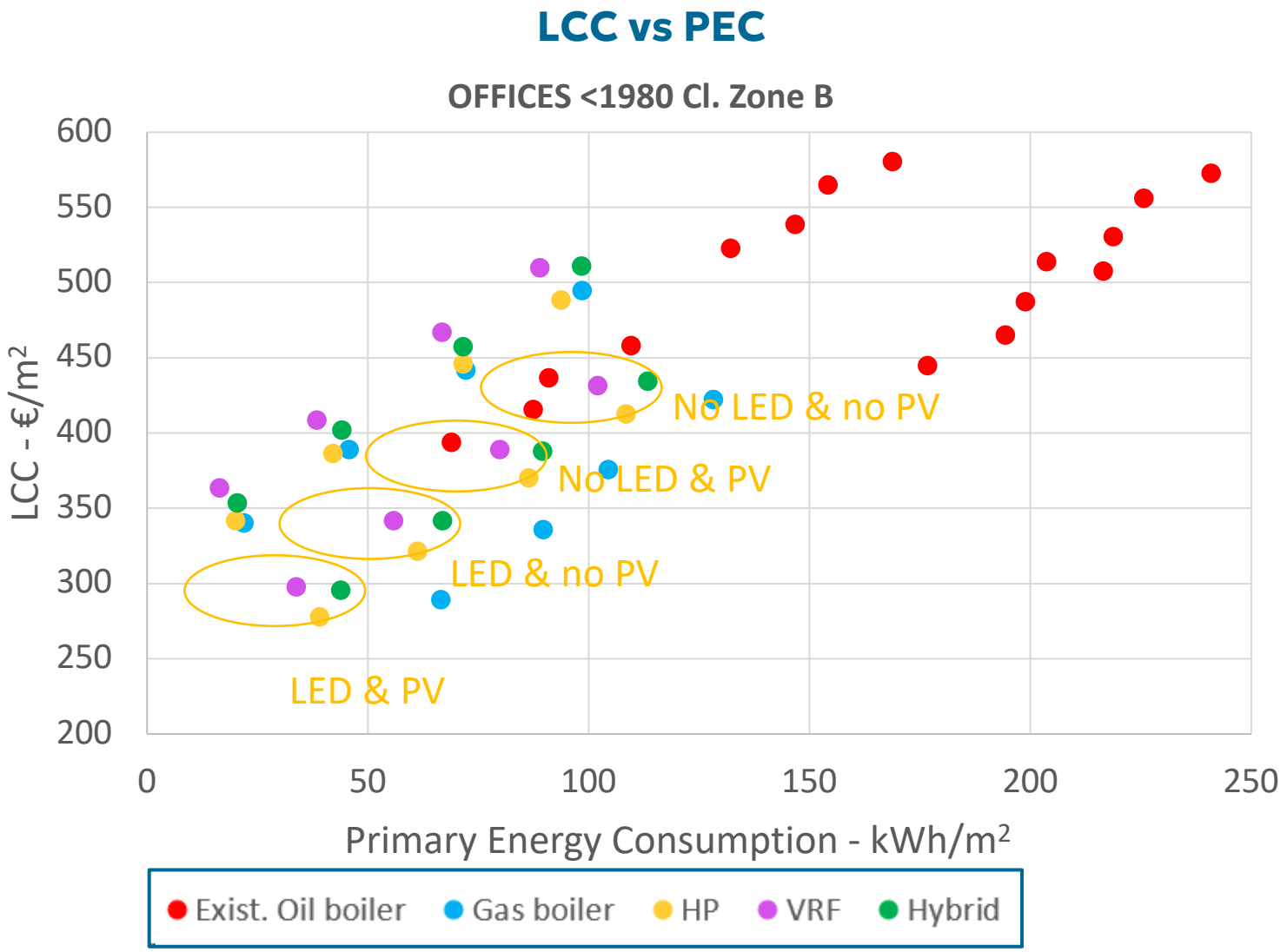
Economic Analysis Results

Office building

Constr. Period 1: pre-1980

Climatic Zone B

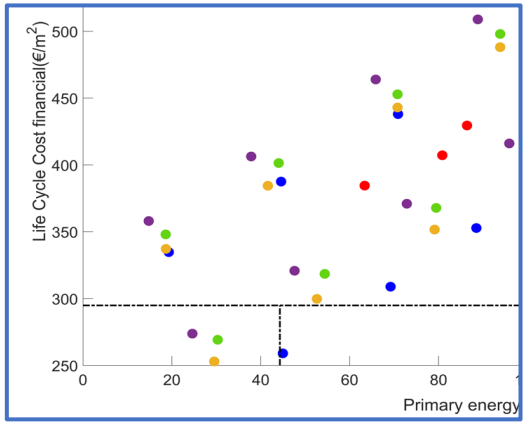
Heating/Cooling systems graph



Economic Analysis Results

