EUHA Study

Energy Efficiency and Cost Effectiveness of Electric Heating in Combination with PV

iTG

05.11.2020

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- Exemplary calculations: Energy demand, primary energy, total annual costs
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- Number of dwellings suited for direct-electric heating

Who is ITG?

Institute of Building Systems Engineering Dresden

ITG Institut für Technische Gebäudeausrüstung Dresden, Forschung und Anwendung GmbH

Work we do

- Studies, technical/scientific advice
- Involvement in standardisation work (DIN V 18599 / EN 15316, EN 12831-1 etc.)
- PEF certificates for district heating networks
- Building performance certificates …

Topics our work deals with

- Energy demand/performance and cost efficiency of buildings and/or their HVAC systems
- Legislation regarding building energy performance (e.g. Energy Saving Ordinance, Energy Saving Act)
- Related subsidy schemes …

Who we work for

- Authorities
- Energy providers / Associations
- Manufacturers / Associations
- Building owners …

Background

Preceding study by ITG regarding the energy efficiency and cost effectiveness direct-electric heating in the context of the German Energy Saving Ordinance / Buildings Energy Act (on behalf of German Federal Association of Surface Heating and Surface Cooling BVF, EUHA-members involved)

EUHA: Can you do a similar study for Europe?

ITG: Sure, why not ☺

Background (Overall Task)

Based on preceding BVF study, exemplary analysis of energy efficiency and cost effectiveness of several HVAC variants for a single-family house:

- 1 building
- 2 different thermal insulation levels
- 7 different HVAC variants
- in 5 European countries

Additional content in the actual study (not covered in slides):

- Considerations regarding the relation between primary energy, renewables and greenhouse-gas emissions
- Extrapolation of model-building energy demand to the EU
- …

Yet more background (Motivation/Introduction EUH)

Motivation for direct-electric heating in modern residential buildings

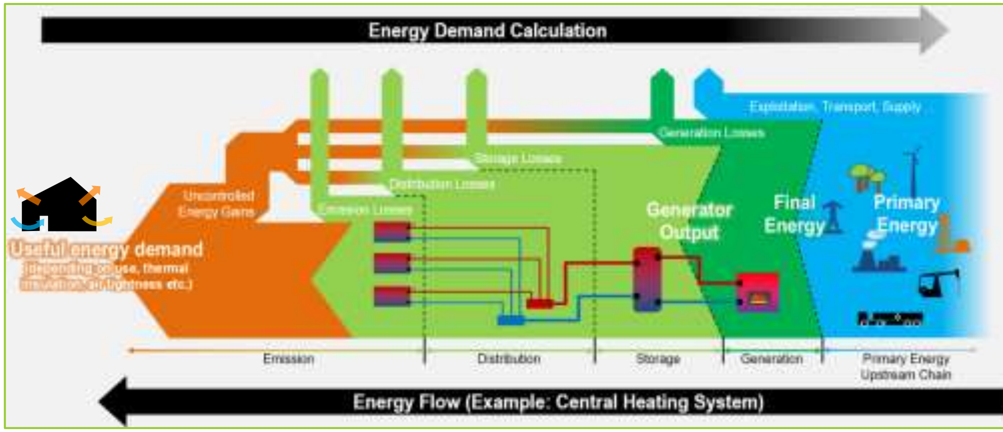
- Simple and relatively low investment costs (compared to hydronic systems), but
  … high energy costs?
  … wasteful use of electricity (“burning” pure exergy)?
  … not exactly environmentally friendly (primary energy, CO2eq)?

→ Well, it depends …

- Decreasing energy consumption for heating due to buildings becoming better (thermal insulation, air tightness)
- Grid power becoming greener
- Steeper price increase for fossil fuels expected (CO2 tax …)
- Future: All-electric society?

→ Electric heating + PV may become more viable economically and ecologically

(Sub)Tasks, calculation methods, input parameters



Energy demand EN 15316 / DIN V 18599

Conversion to EU countries (CZE, FRA, NLD, SWE)

Country-specific PV output

Property			Level of thermal insulation[a]	
			High	Very high
Thermal transmittance, U-value	Walls	W/m²K	0,20	0,13
	Roof		0,15	0,13
	Floor slab		0,25	0,20
	Window		0,90	0,70
	Door		1,70	1,40
	Thermal bridges[b]		0,03	
Air tightness, n_{50}		h^{-1}	1,0	
Geometry	External volume[c], V_e	m³	554	
	Net floor area[d], A_{NGF}	m²	162	
	Living space area, A_W	m²	150	
	[illegible]	m^{-1}	0,74	

Balance of electricity demand and PV output

System/Property			Value
PV-System	Module surface area	m²	49,8
	Cell type		Monocrystalline Silicon
	Peak power	kW_{peak}	8,16 average over 25 years[a] (9,06 for new modules)
	Orientation	—	S
	Angle (≙ roof slope)	°	37
Ventilation system	Type		Supply/exhaust with heat recovery
	Annual operating time		Heating season only[b]

Research + Input EUHA: PEF, energy prices, investment costs …

No.	Room heating		Domestic water heating	PV battery	Abbreviation
	Generation	Emission			
1	Gas condensing boiler	Underfloor heating (35/28 °C)	Hot water storage tank, sharing heat generator with room heating	No	Boiler + Hot water tank
2	Electric air source heat pump				ASHP + Hot water tank
3			Electric flow water heater	Yes	ASHP + Flow heater + Battery
4	Electric underfloor heating		Electric heat pump water heater[a]	No	EUFH + HP water heater
5			Electric hot water storage tank		EUFH + E hot water tank
6				Yes	EUFH + E hot water tank + Battery
7			Electric Flow water heater		EUFH + Flow heater + Battery

Results

- Final energy balance
- Primary energy
- Energy costs
- Total annual costs

Overview: (Sub)Tasks and calculation methods

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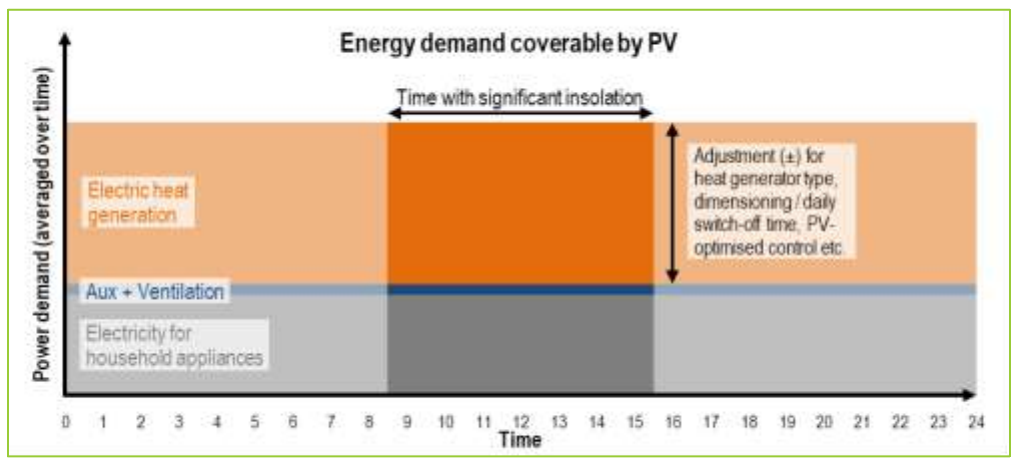
Degree days based on monthly mean values for a heating limit temperature of 10 °C; from PVGIS TMY data

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Σ
Germany Potsdam (German reference TMY)	279	227	164	24	0	0	0	0	0	16	177	282	1.169
Czech Republic Prague: 50°05'N 14°25'E	313	381	143	24	0	0	0	0	0	68	138	431	1.498
France Paris: 48°51'N 02°21'E	143	185	102	0	0	0	0	0	0	0	81	192	703
Netherlands Amsterdam: 52°22'N 04°54'E	267	154	124	51	0	0	0	0	0	0	60	226	882
Sweden Stockholm: 59°20'N 18°03'E	446	370	310	123	0	0	0	0	0	65	198	397	1.909

Mean solar radiation intensity [W/m²] on the roof pane (S 37°); from PVGIS TMY data

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Germany Potsdam (German reference TMY)	53	55	122	216	224	233	201	196	158	114	42	27
Czech Republic Prague: 50°05'N 14°25'E	34	99	180	222	156	226	187	189	167	135	62	61
France Paris: 48°51'N 02°21'E	72	92	166	223	210	241	228	210	192	145	57	62
Netherlands Amsterdam: 52°22'N 04°54'E	39	72	167	223	210	216	213	202	153	107	67	50
Sweden Stockholm: 59°20'N 18°03'E	18	54	152	220	224	247	211	186	181	78	43	8



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Overview: (Sub)Tasks and calculation methods

Energy demand EN 15316 / DIN V 18599

Conversion to EU countries (CZE, FRA, NLD, SWE)

Country-specific PV output

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Country	Primary energy factor [$kWh_{prim}/kWh_{fin,HI}$]	
	Natural gas	Electricity (grid power)
Germany	1,1	1,8
Czech Republic	1,0	2,6
France	1,0	2,3[a]
Netherlands	1,0	1,45[a]
Sweden	1,0[b]	1,6

a As of 2021

b In Sweden, natural gas and district heating have the same primary energy factor (1,0).

Country	Consumer energy price [€/$kWh_{fin,HI}$], including tax etc.				
	Natural gas	Electricity			
		Drawn from grid		PV Fed to grid	
		Tariff	Applied to	Tariff	Balancing method
Germany	0,0752	General use: 0,3088 Heating: 0,2	Variant 1, HVAC + household Variants 2–7, HVAC only	-0,0944	Momentary values (feed in and draw count separately)
Czech Republic	0,0586	General use: 0,1748 Heating: 0,117	Variant 1, HVAC + household Variants 2, 4–6[a], HVAC + household	-0,04	
France	0,1049	High: 0,1667[b] Low: 0,1195[b]	Variant 1, HVAC + household Variants 2–7, HVAC only	-0,10	
Netherlands	0,0921	General use: 0,2250	Variants 1–7, HVAC + household (no low/heating tariff in place)	-0,05	Annual value (only either feed in or draw at the end of the year)
Sweden	0,087[c]	Low: 0,128	Variants 1–7, HVAC + household (low tariff applicable to everything, no distinction)	-0,005	Momentary values (feed in and draw count separately)

a Flow-through water heaters are uncommon in CZE due to electricity base prices depending on the amperage requirement of the building. No costs/prices will be shown for variants with flow water heaters (3, 7).

b Averaged between numbers from different EUHA members as well as between high/low and day/night pricing schemes

c Natural gas costs about the same as district heating per kilowatt hour in Sweden.

Overview: (Sub)Tasks and calculation methods

- Energy demand EN 15316 / DIN V 18599
- Conversion to EU countries (CZE, FRA, NLD, SWE)
- Country-specific PV output
- Balance of electricity demand and PV output
- **Research + Input EUHA: PEF, energy prices, investment costs …**
- Results
  - Final energy balance
  - Primary energy
  - Energy costs
  - Total annual costs

Sources Investment costs		
Country	**Source**	**Notes/Details**
Germany	Own calculation	Based on averaged catalogue prices, usual vendor discounts, labour costs, margins and tax
Czech Republic	Fenix	Prices provided for some items; average cost level of about 80 % compared to Germany
France	Danfoss, Fenix	Prices provided for some items: average cost level of about 110…120 % compared to Germany
Netherlands	Magnum	Prices provided for PV systems; Otherwise similar to Germany
Sweden	Ebeco	Similar to Germany

Variant	1	2	3	4	5	6	7
Heat generation for room heating Central heat generator (boiler or heat pump), pump, control, mounting hardware	Gas condensing boiler ca. 12 kW: 3.600 €	Electric air source heat pump with domestic water heating 6,2 kW: 10.200 € 5,3 kW: 9.700 €	without domestic water heating 5,7 kW: 10.000 € 4,8 kW: 9.500 €	—			
Underfloor heating system 150 m² Underfloor heating tubing/cable/mat, mounting system/hardware, room temperature control, floor screed	Hydronic underfloor heating (35/28 °C) Underfloor heating tubing, manifold, heat distribution inside building (tubing, insulation, fittings, mounting hardware) 11.300 €			Electric underfloor heating Electric Underfloor heating system (e. g. heating cable/mat) 9.000 €			
Domestic water heating	Hot water storage tank, sharing heat generator with room heating standard tank 1.600 €	heat-pump-specific tank 2.900 €	Electric flow water heater 800 €	Electric heat pump water heater 4.200 €	Electric hot water storage tank 2.200 €		Electri water 80
Tap / Hot water distribution Tubing, insulation, fittings, mounting hardware, circulation pump in case of central water heating	1.300 €	1.300 €	200 €	1.300 €	1.300 €		20
Electric/Gas installation heating / hot water	700 €	500 €	550 €	150 €			
Gas connection to grid	2.100 €	—					
Chimney	2.900 €	—					
Ventilation system Supply/exhaust ventilation system with heat recovery, ducts, in-/outlets, mounting hardware	9.000 €						
PV system ~50 m², ~9 $kW_{p,max}$ (8,16 $kW_{p,25a}$) including mounting hardware, inverter, installation material	15.200 €						
Battery ~9 kWh, lithium-based including mounting and installation material	—		9.300 €	—		9.300 €	

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Overview: (Sub)Tasks and calculation methods

Energy demand EN 15316 / DIN V 18599

Conversion to EU countries (CZE, FRA, NLD, SWE)

Country-specific PV output

Balance of electricity demand and PV output

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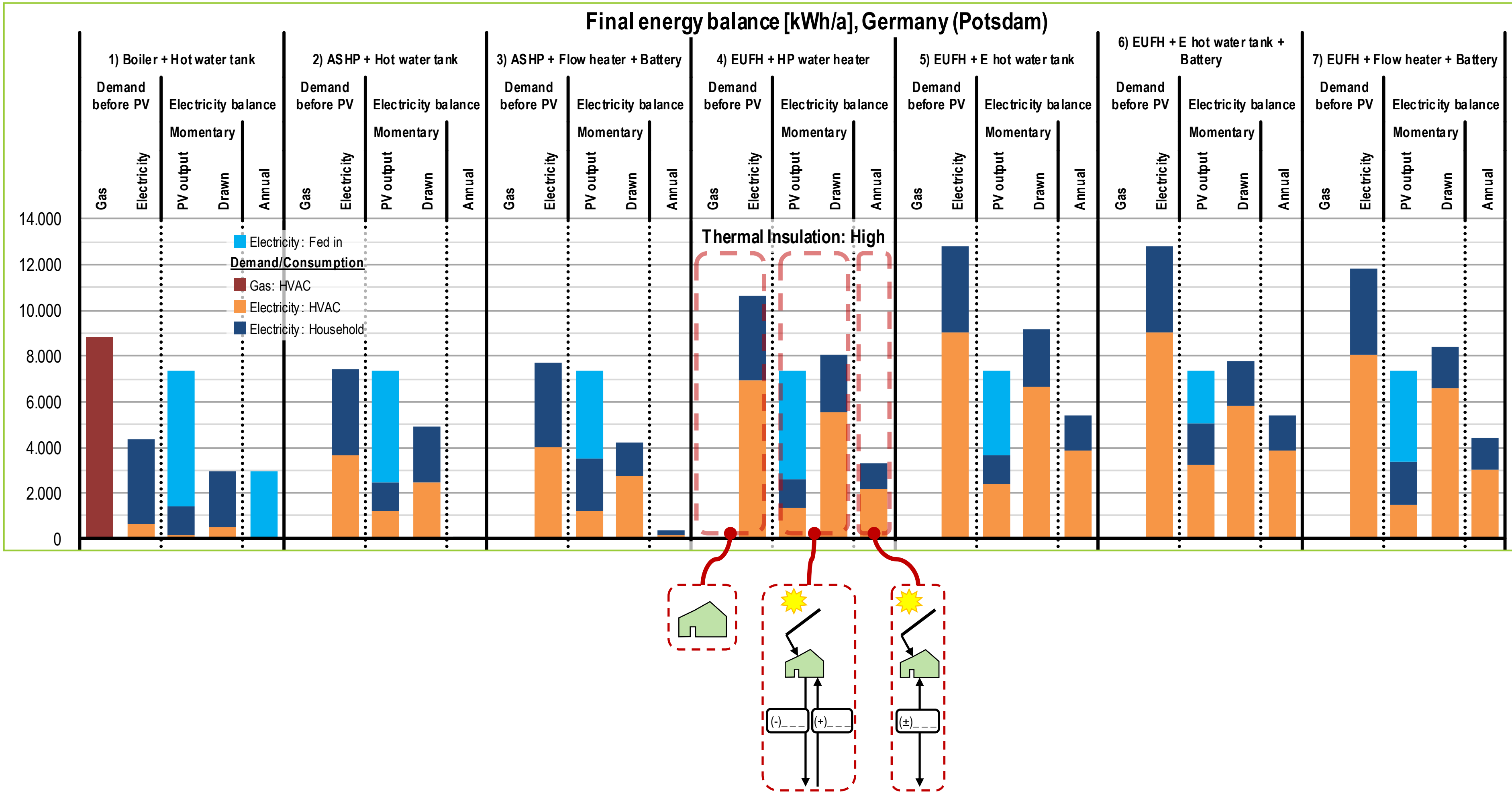
System/Component	Service life [a][a]	Annual costs as percentage of initial investment costs	
		Repair[b]	Maintenance etc.[c]
Gas condensing boiler	18	1,50 %	2,92 %
Heat pump	18	1,00 %	1,32 %
Hydronic underfloor heating	50	1,00 %	0
Electric underfloor heating	50	0,50 %[d]	0
Hot-water storage tank	20	1,00 %	0,63 %
Flow water heater	15	1,00 %	0
Hot-water distribution	30	0,50 %	0
Electric/Gas installation and connection to grid	50	1,00 %	0
Chimney	50	1,00 %	1,59 %

