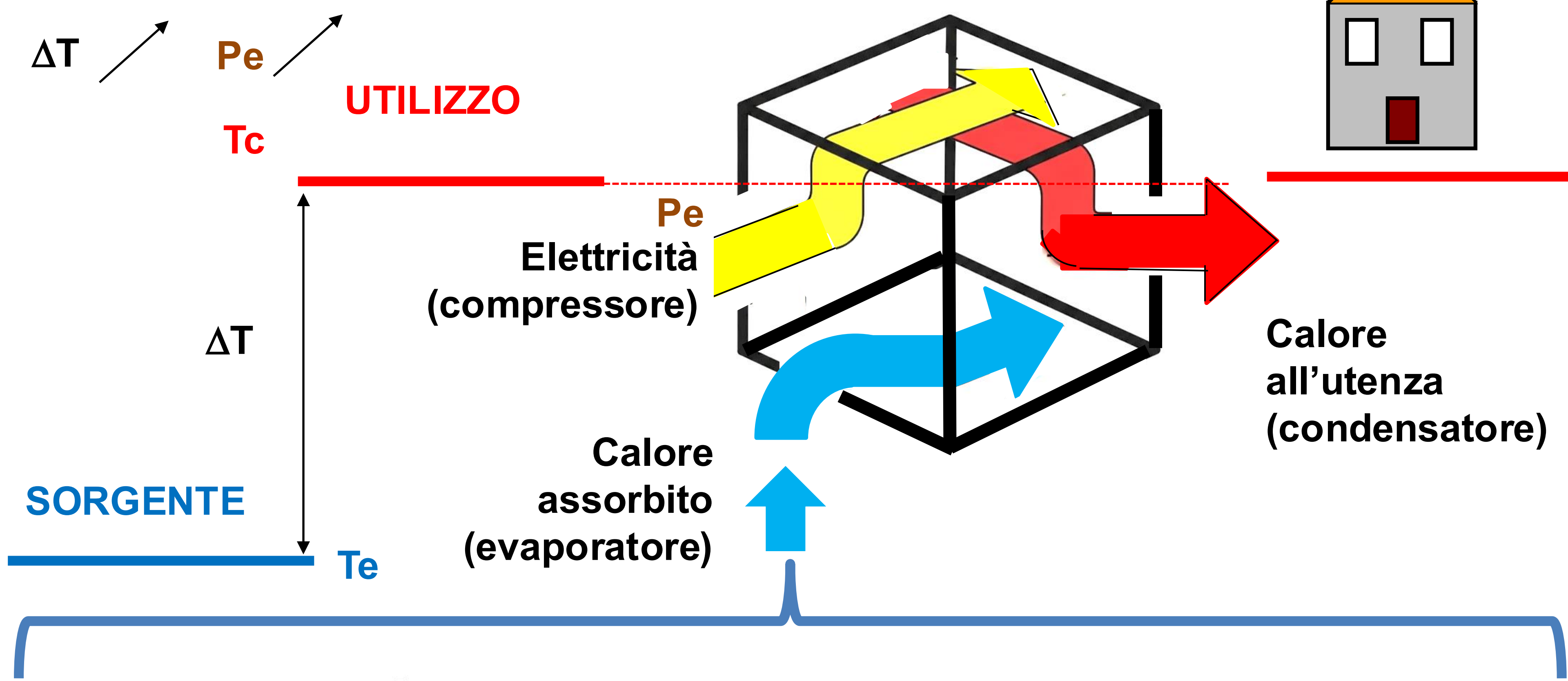
Il ruolo delle pompe di calore nella transizione energetica

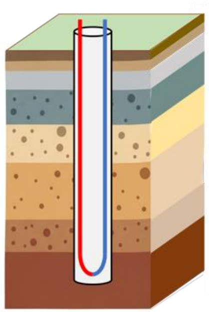
Michele De Carli
Centro Studi di Economia e Tecnica dell'Energia Giorgio Levi Cases
Università degli Studi di Padova

Le pompe di calore e il futuro della climatizzazione sostenibile
Padova, 24 febbraio 2026