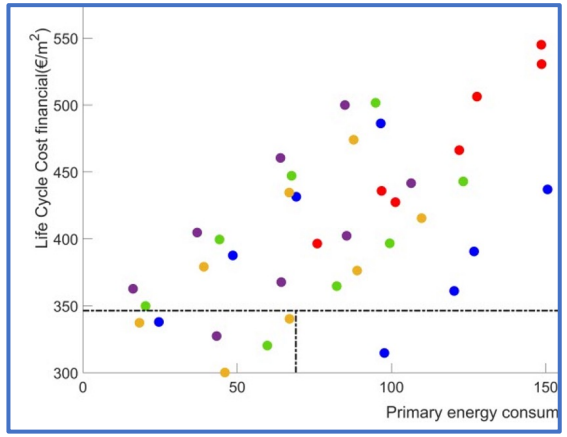
Office building

Constr. Period 1: pre-1980



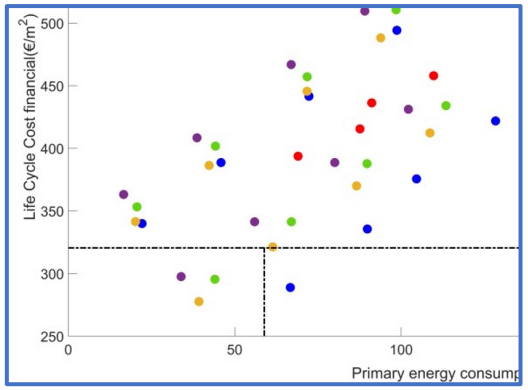
Zone A

Zone C



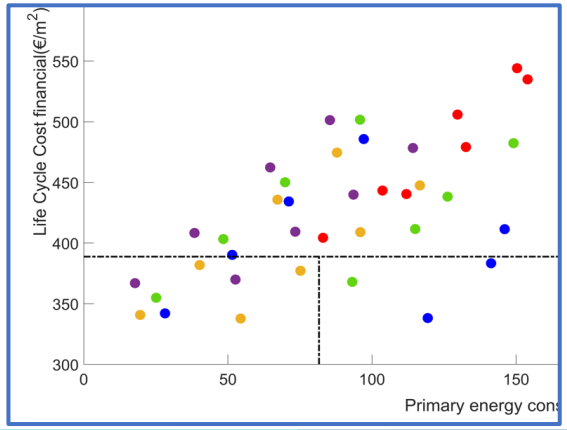
Cost optimal regions
All technologies
With PVs & LED