Results: Final energy balance (example)



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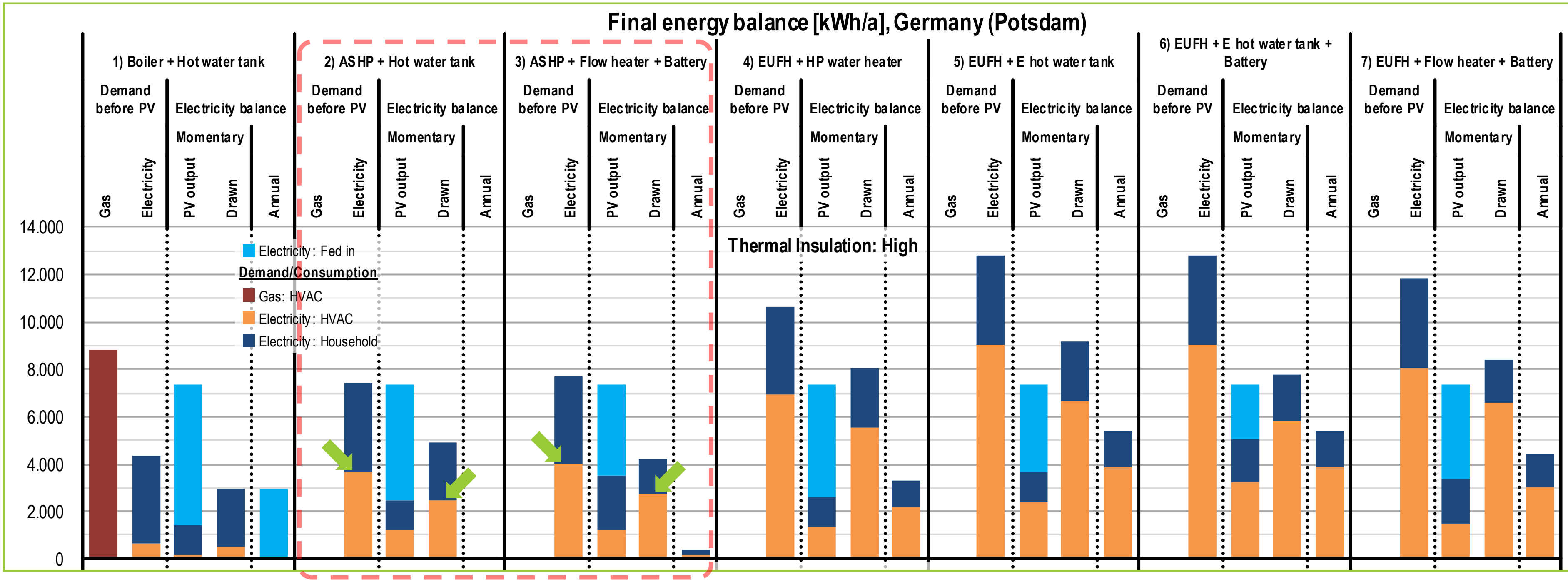
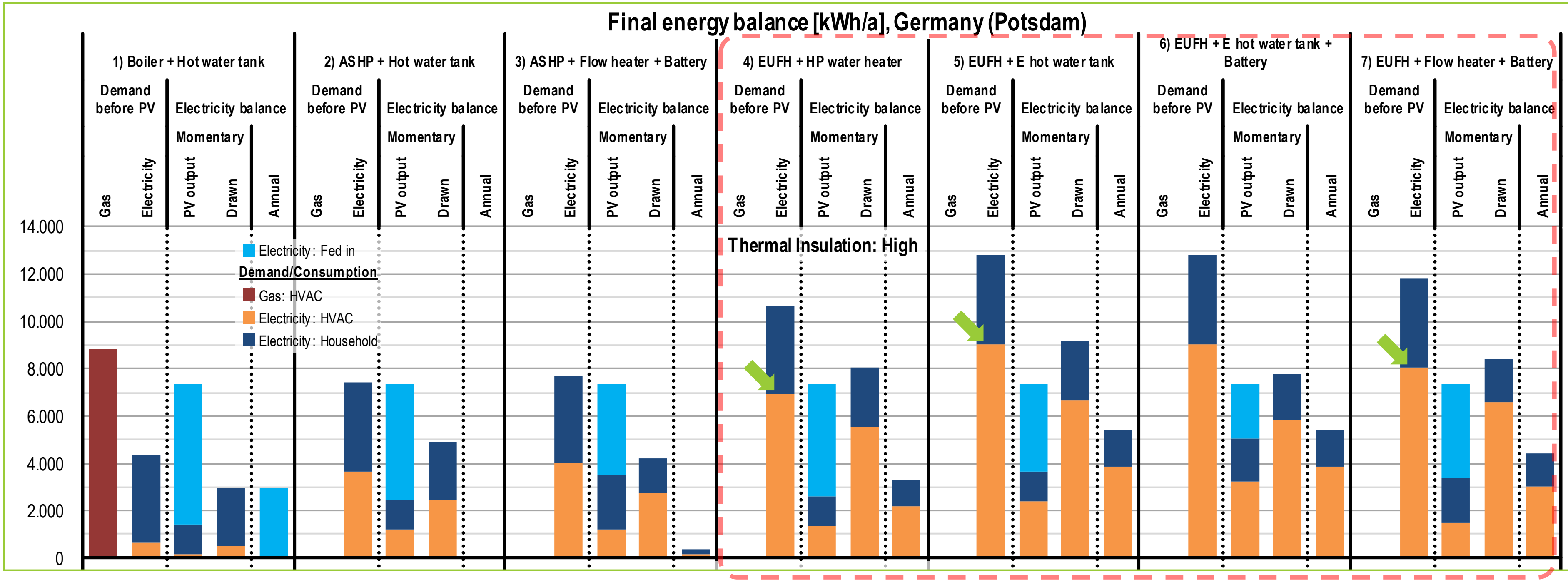


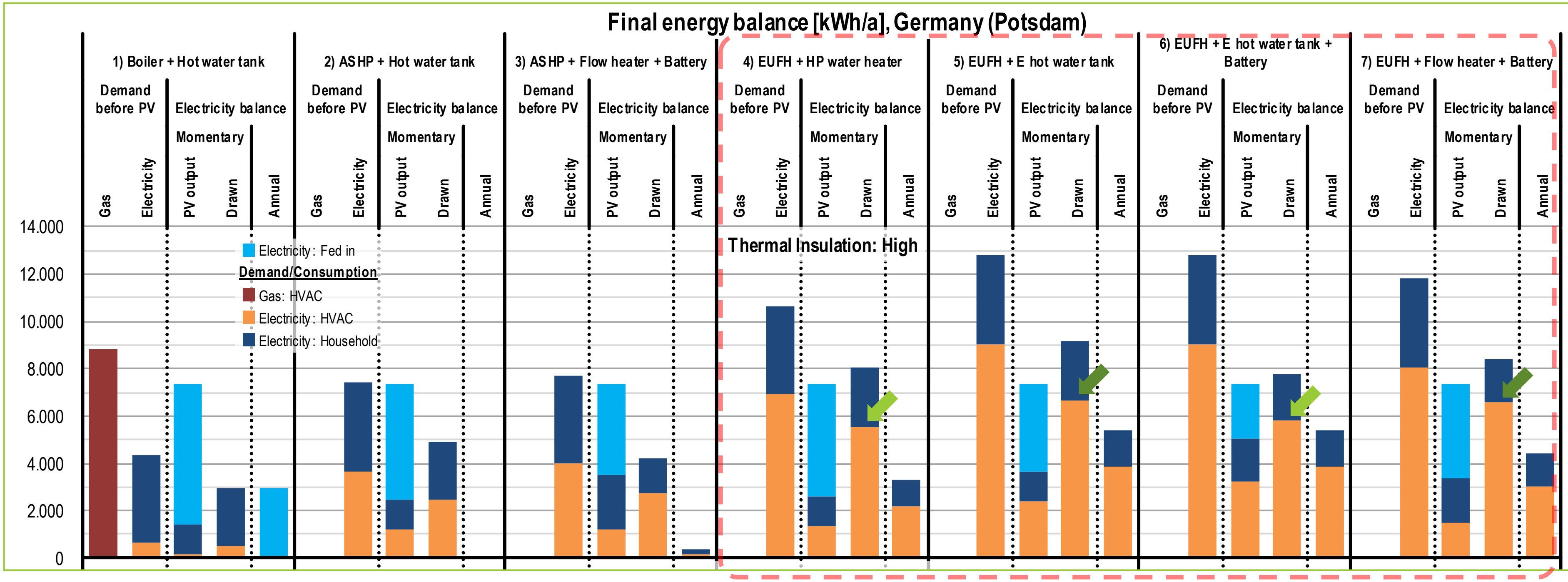
- Heat pump: Lowest final energy demand of electrically heated variants before and after PV

Results: Final energy balance (example)



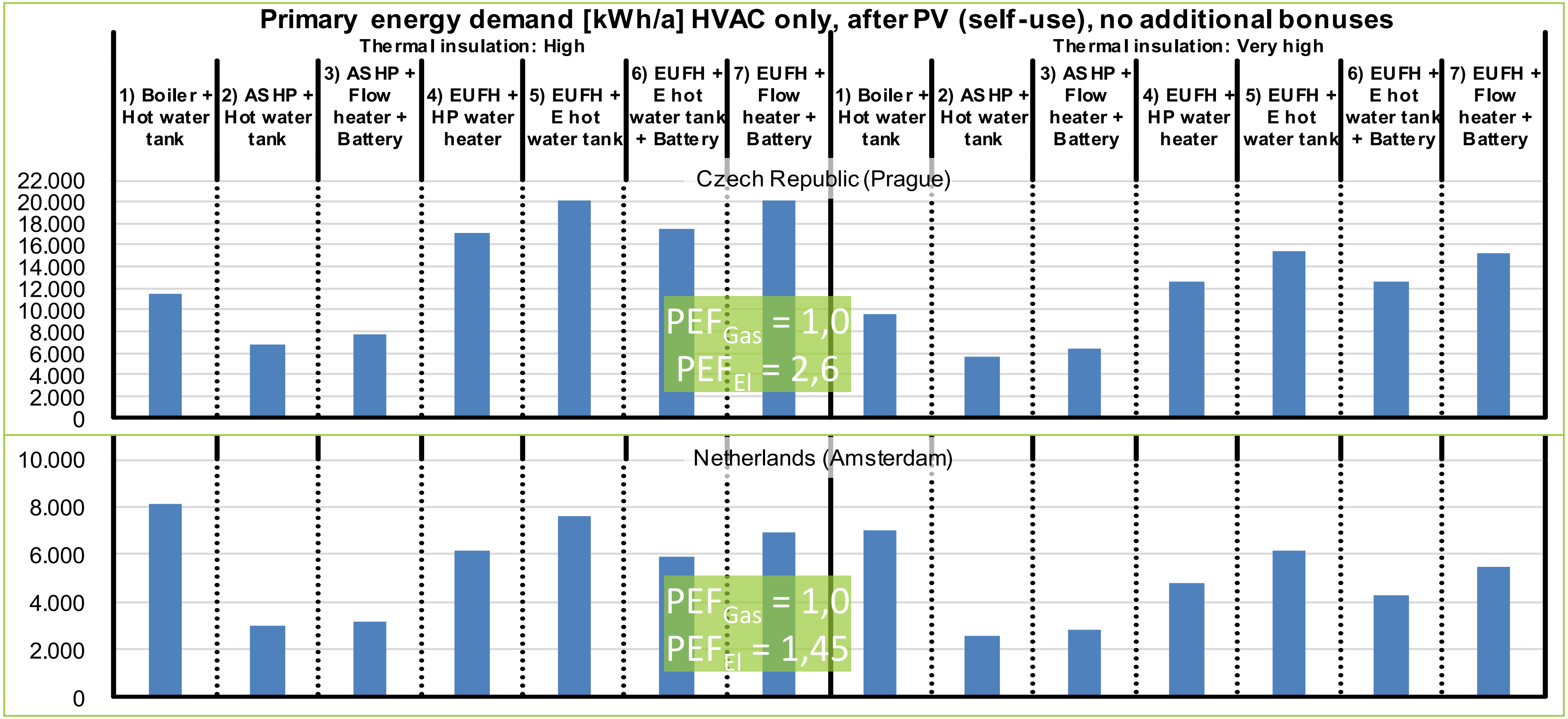
- Electric underfloor heating
  - Demand before PV, order from lowest to highest:
    - Heat-pump water heater(4)
    - Flow water heater (7)
    - Central hot-water tank (5/6)

Results: Final energy balance (example)



- Electric underfloor heating
  - Actual draw (after PV):
    - Central hot-water tank with battery (6) similar to heat-pump water heater (4); slightly better/worse depending on country-specific PV output
    - Flow heater with battery (7) similar to central hot-water tank without battery (5); slightly better/worse depending on country-specific PV output (better for DEU, CZW, FRA, NLD, worse for SWE)

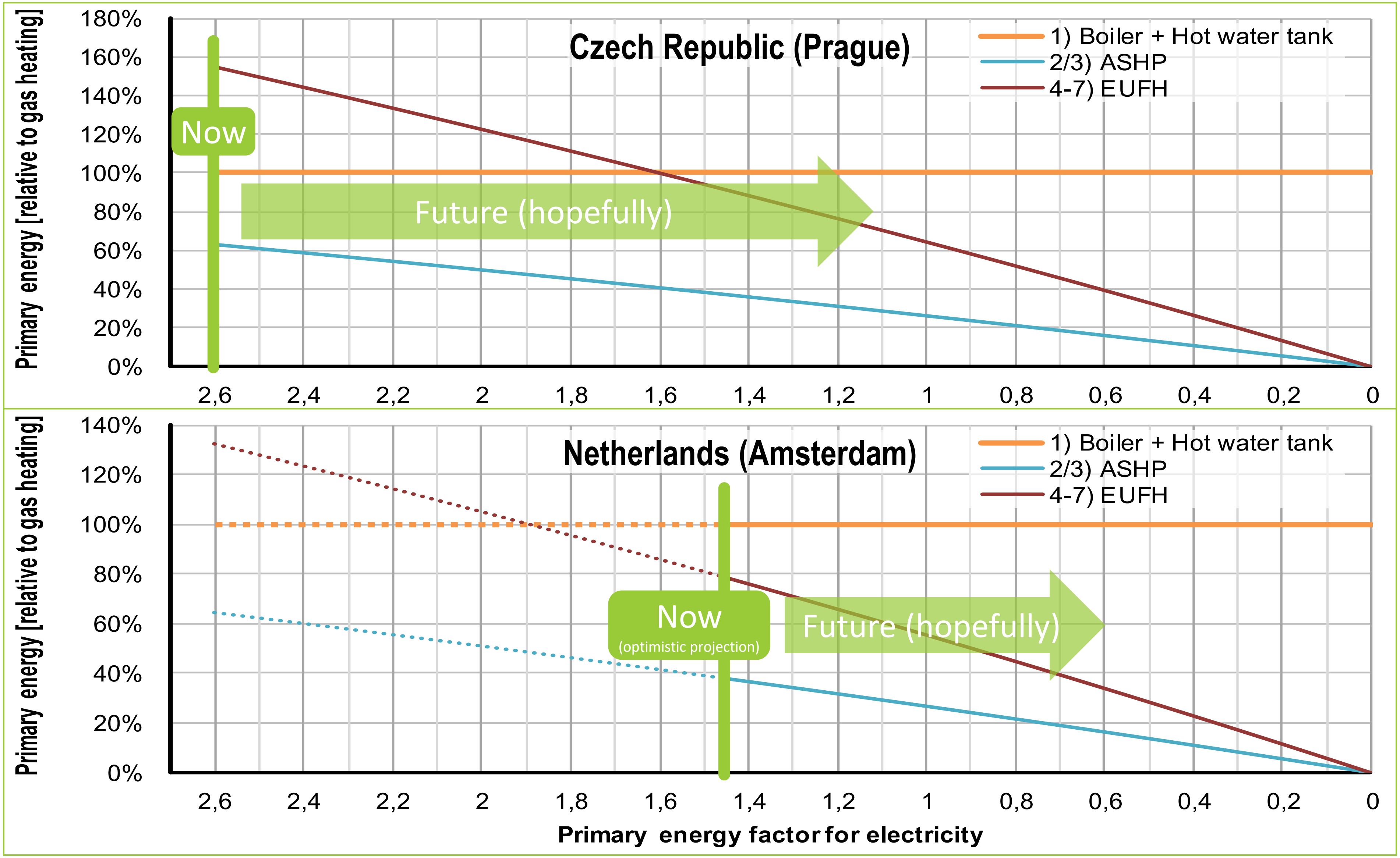
Results: Primary energy demand (example)



- Similar trend to final energy demand, but different scaling due to differences in
  - Primary energy factors (between countries, between gas and electricity)
  - Country-specific final energy demand (weather) and PV gains (solar insolation)

Results: Aggregated primary energy demand (example)