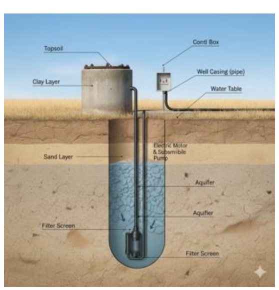
Funzionamento di una PDC



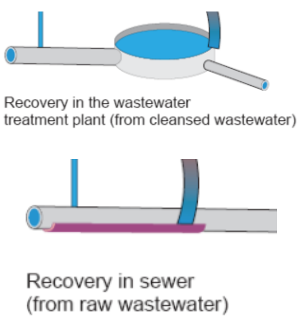
Aria



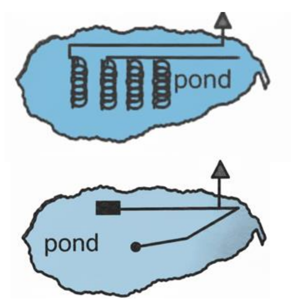
Sonde geotermiche



Acqua di falda

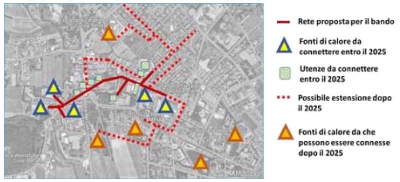


Reflui civili