Insulation in zones C & D



Zone B

Zone D



Exist. Oil boiler Gas boiler

HP VRF Hybrid

Economic Analysis Results

Office building

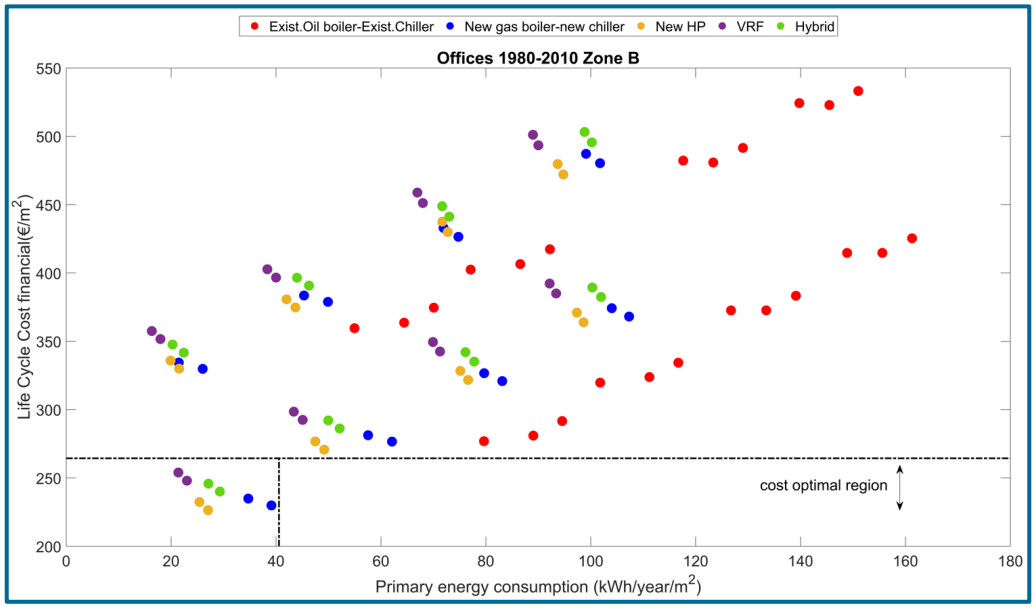
Constr. Period 2: 1980-2010

Climatic Zone B

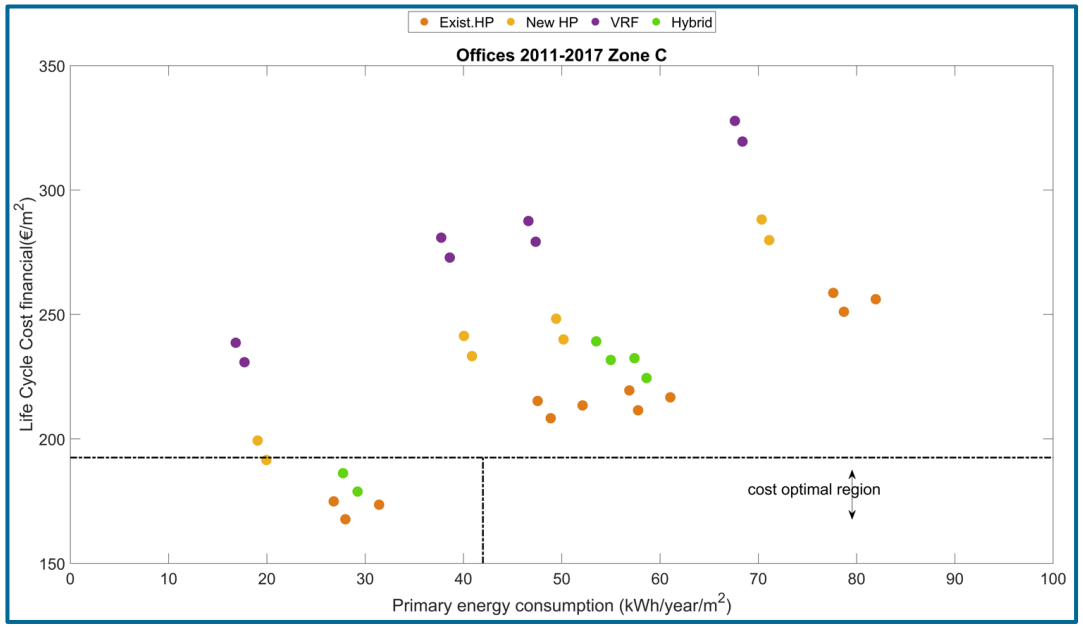
LCC vs PEC

Constr. Period 3: 2011-2017

Climatic Zone C



All alternative technologies combined with PV and LED within cost optimal region



Fewer alternative technologies combined with PV and LED within cost optimal region

Basic Conclusions on Office Buildings

General Remark: Office building has **less heating** demand and higher cooling while **lighting** consumption is also significant.
Alternative systems LCC-PEC are very close to each other when in the same PV, LED cluster.

Office building

Constr. Period 1: pre-1980

- Alternatives in cost optimal region **do not include gas systems in zones A & B** but do include them in zones C & D.
- **Lower PEC give VRF systems, highest PEC gas-chiller systems**.
- HP gives lower LCC and PbP in zones A,B,C marginally in comparison to Gas and Gas gives less in zone D.
- PEC increases from mild to coldest climate zone but not intensively due to less heating demand.
- **PV systems show less LCC and less PEC** in every case and have low impact on PbP.
- Insulation is included in cost optimal scenarios only in zones C & D.

Constr. Period 2: 1980-2010

- **All new systems only combined with PVs & LED** within cost optimal region.
- PEC increase from mild to coldest climate zone is very limited due to existence of basic insulation.
- PV systems show less LCC and less PEC in every case and have low positive impact on PbP.
- Adding extra insulation is not included in any cost optimal regions.

➢ For both CP1 & CP2 low payback period is achieved by **all technologies**

Basic Conclusions on Office Buildings

Office building

Constr. Period 32: 2011-2017

- Existing HP show less LCC.
- **New HP and Hybrid systems in combination with PVs & LED** are within cost optimal region.
- PbP less than 15 years is given by Existing HP, new HP and Hybrid. VRF only in zones A & B.

Constr. Period 32: 1980-2018-2023

- **Existing HP and a few hybrid** scenarios **always combined with PVs** are within cost optimal region.

LCC, PEC & DPP Performance table

Office building | **Best Interventions Packages for LCC, PEC & DPP for all periods and climate zones for OB**

		Lowest LCC				Lowest PEC				Lowest DPP			
	CP/Cl.Z	A	B	C	D	A	B	C	D	A	B	C	D
Office Building	CP1	New HP No Insulation New AHU LED PV				New VRF Insulation New AHU LED PV				All technologies produce similar results			
	CP2	New HP No Insulation Upgrade AHU LED PV				New VRF Insulation New AHU LED PV				All technologies produce similar results			
	CP3	Existing HP LED PV				New VRF LED PV				Existing HP PV			
	CP4	Existing HP PV				New VRF PV				Existing HP PV			