Aggregated by thermal-insulation level and main heat generator



Influence of PEF for electricity: Findings/Outlook

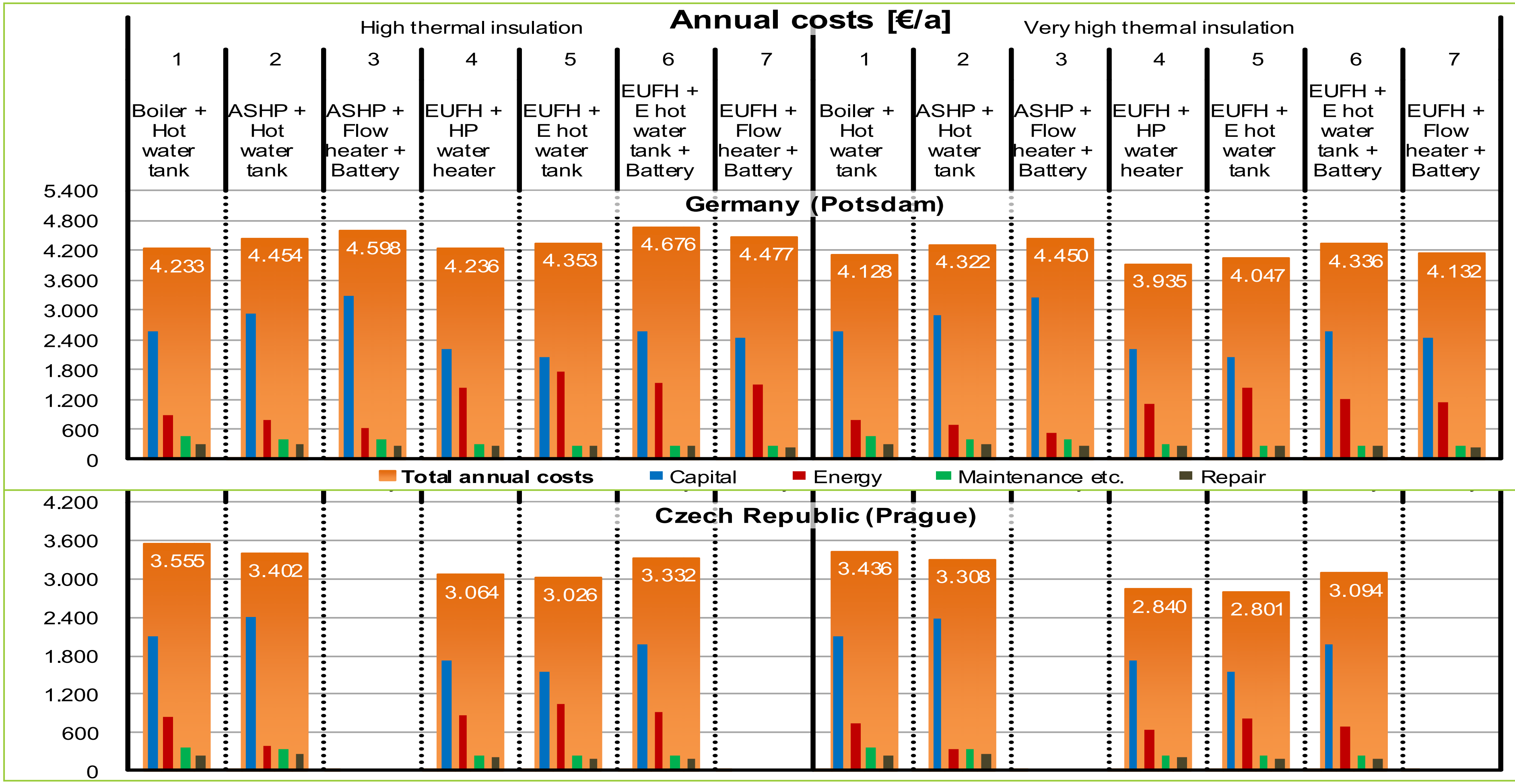
- Direct-electric heating in combination with PV, on average, causes more primary energy demand than gas heating with PV right now. With ongoing and growing efforts towards electricity from renewable energy sources and also extrapolating from the recent past, this is most likely a matter of time only.

- In contrast, basically no potential to make natural gas and condensing boilers any better in terms of efficiency, primary energy, climate-effecting/pollutant emissions than they are now

→ To a certain degree, these findings also apply to greenhouse gases

- Comparison highly depends on the made assumptions and the reference to compare against
  - For example, primary-energy-wise, direct-electric heating usually scales better with the building's heat demand (thermal insulation, air tightness) than gas heating. Therefore, different results may show for an even better thermal insulation than was assumed here.
  - With direct-electric heating (+ PV) often causing lower total annual costs than gas heating (+ PV), part of the saving could potentially be invested in better thermal insulation.

Results: Total annual costs (example)



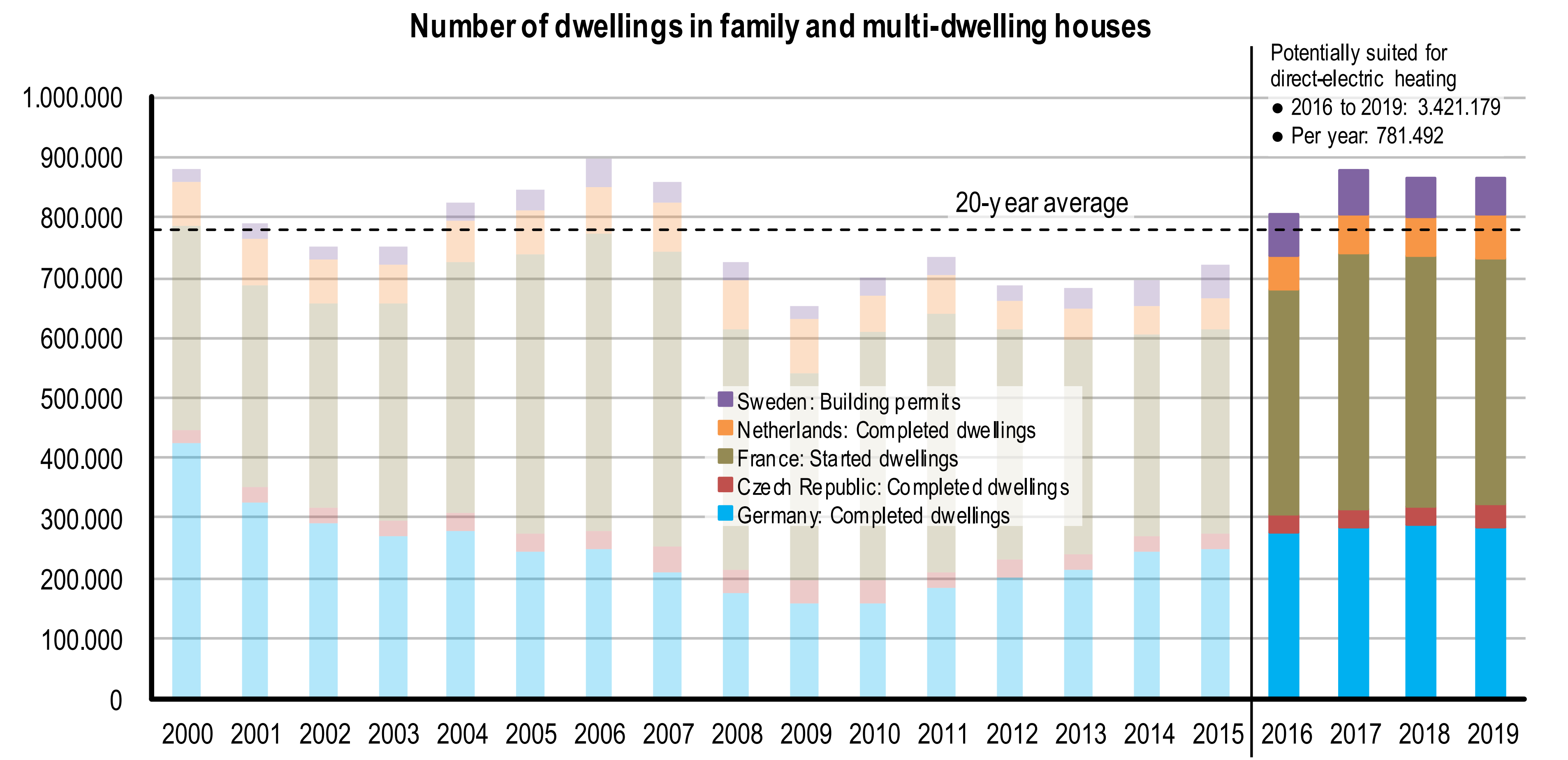
- Direct-electric heating in combination with PV – in highly insulated buildings – often economically interesting or even favourable (compared to gas heating with PV)
- Profits more from lower heat demand (-> better thermal insulation) than gas heating

Total annual costs: Outlook

- No further potential for efficiency and price optimisation for gas condensing boilers (mature technology)
- PV prices dropped significantly in recent years (probably moving towards stagnation) – reduced potential for price optimisation (scale effects etc.)
- Still some optimisation potential for batteries to be expected
  - PV batteries today = Lithium-Ion:
    - Recent development mainly driven by electromobility / car industry
    - Still rather young technology (at least in that context/scale)
  - Possibility: Economically feasible reconfiguration and reuse of old traction batteries in near future(?)
  - Ongoing development of alternative battery systems for stationary use
- Steeper price increase for fossil fuels than for electricity from renewable sources to be expected (e. g. carbon tax)

Number of dwellings potentially suited for direct-electric heating

- Assumption: New buildings from 2016 onwards probably suited for direct-electric heating



Thank you for your attention!

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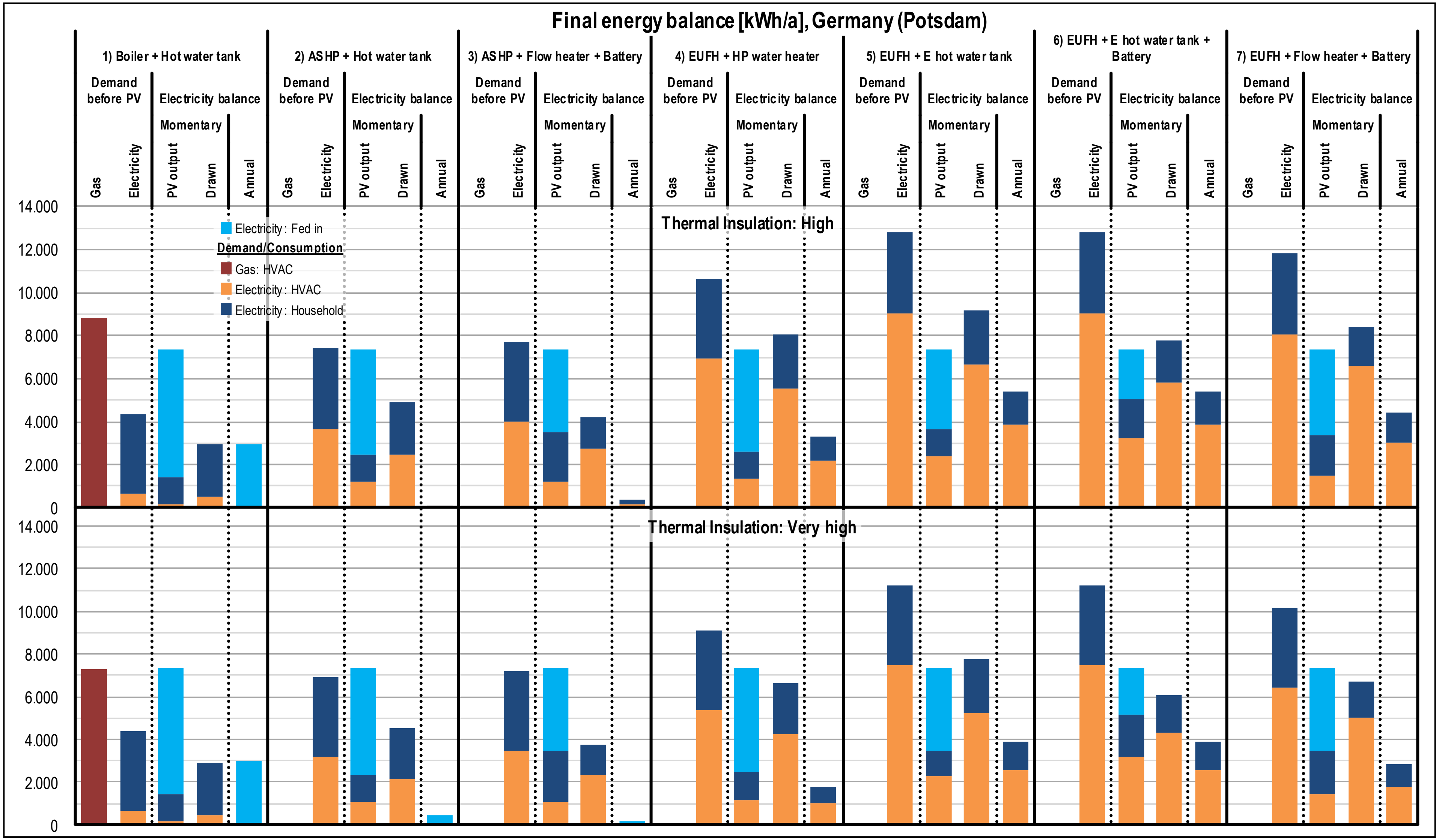
A few additional slides, just in case …

(There is even more in the actual study)

Final energy balance



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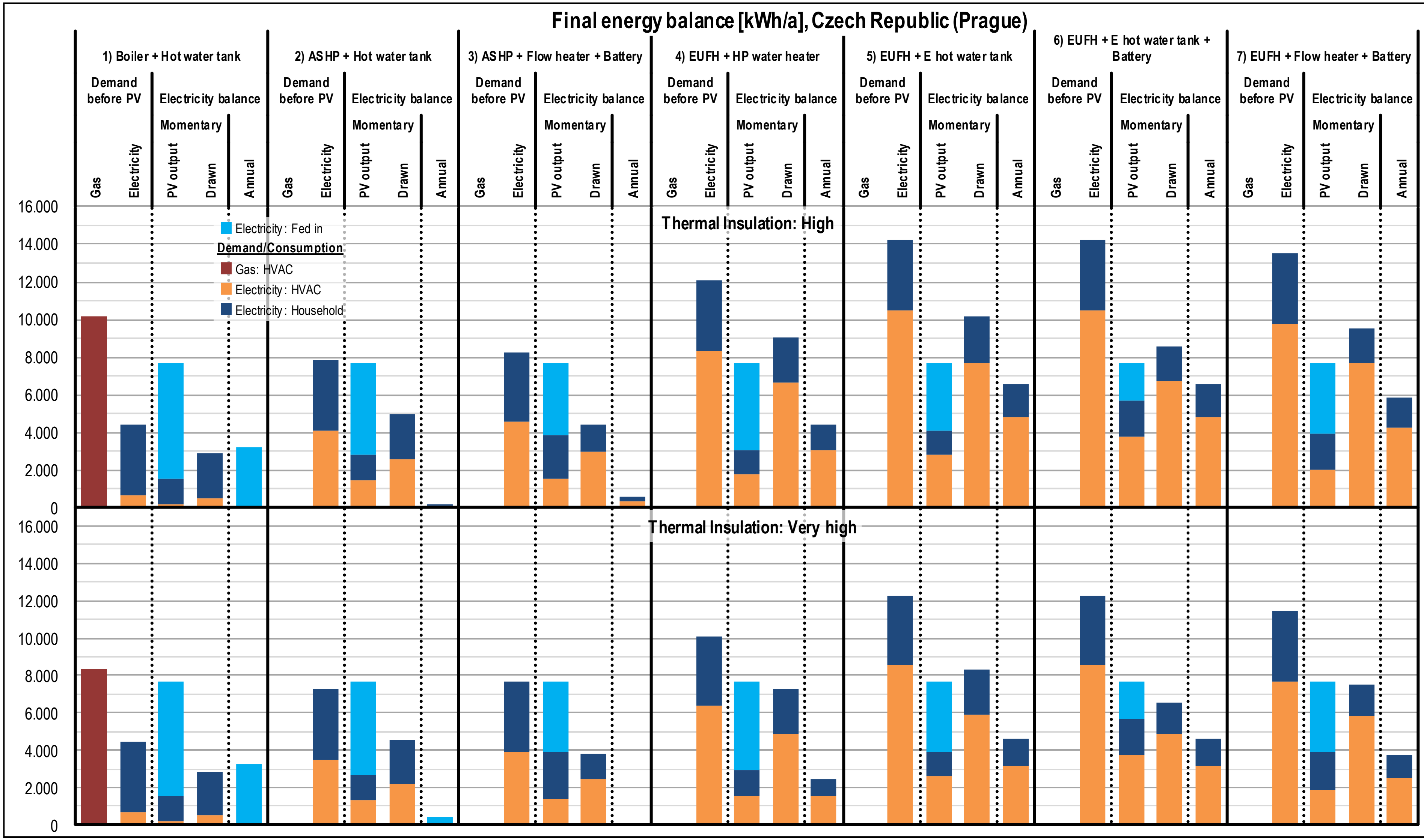