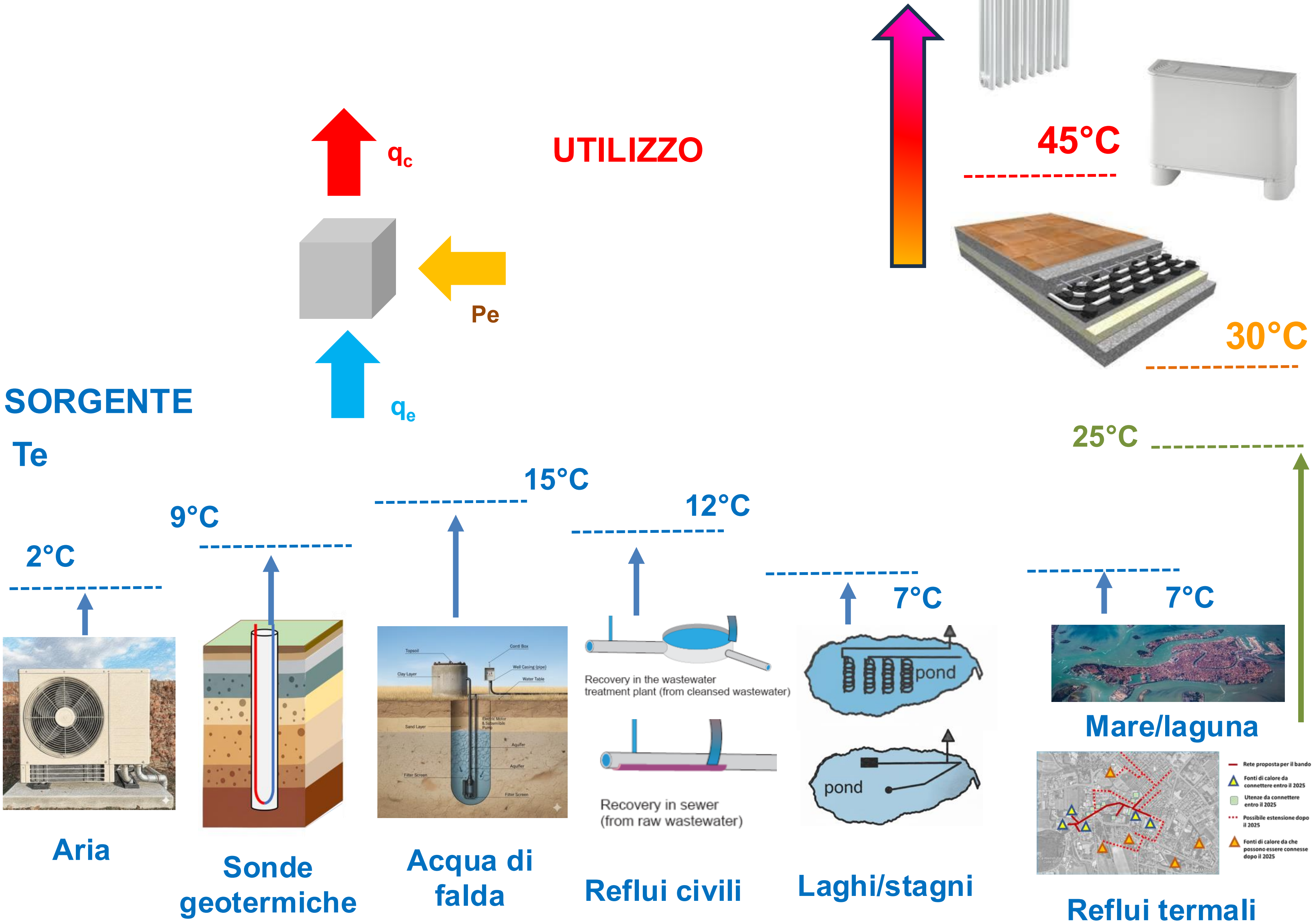
Laghi/stagni

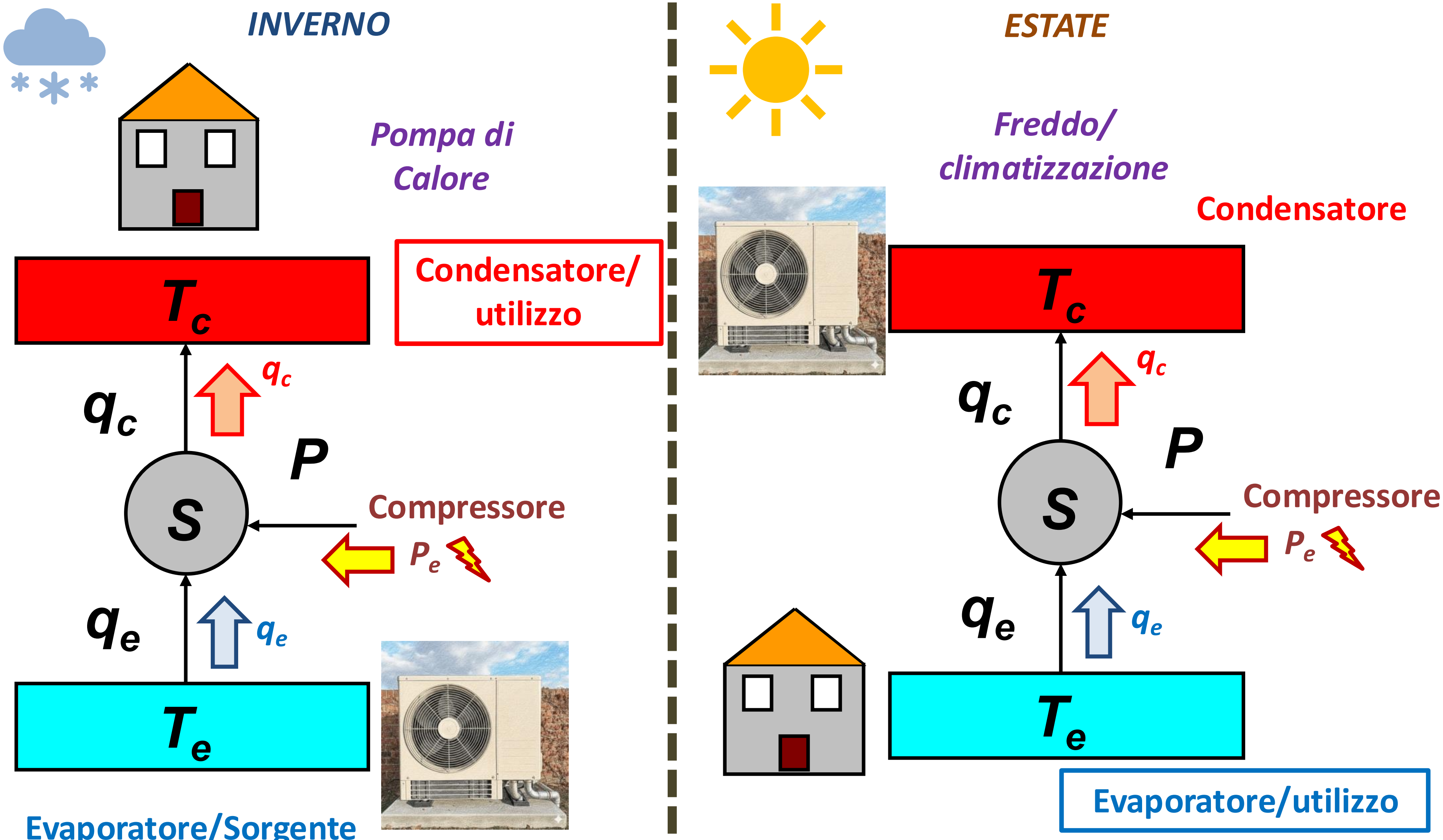
Mare/laguna



Reflui termali

Livelli termici





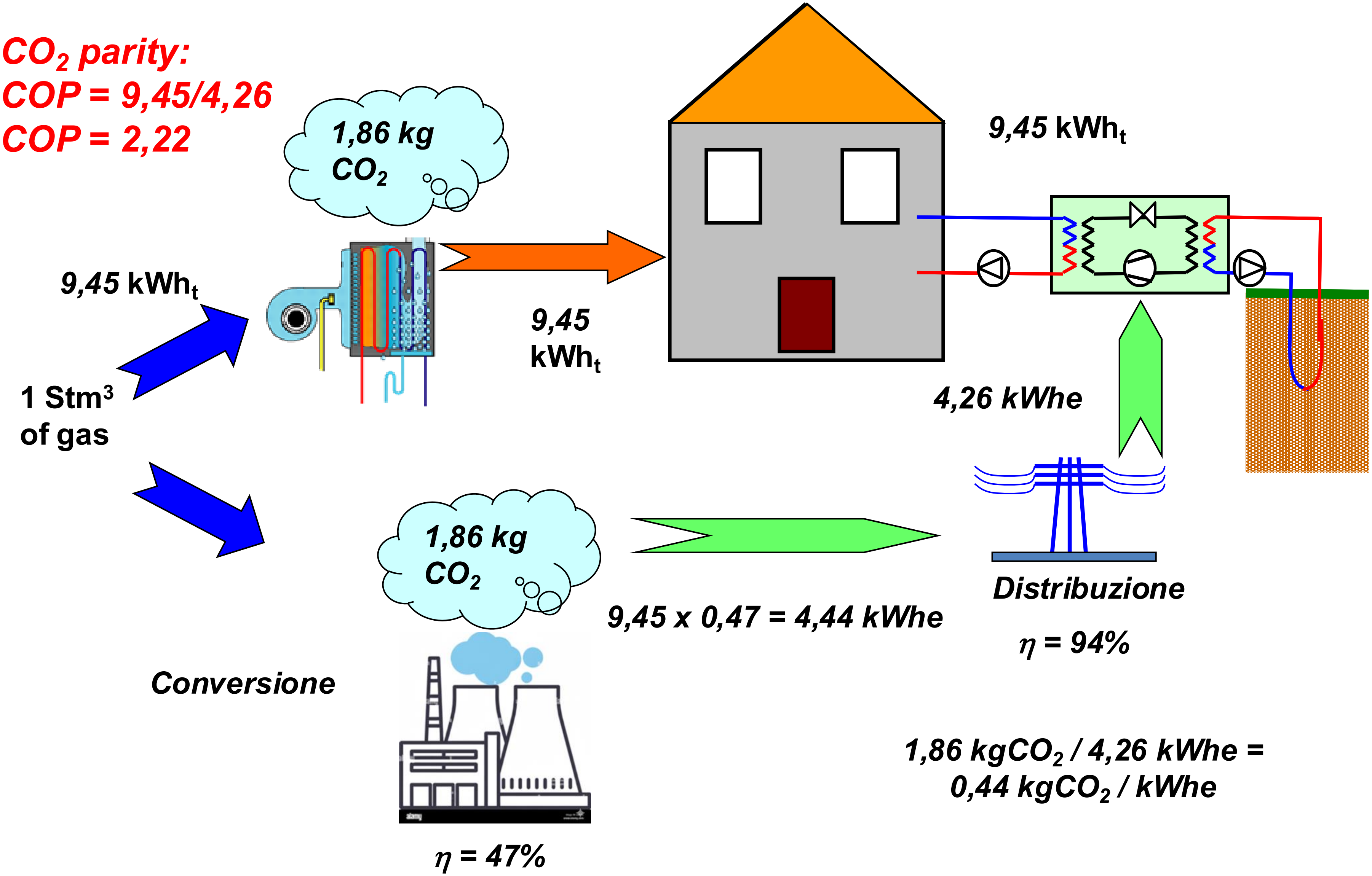
Coefficient of Performance → $COP = \dfrac{q_c}{P_e}$

Energy Efficiency Ratio → $EER = \dfrac{q_e}{P_e}$

In ogni caso: $q_c = q_e + P_e$

Come risparmiare CO_2 con una PDC?

CO_2 parity:
COP = 9,45/4,26
COP = 2,22



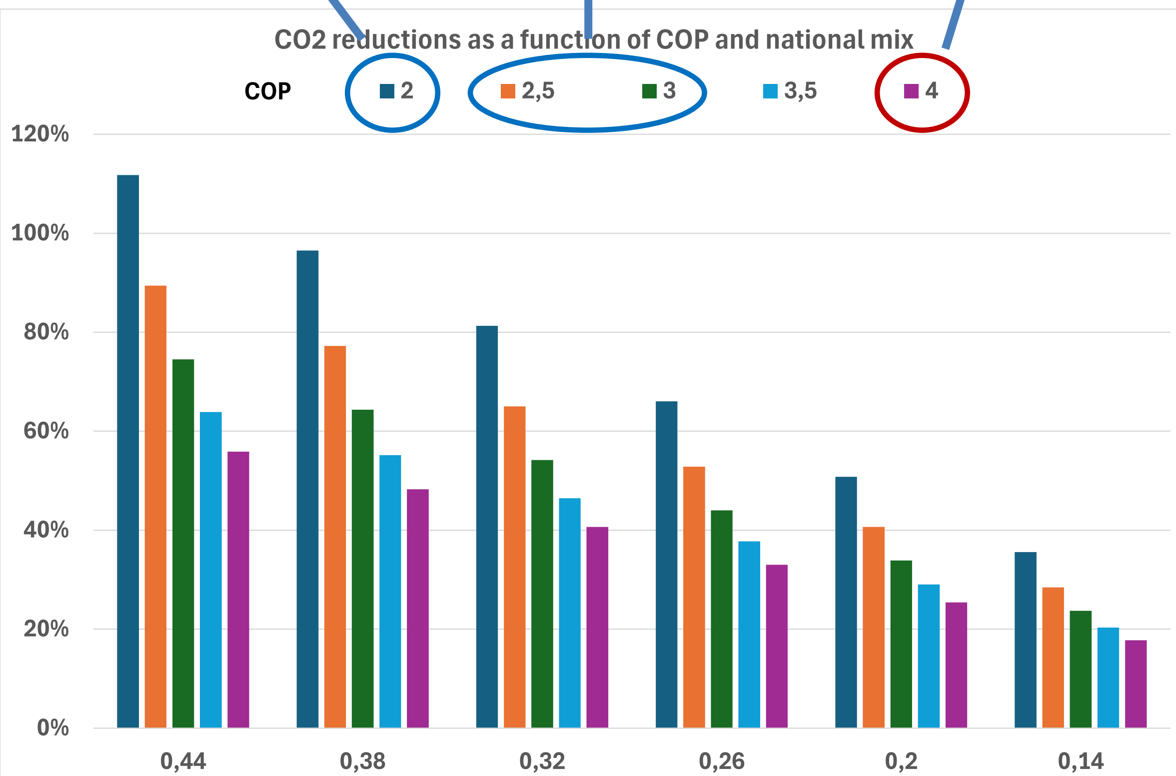
Vero per l'energia primaria e se avessimo solo centrali termoelettriche a gas

Energy mix in un Paese

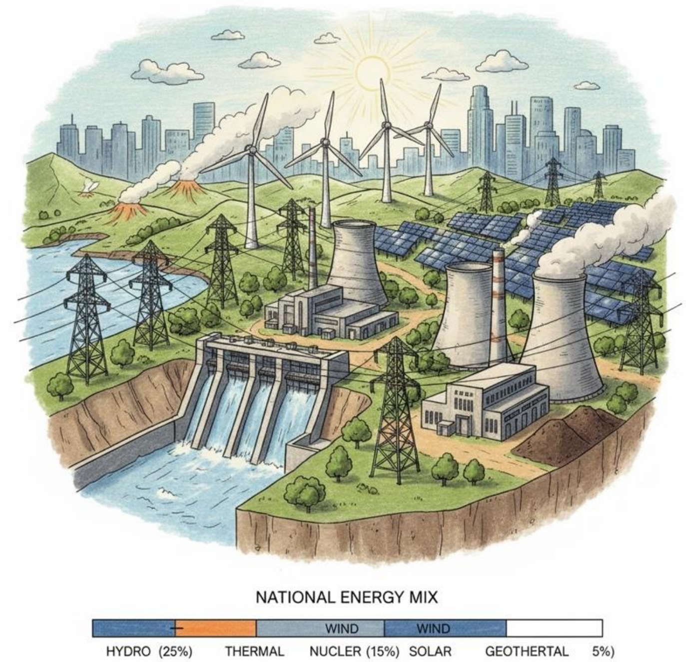
Mantenendo radiatori (PDC aria-acqua AT/ibrido)