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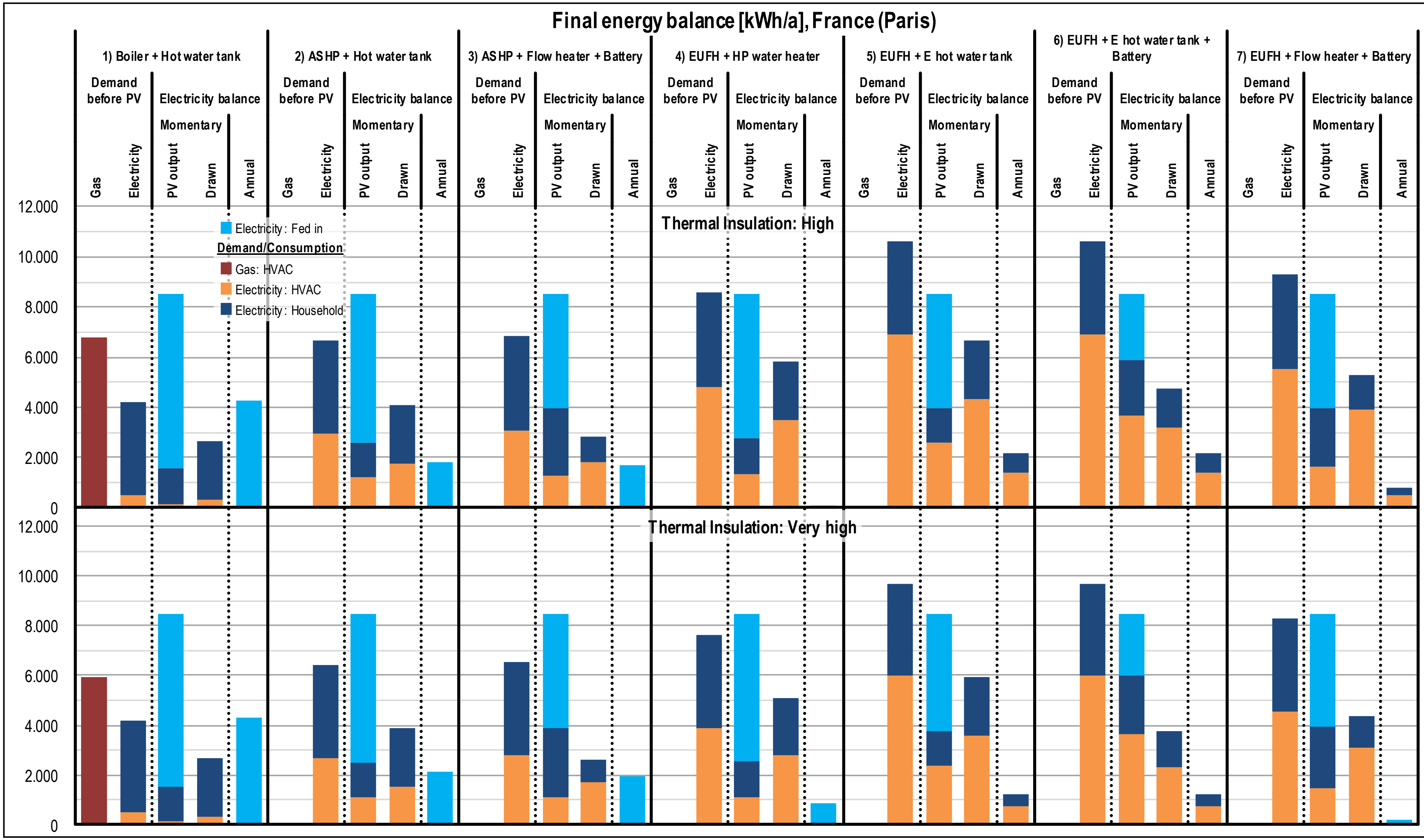

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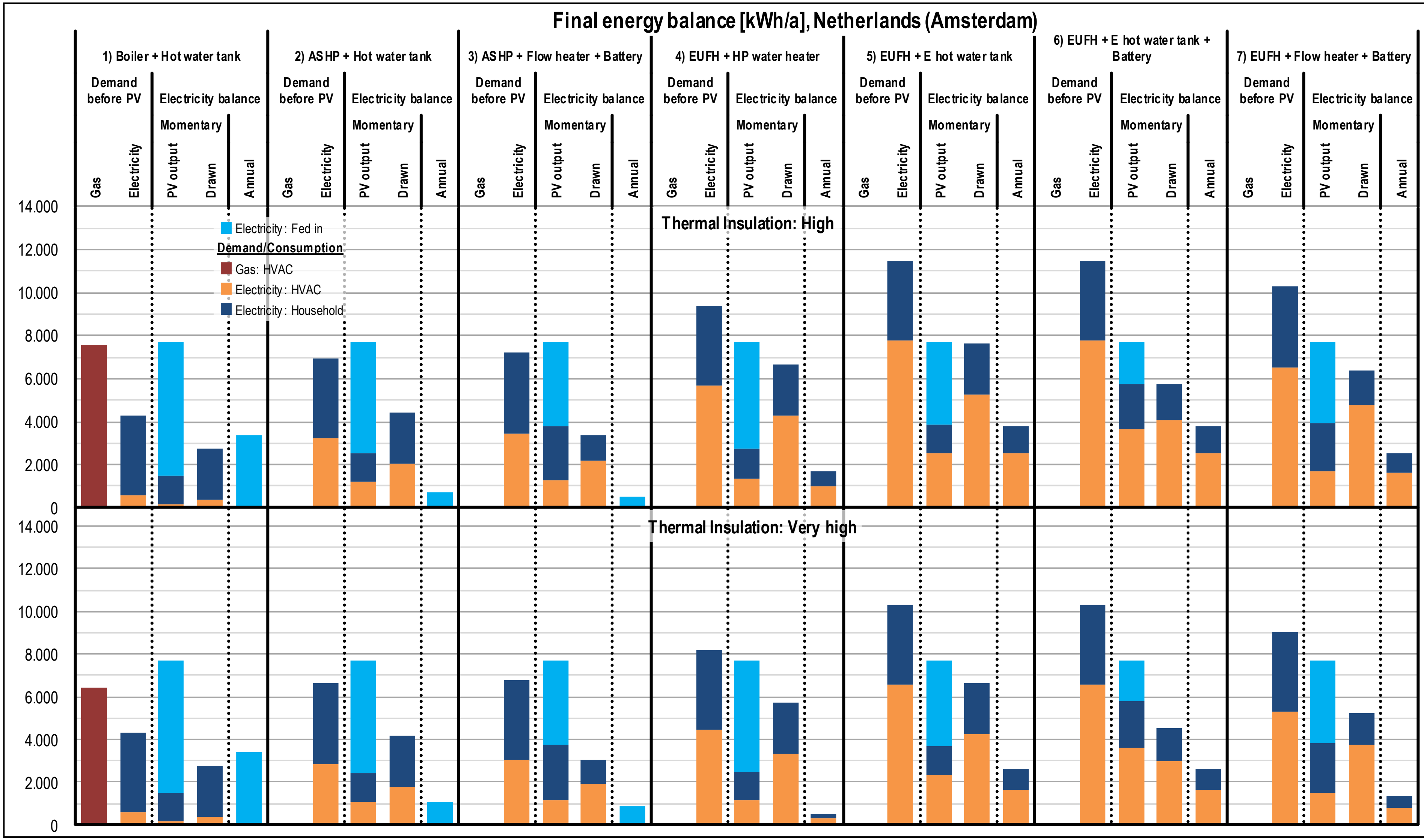

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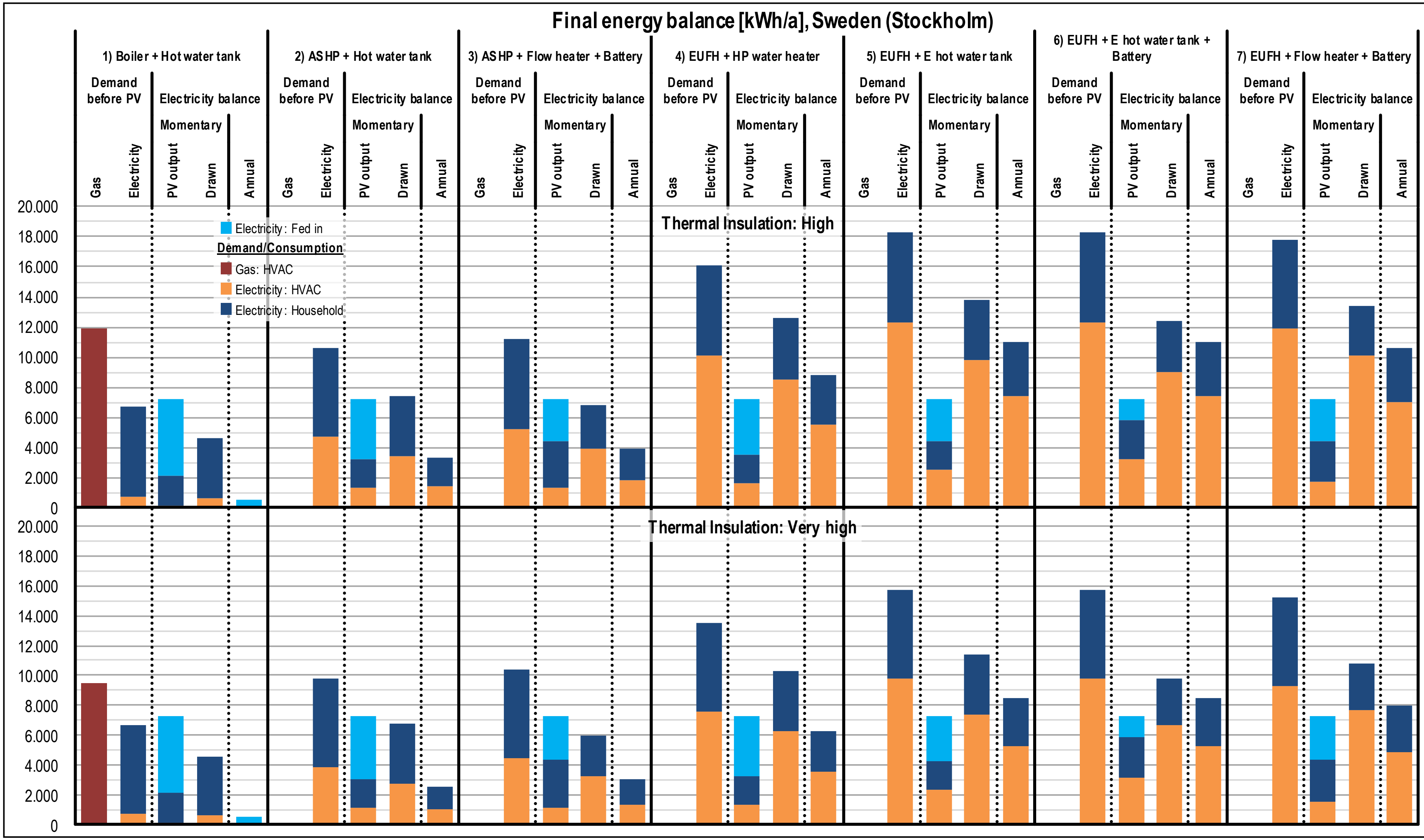
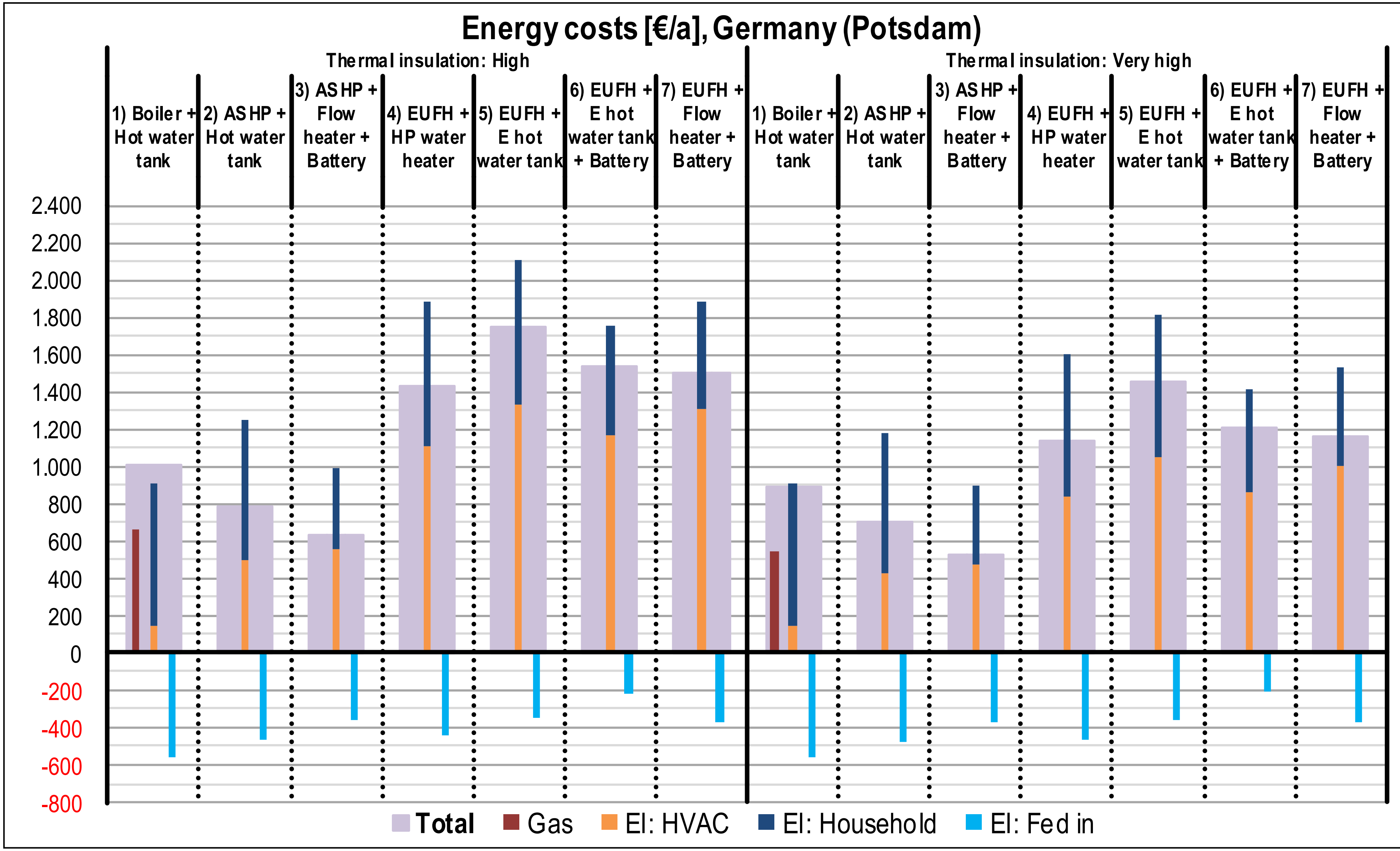


Energy costs



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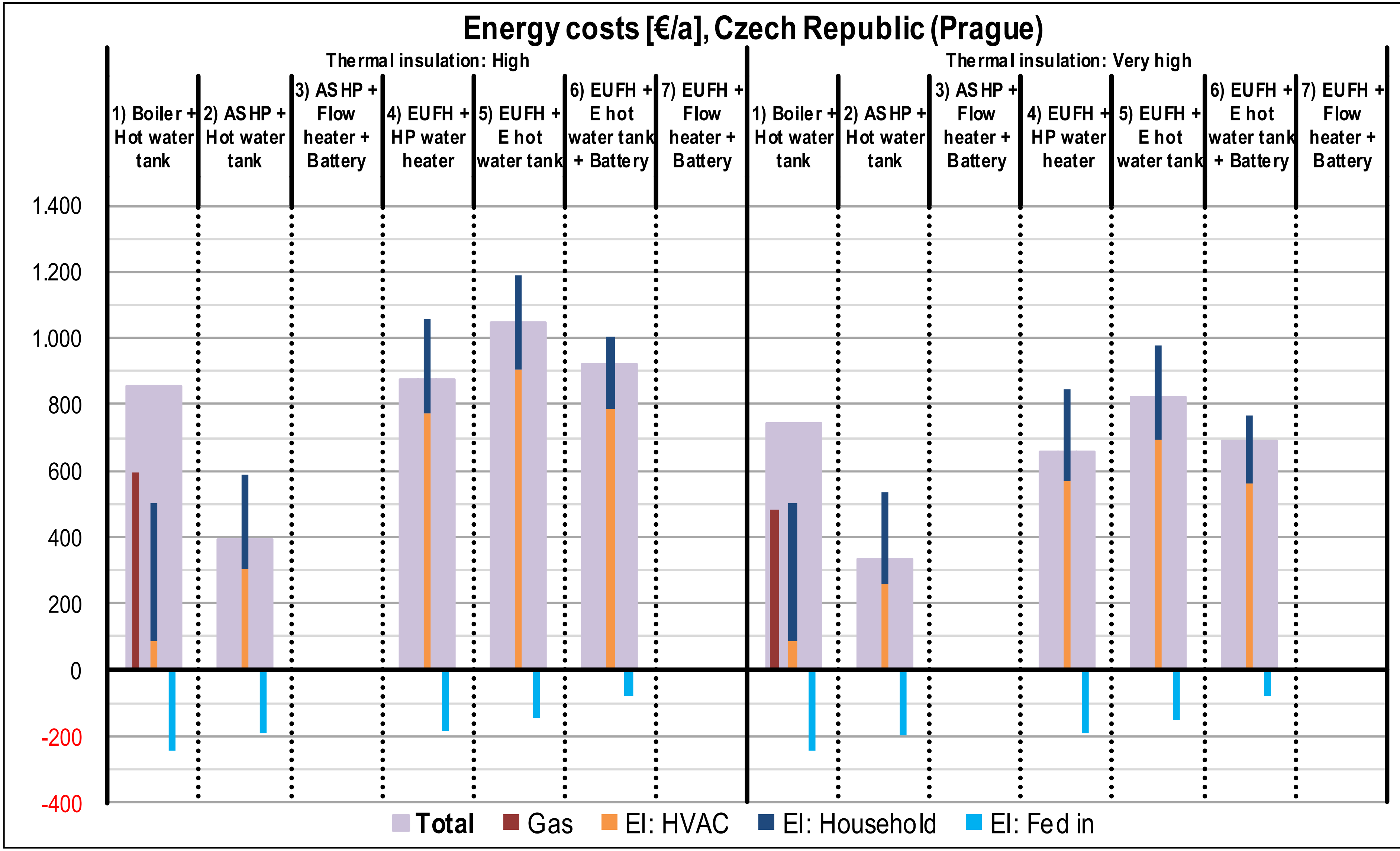

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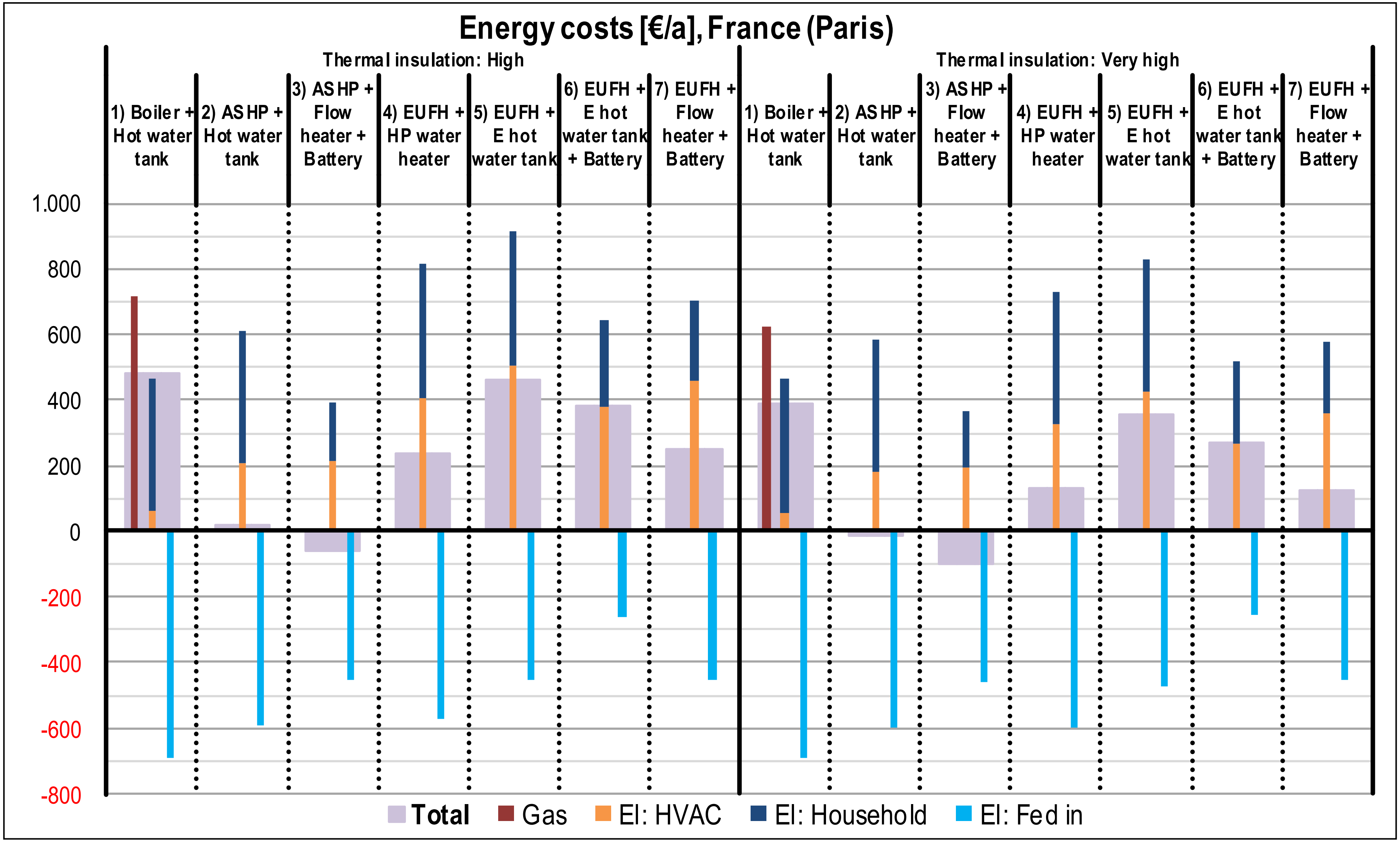

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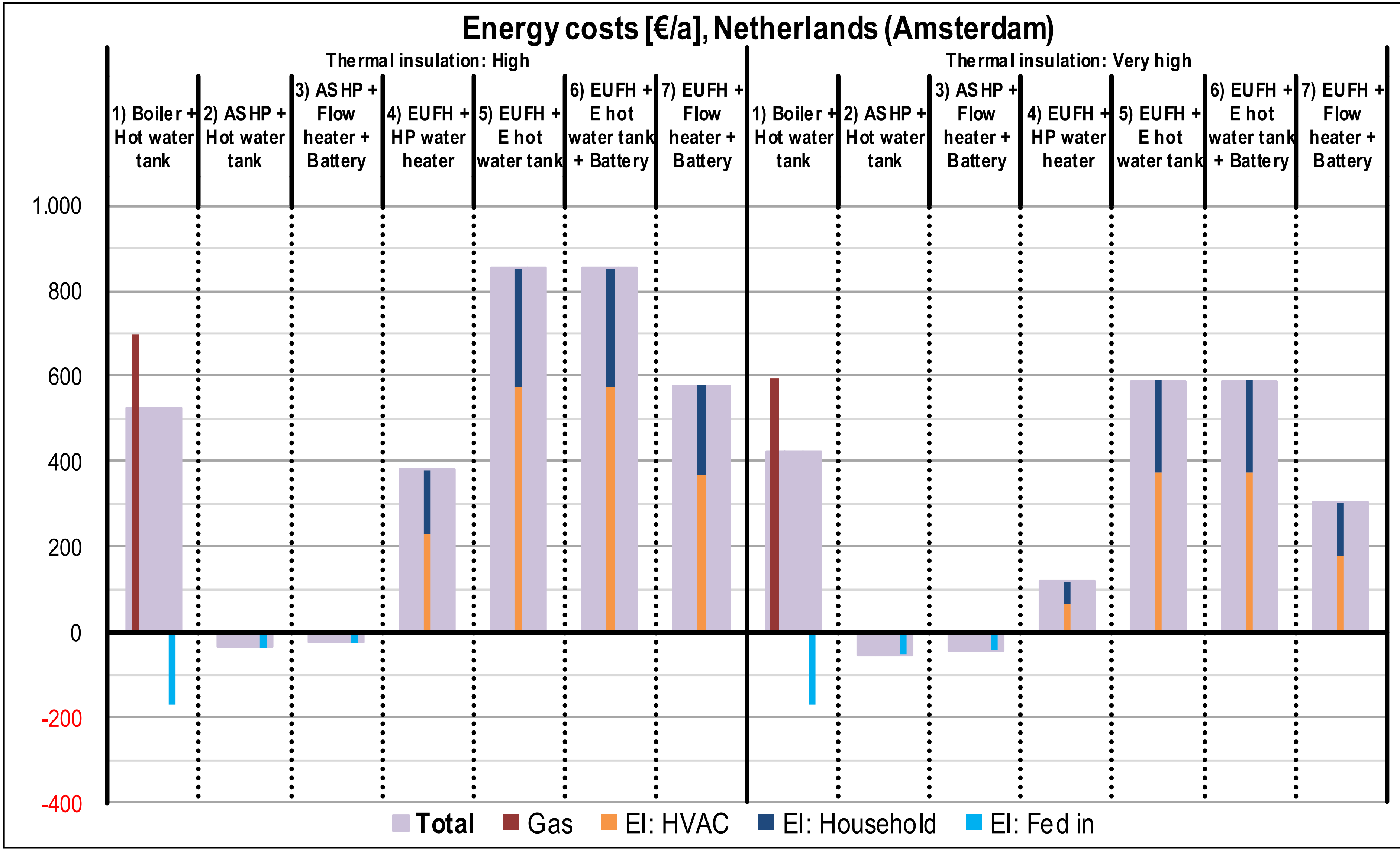

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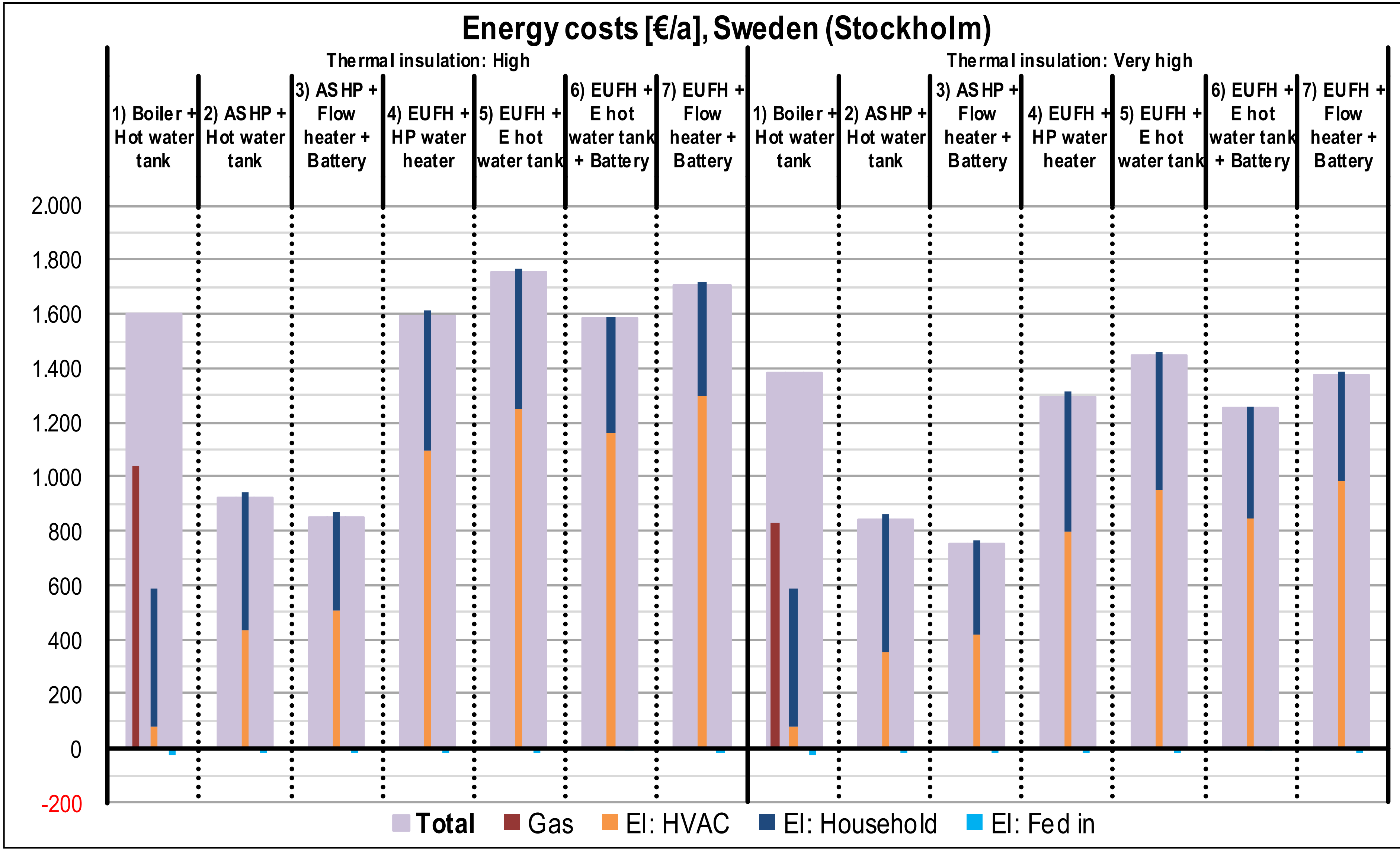
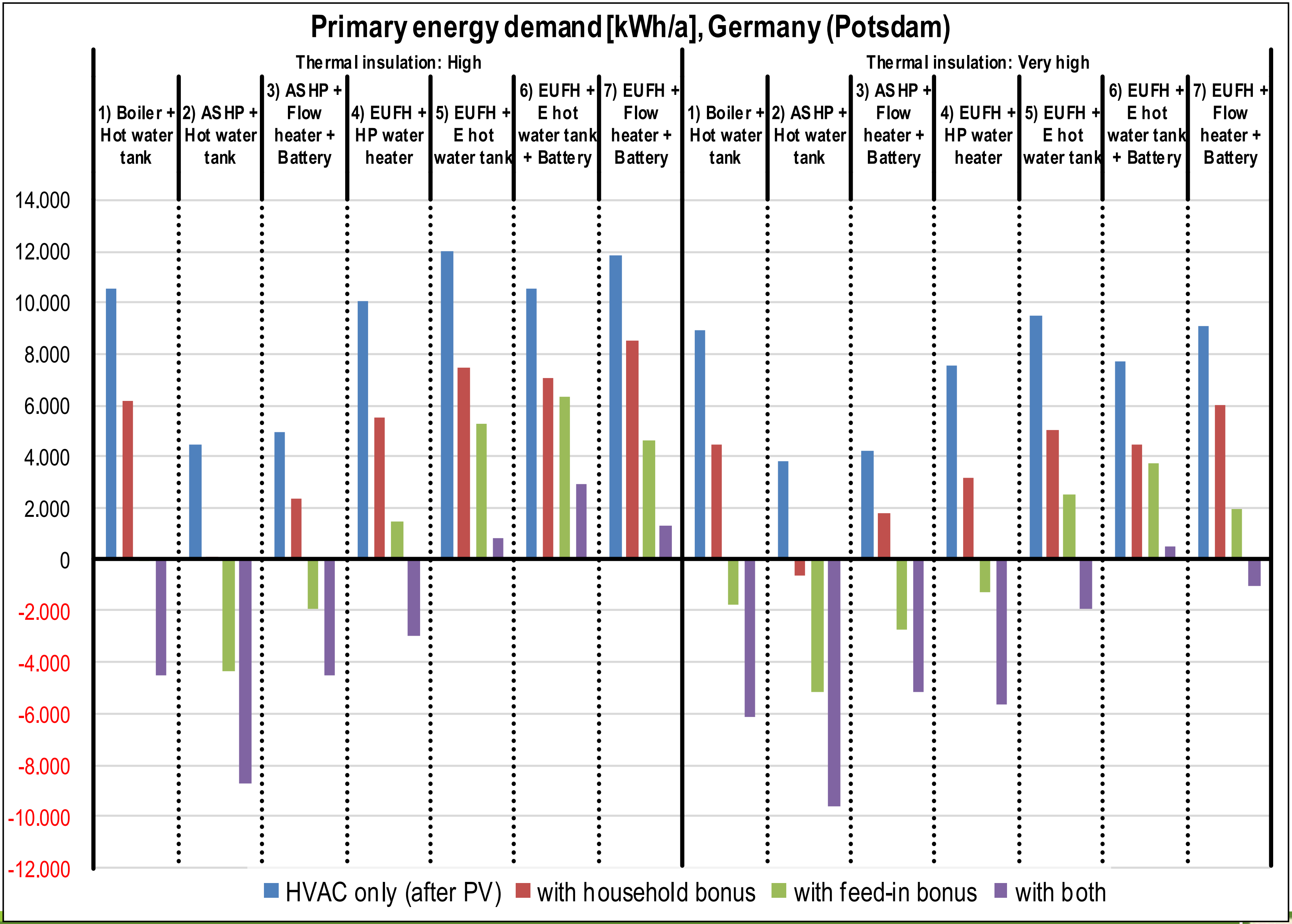


Primary energy demand (Demand: HVAC only)