Aria-acqua con radiante/fan-coil

Geotermico con radiante/fan-coil



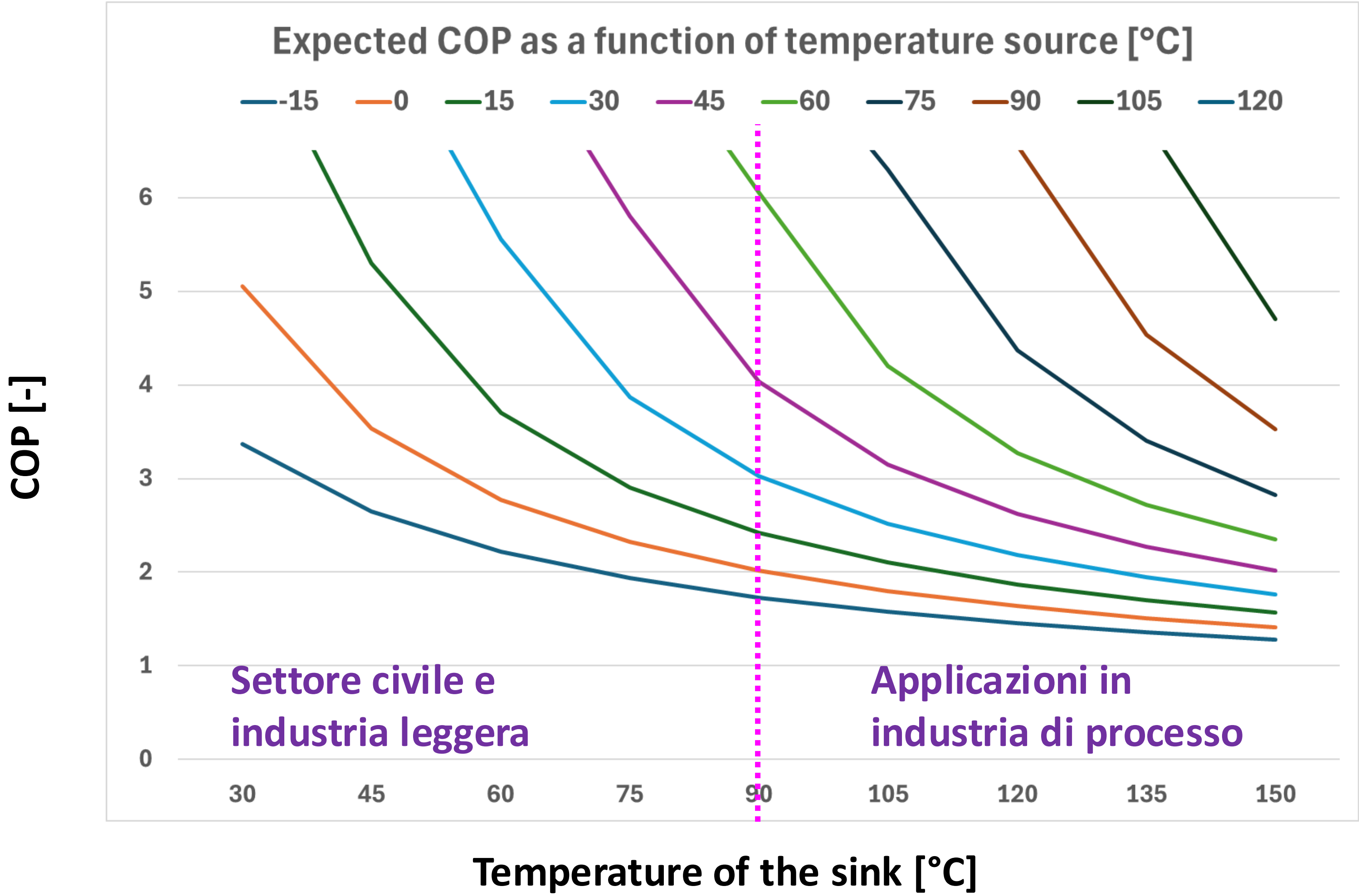
Emissions for the energy mix [kgCO2/kWhe]