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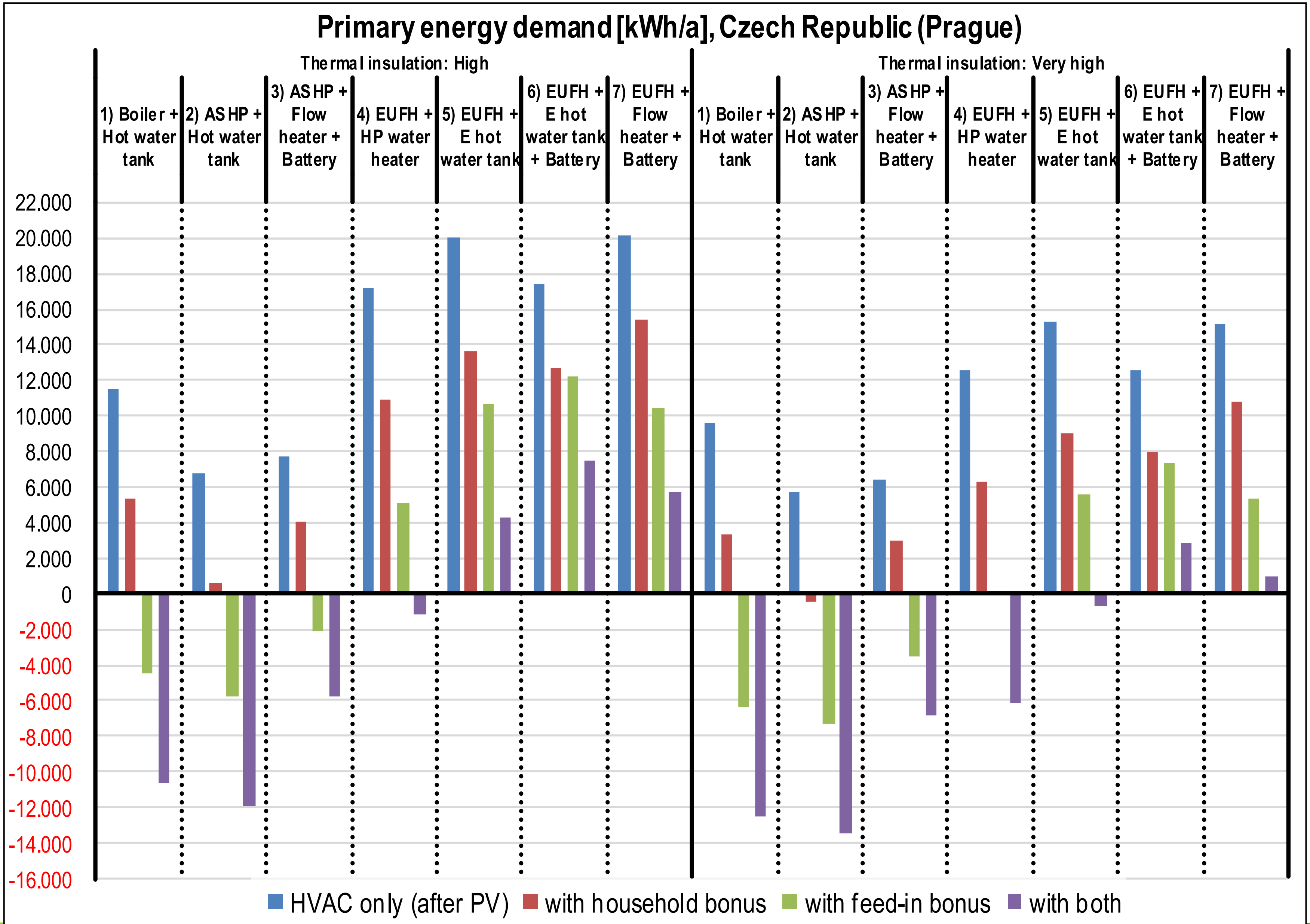

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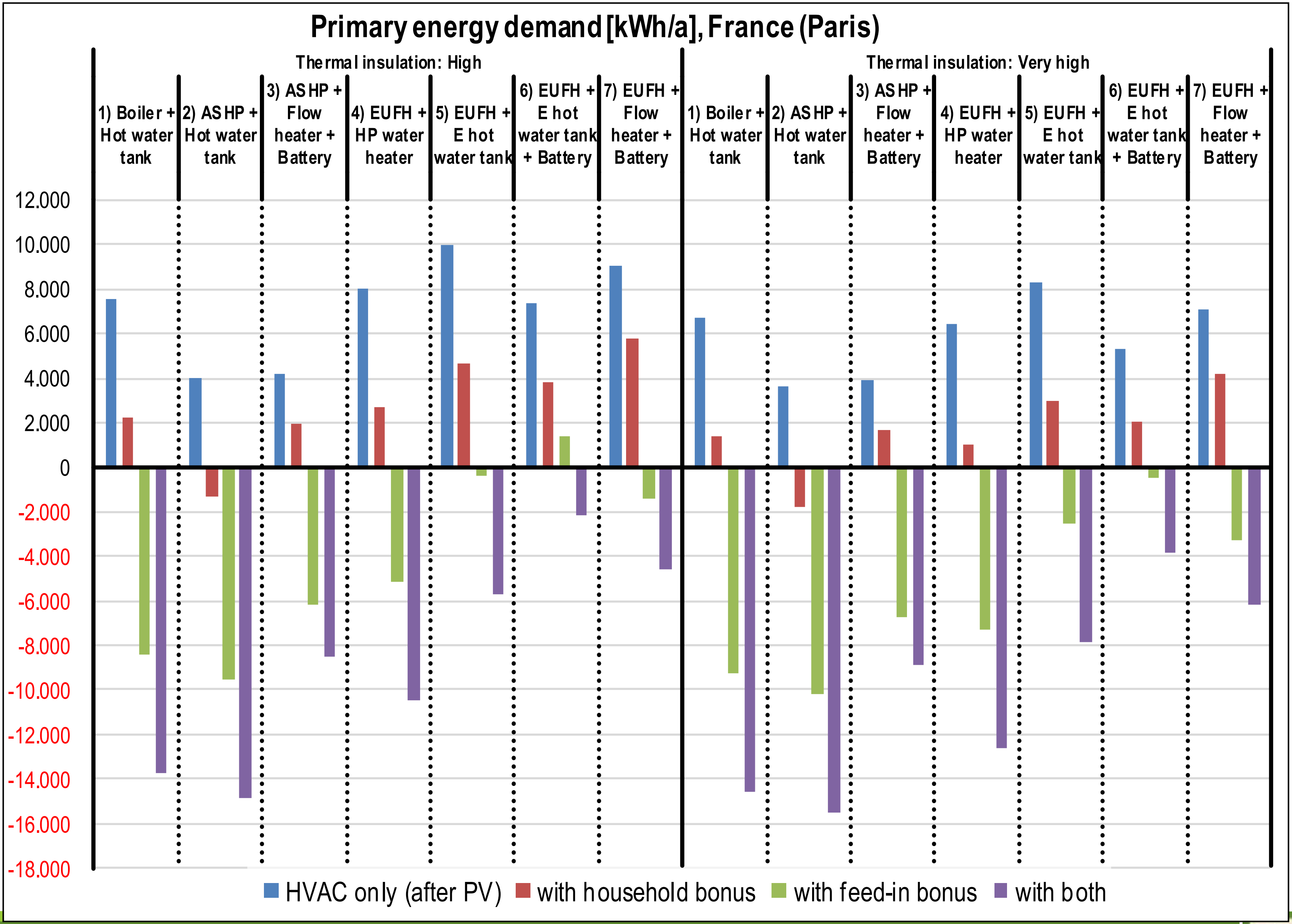

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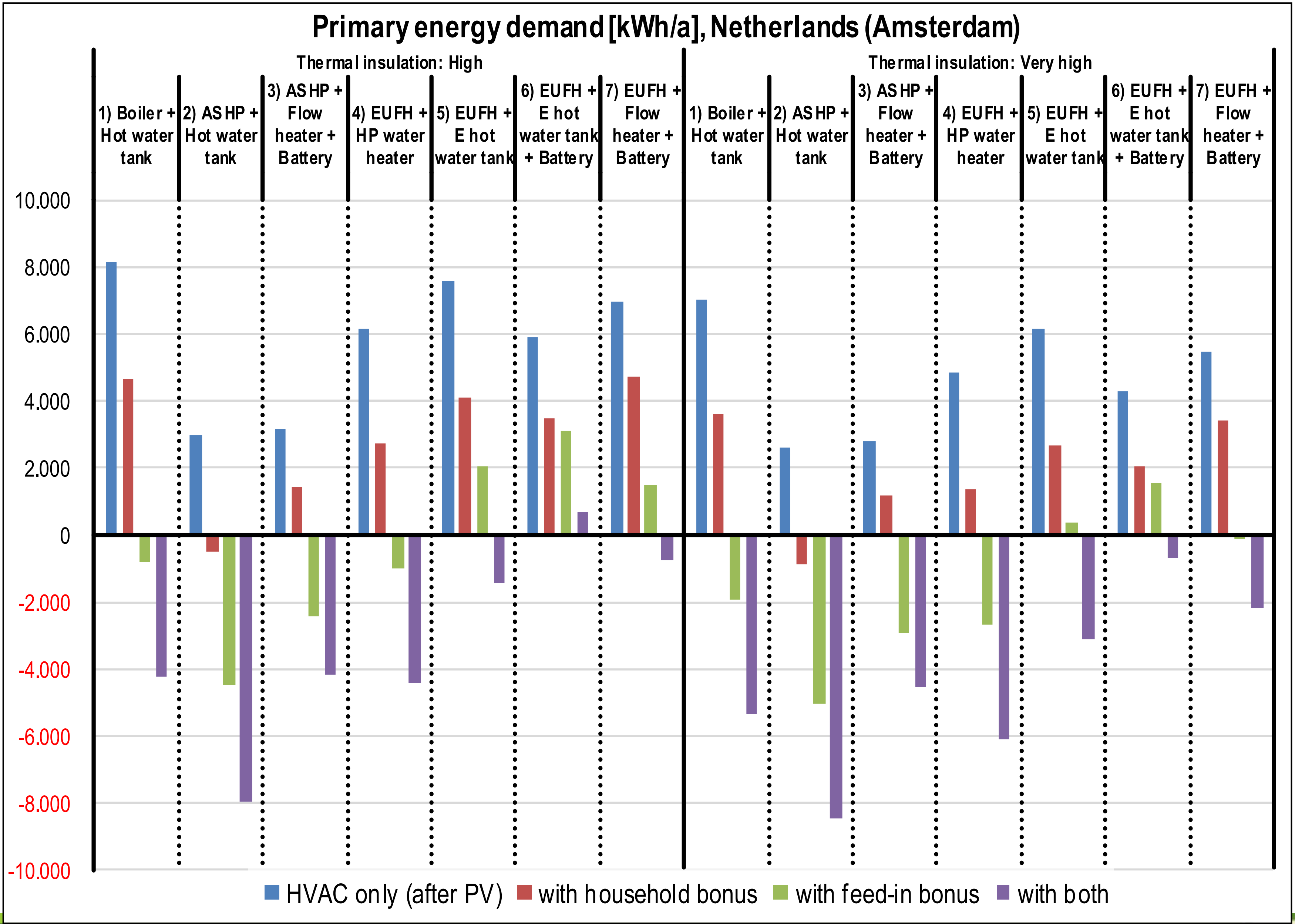

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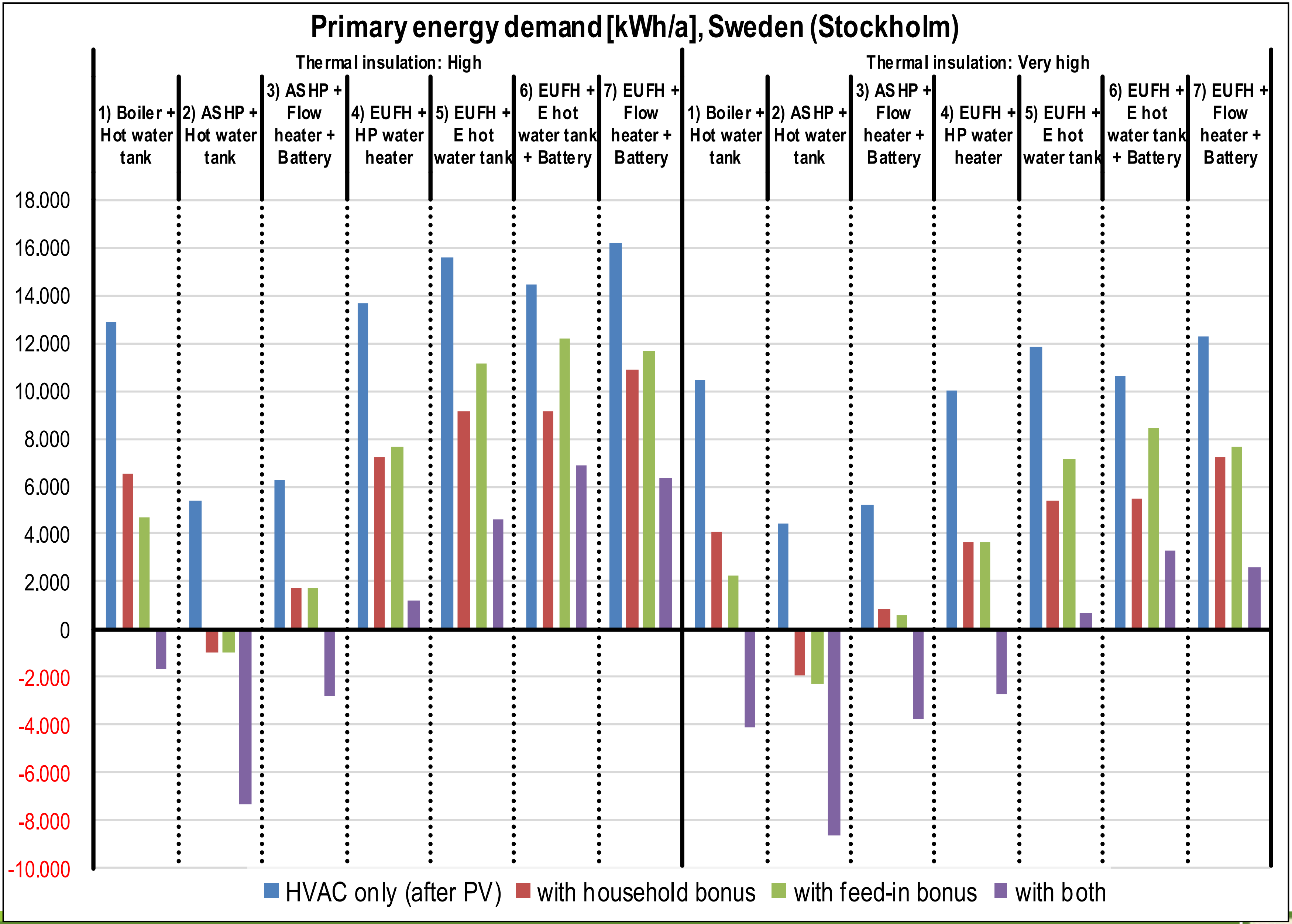
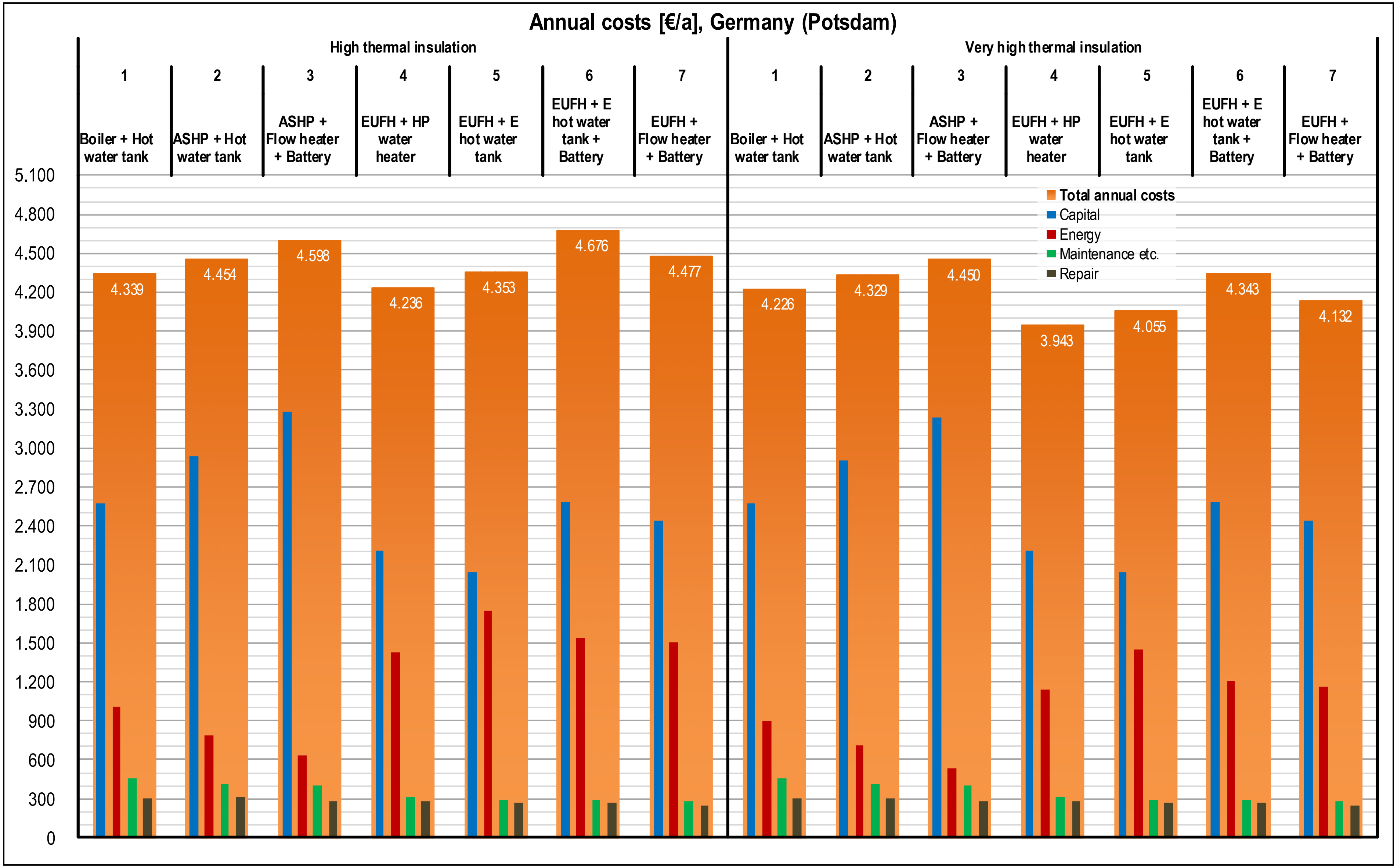


Total annual costs



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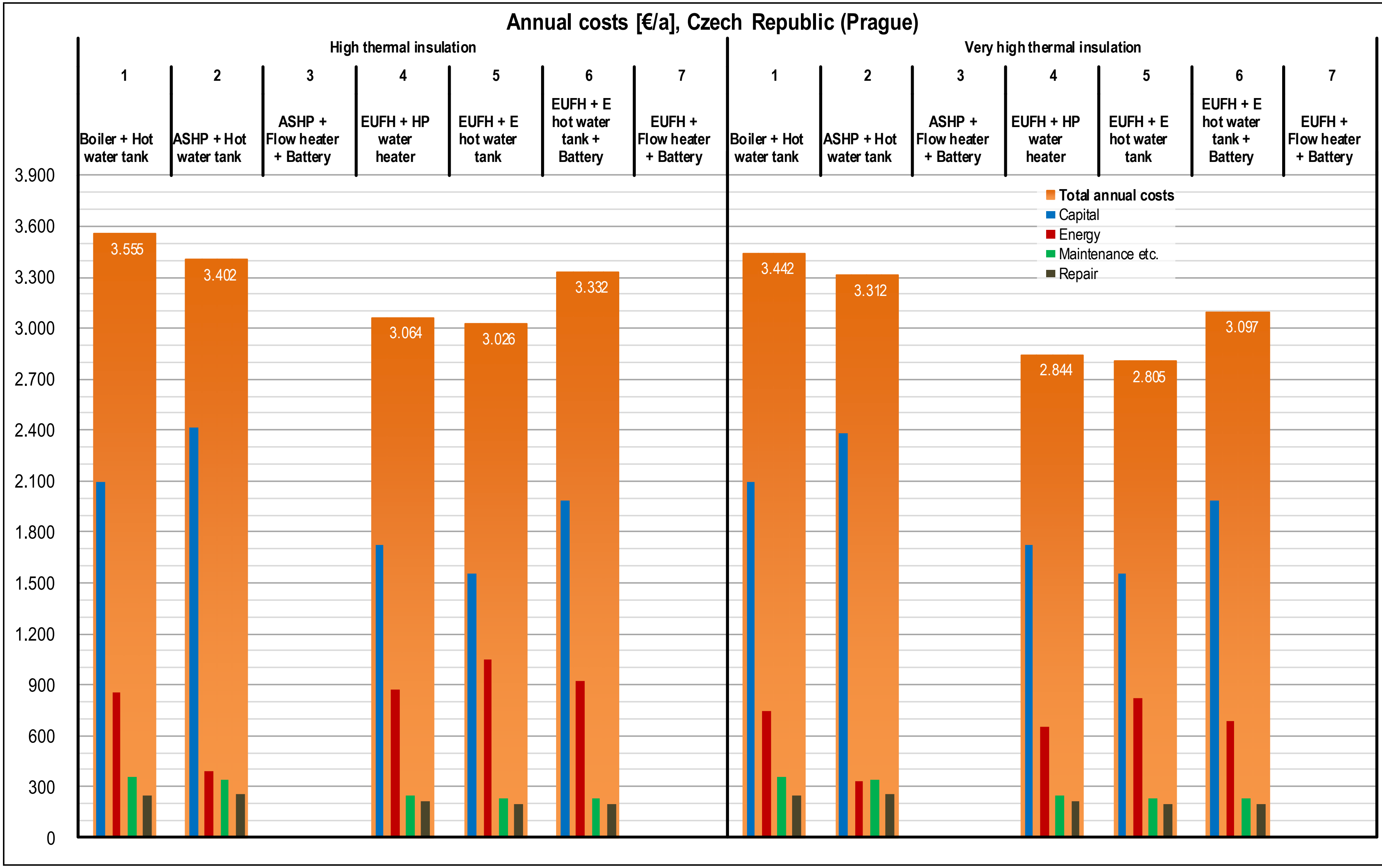

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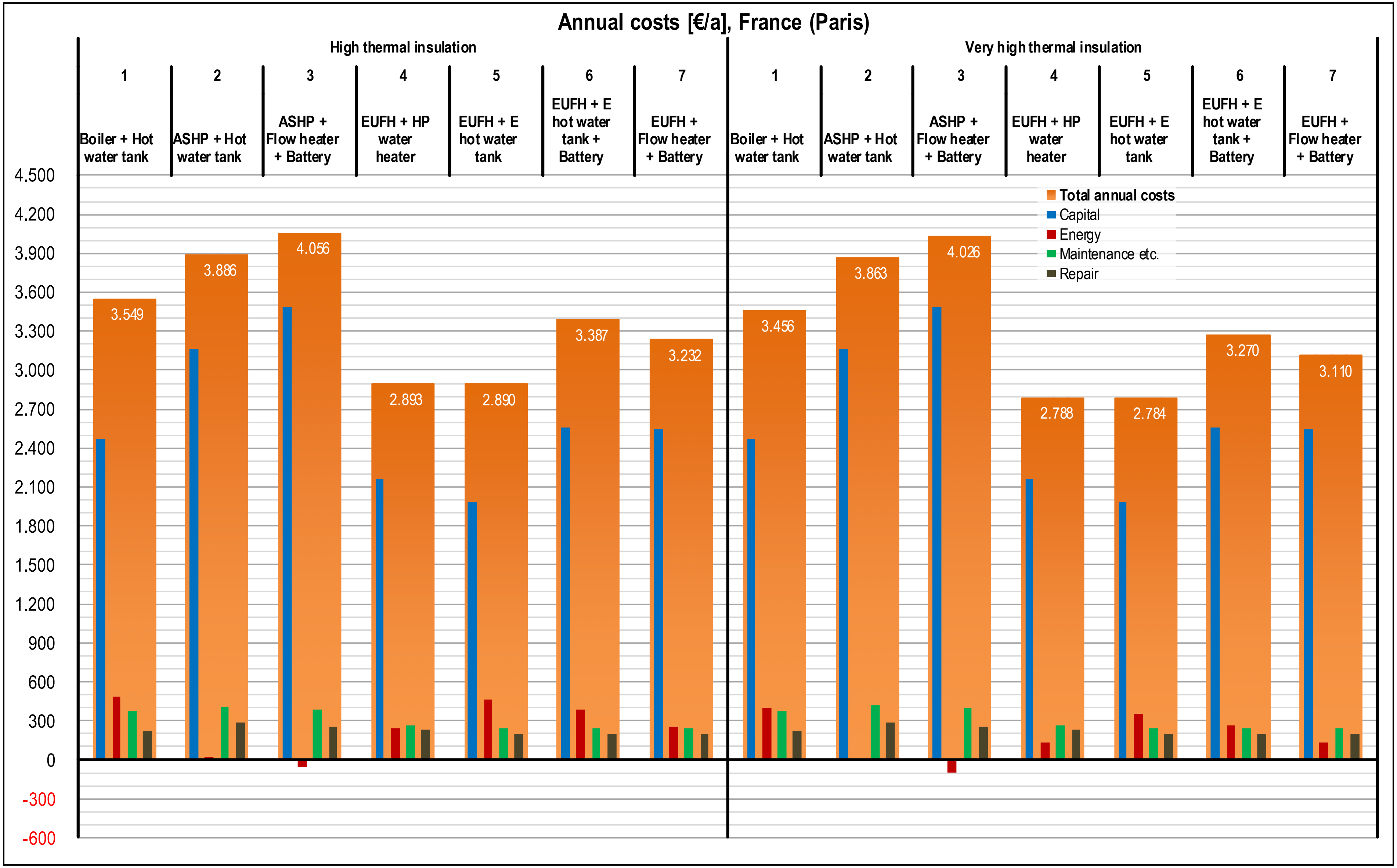

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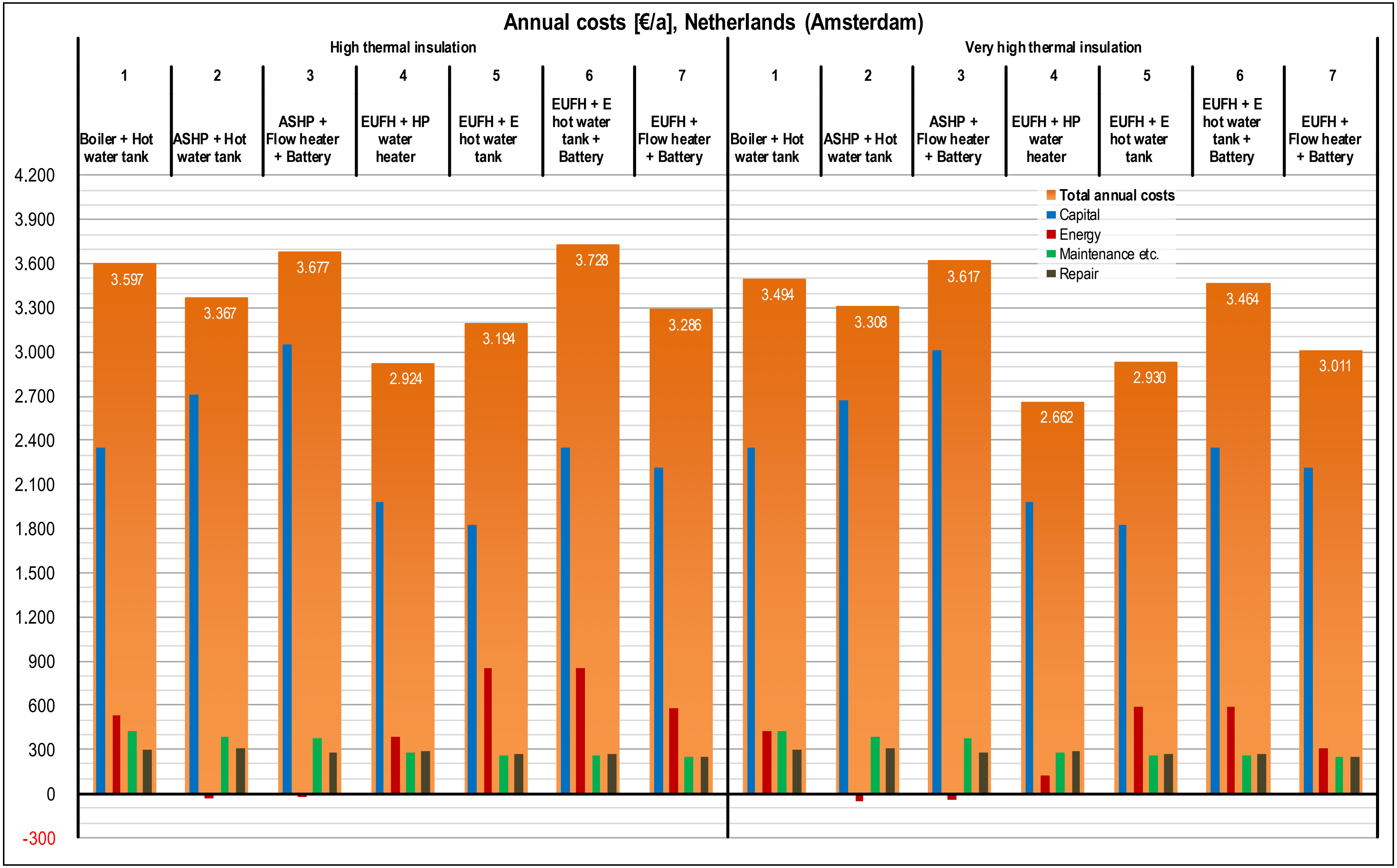