Elettrico tutto a gas

Attuale mix elettrico in Italia

COP in funzione di temperature di sorgente e utilizzo

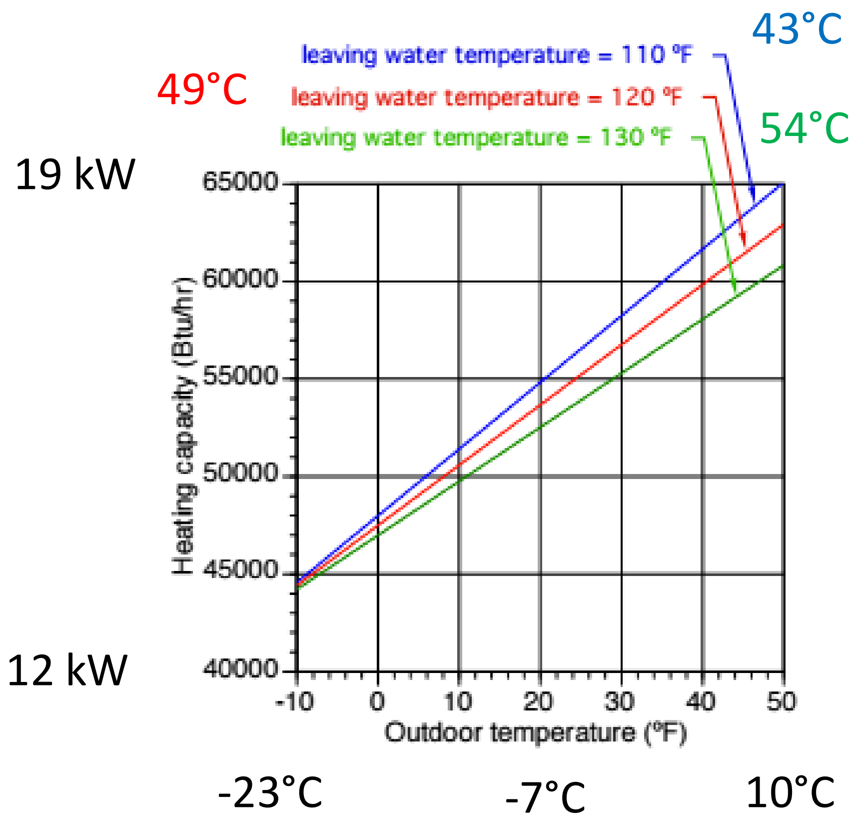


Tipi di Pompe di calore

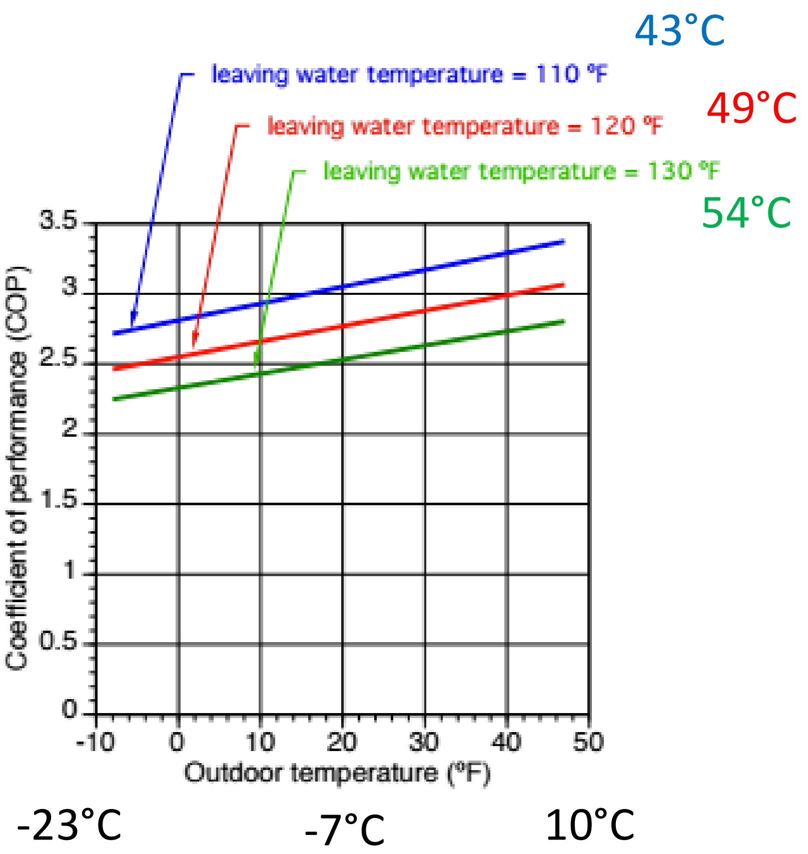
Sorgente	Fluido in ambiente	
Aria	Aria	Machcine a espansione diretta
Aria	Acqua	Air-source heat pumps (ASHP)
Acqua	Aria	Utilizzate in USA/CA
Acqua	Acqua	Utilizzate in EU, tra queste le Ground Source Heat Pumps (GSHP)

Due aspetti importanti per le PDC aria-acqua

Più fredda è la sorgente, minore è la potenza termica resa

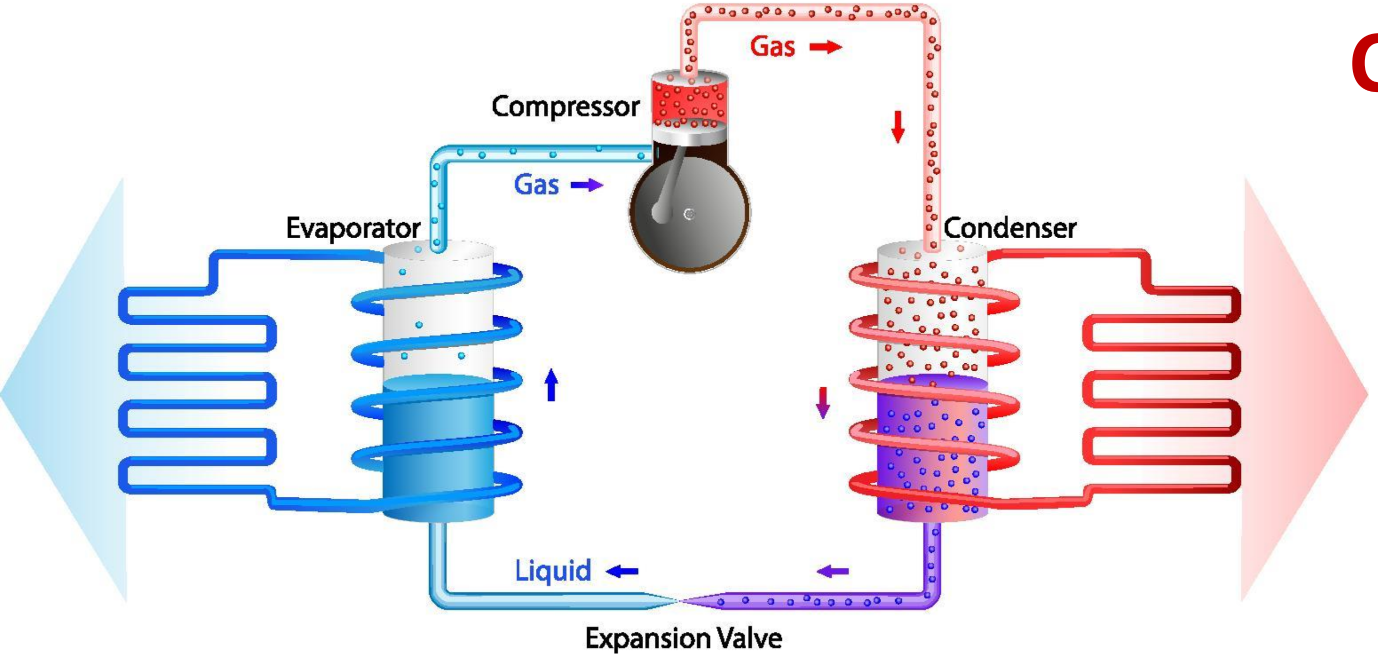


Più fredda è la sorgente, minore è il COP



https://blog.heatspring.com/low-ambient-air-water-heat-pumps/

COMPONENTI DI UNA PDC



https://heatpumps.ca/articles/how-heat-pumps-work

- Compressore
- Condensatore
- Organo di laminazione
- Evaporatore

Uno studio in campo sulle PDC in UK (2024)