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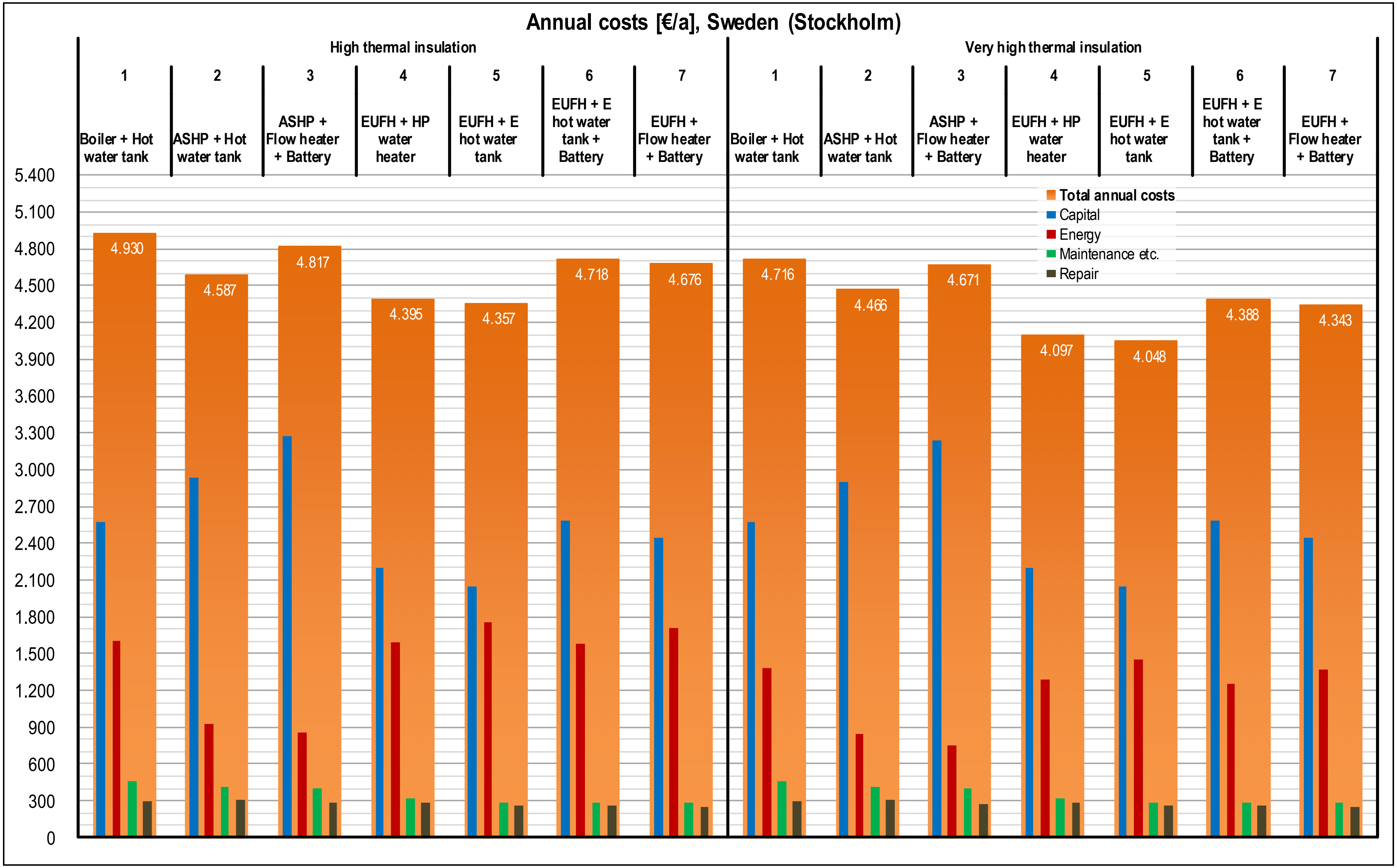
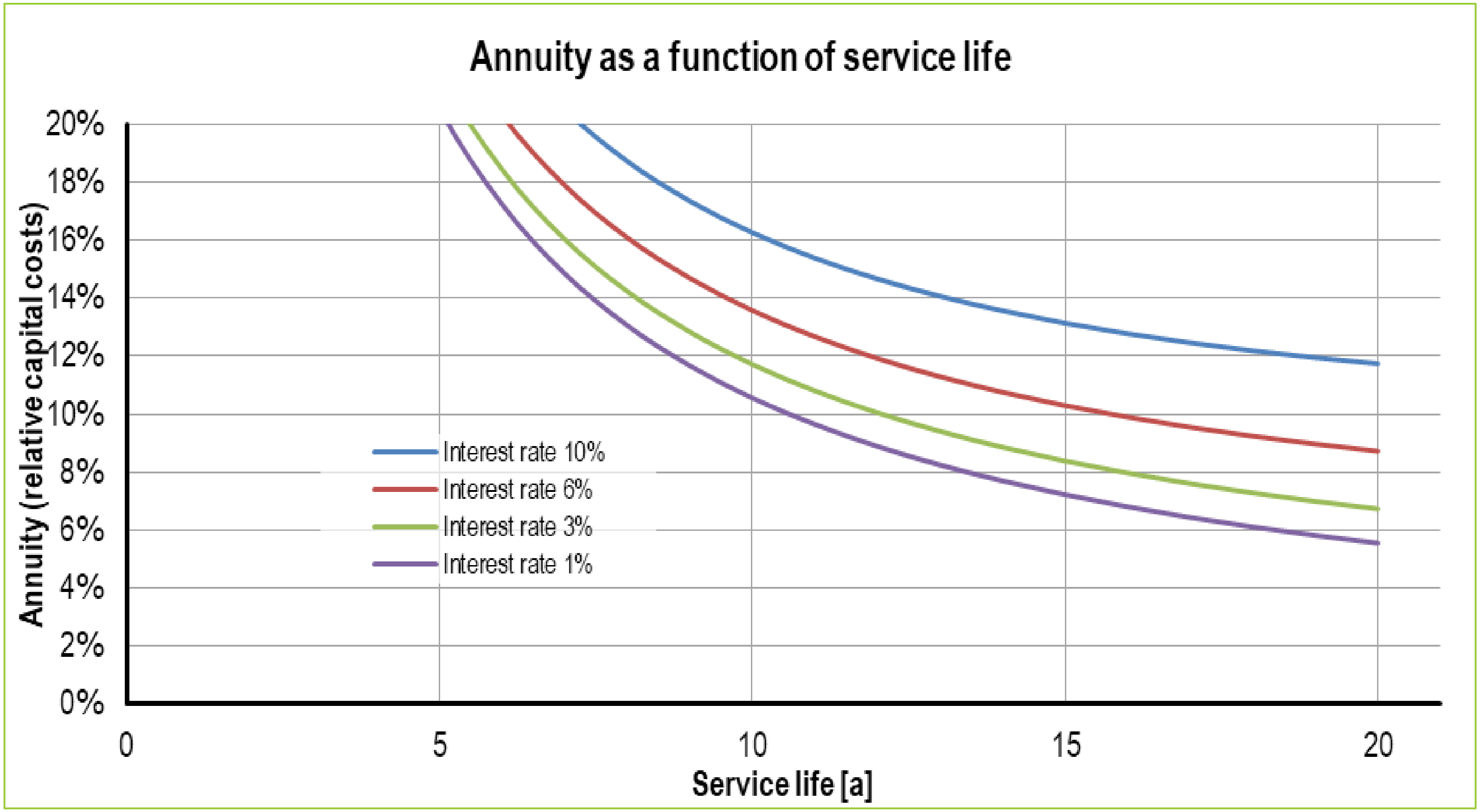
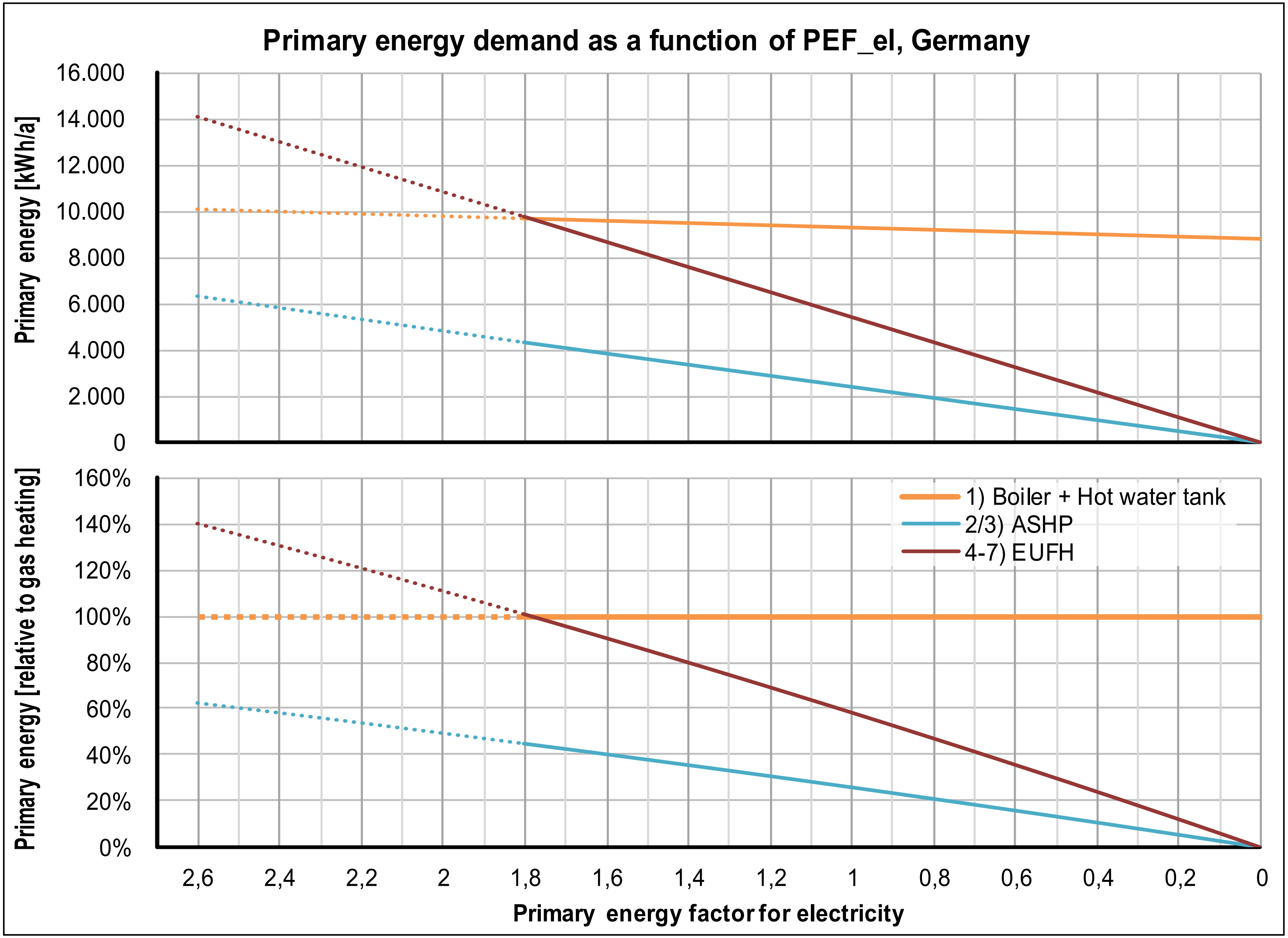


Total annual costs: Input data

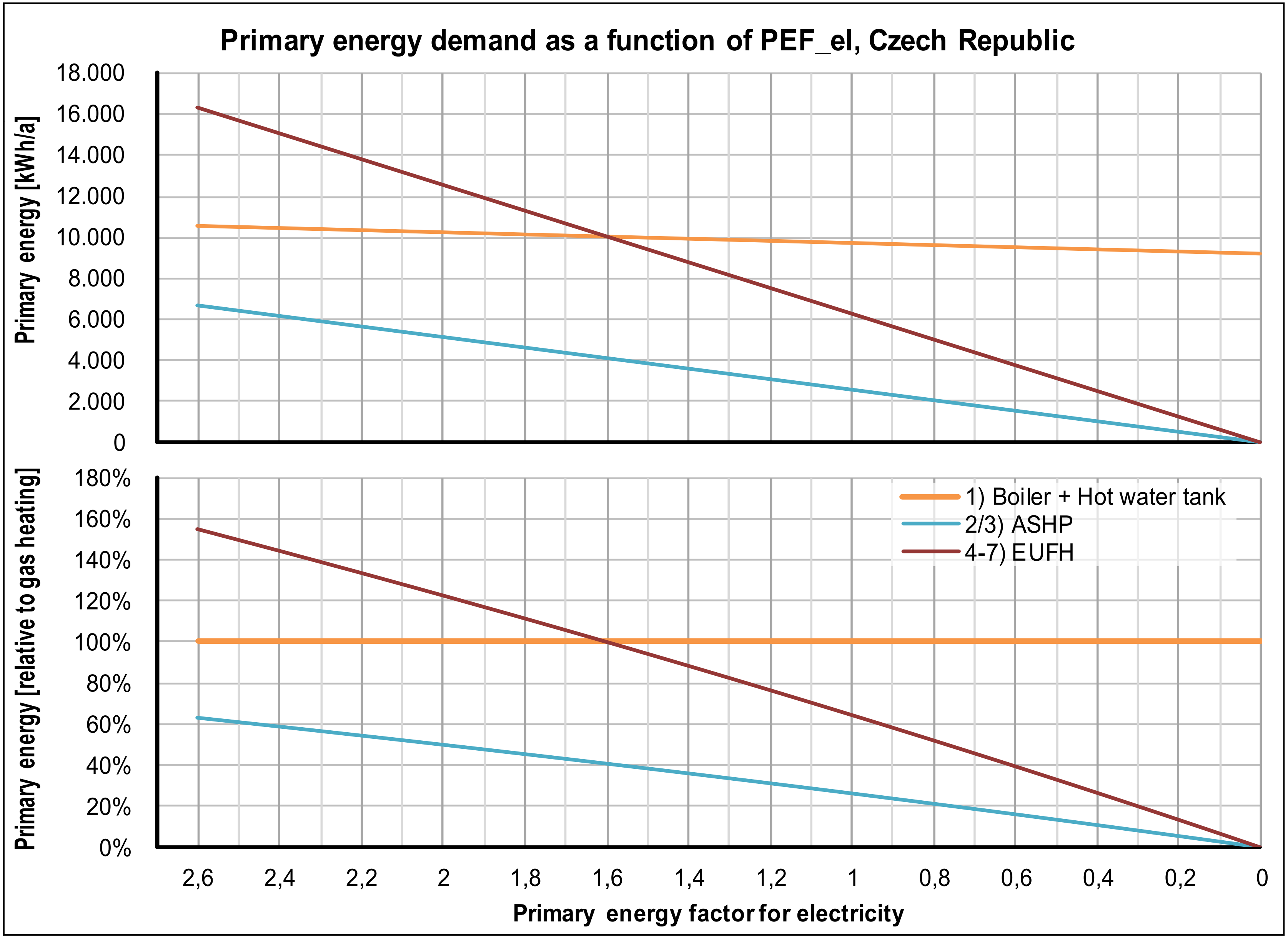
Influence of service life span and annual interest rate



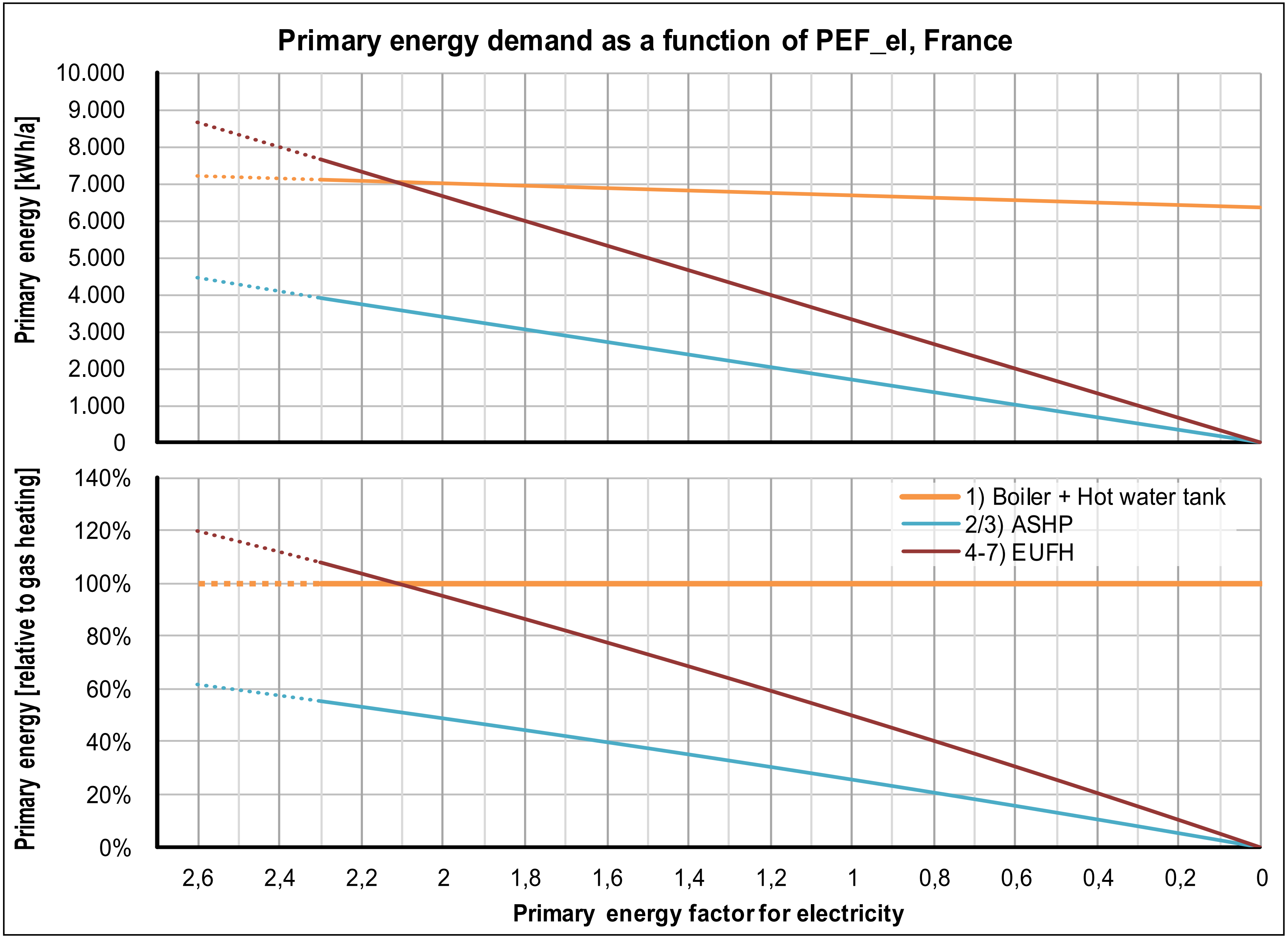
Influence of PEF for electricity



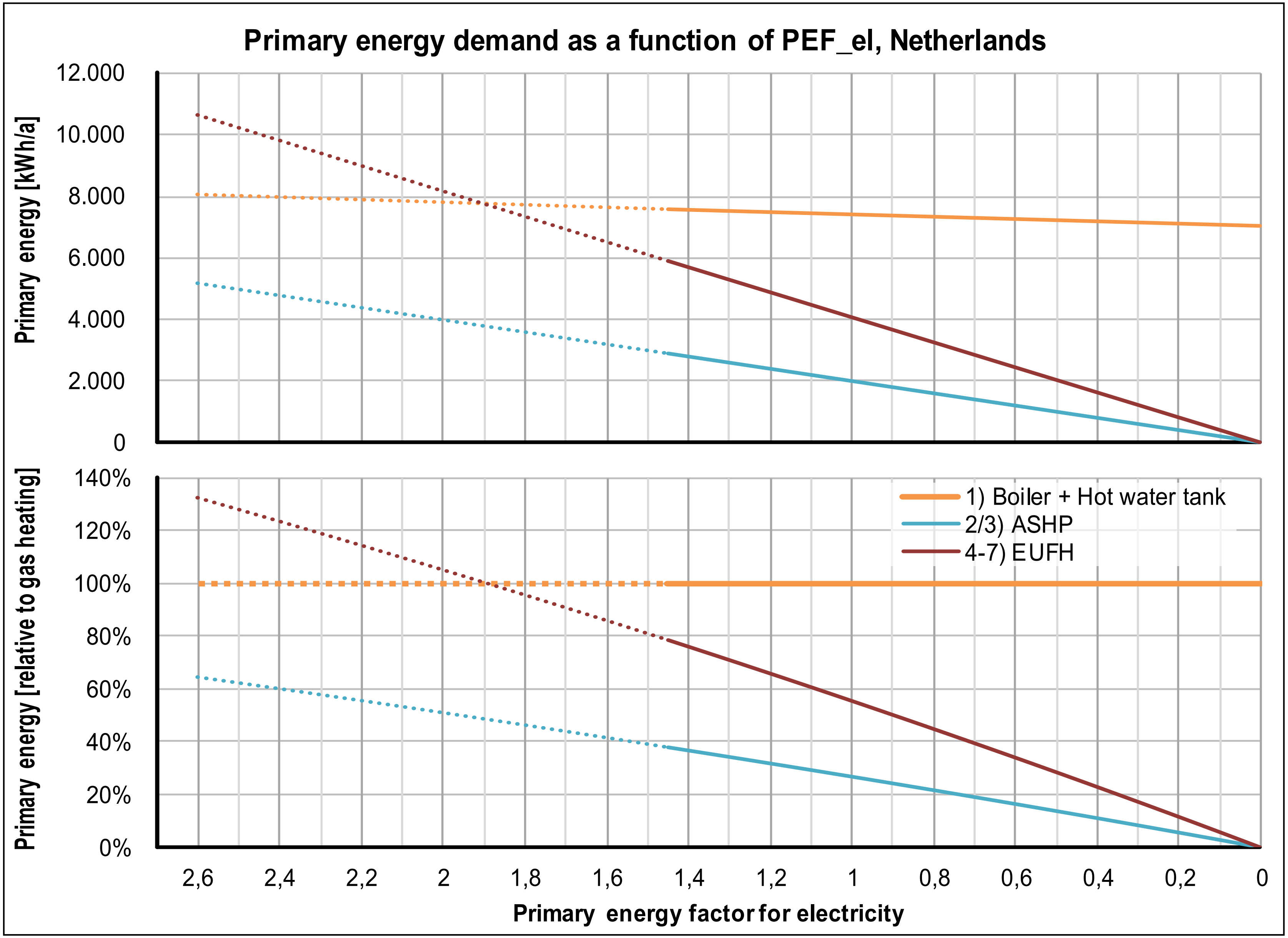
Influence of PEF for electricity



Influence of PEF for electricity



Influence of PEF for electricity



Influence of PEF for electricity