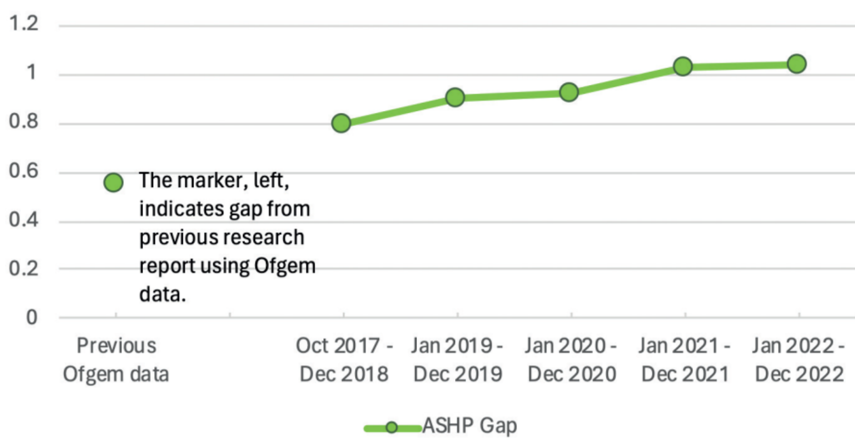
rb&m research

In-Situ Heat Pump Performance

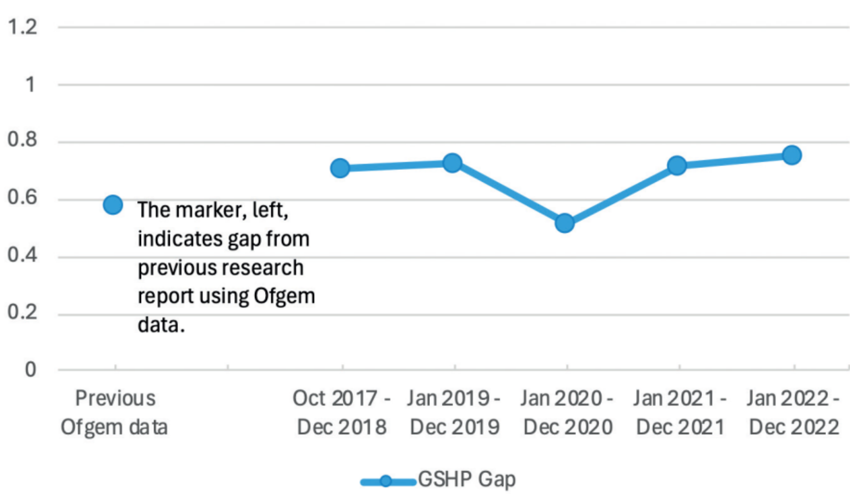
Analysis of Ofgem Data 2017–2022

November 2024

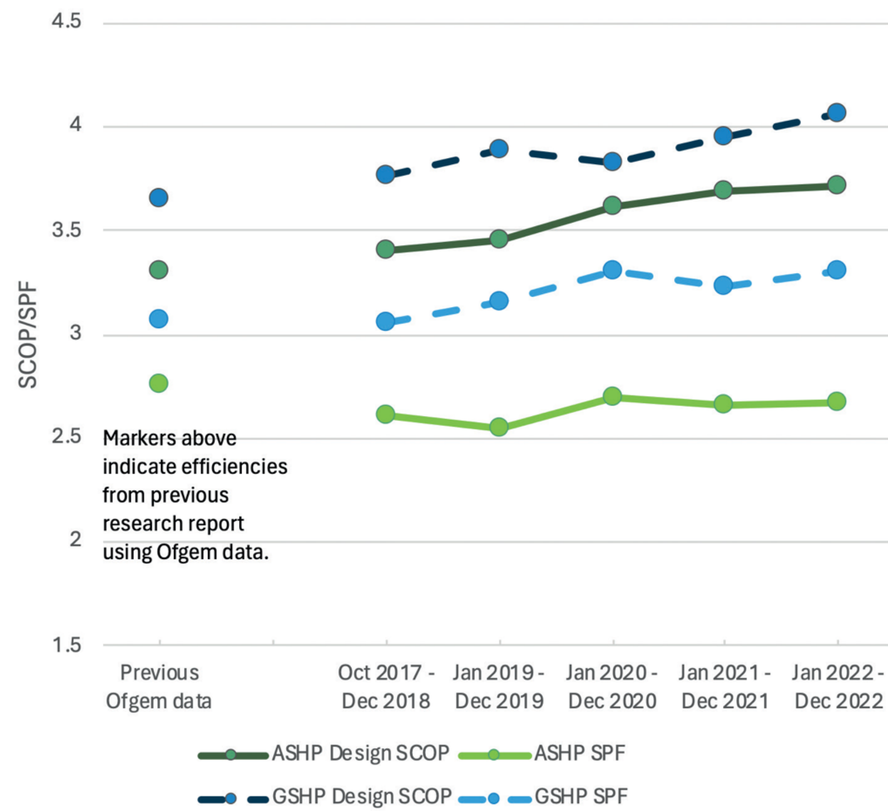
ASHP - Gap Between Design SCOPs and SPF



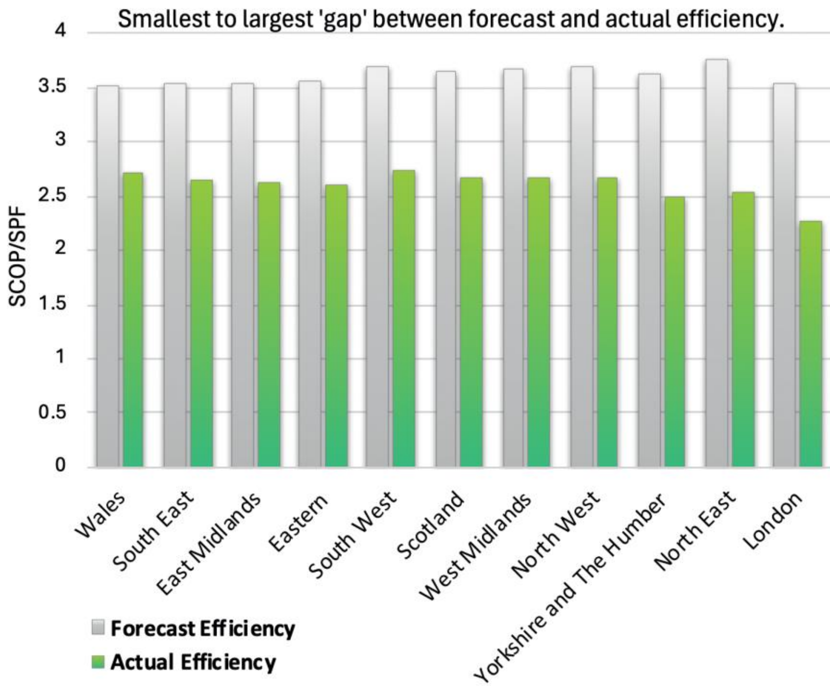
GSHP - Gap Between Design SCOPs and SPF



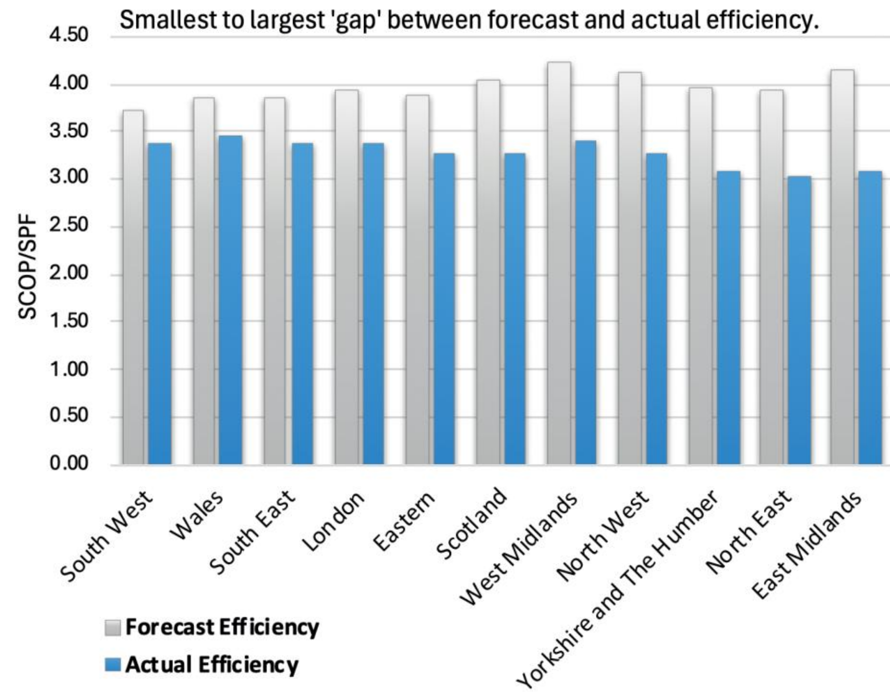
ASHP and GSHP Efficiencies By Installation Year



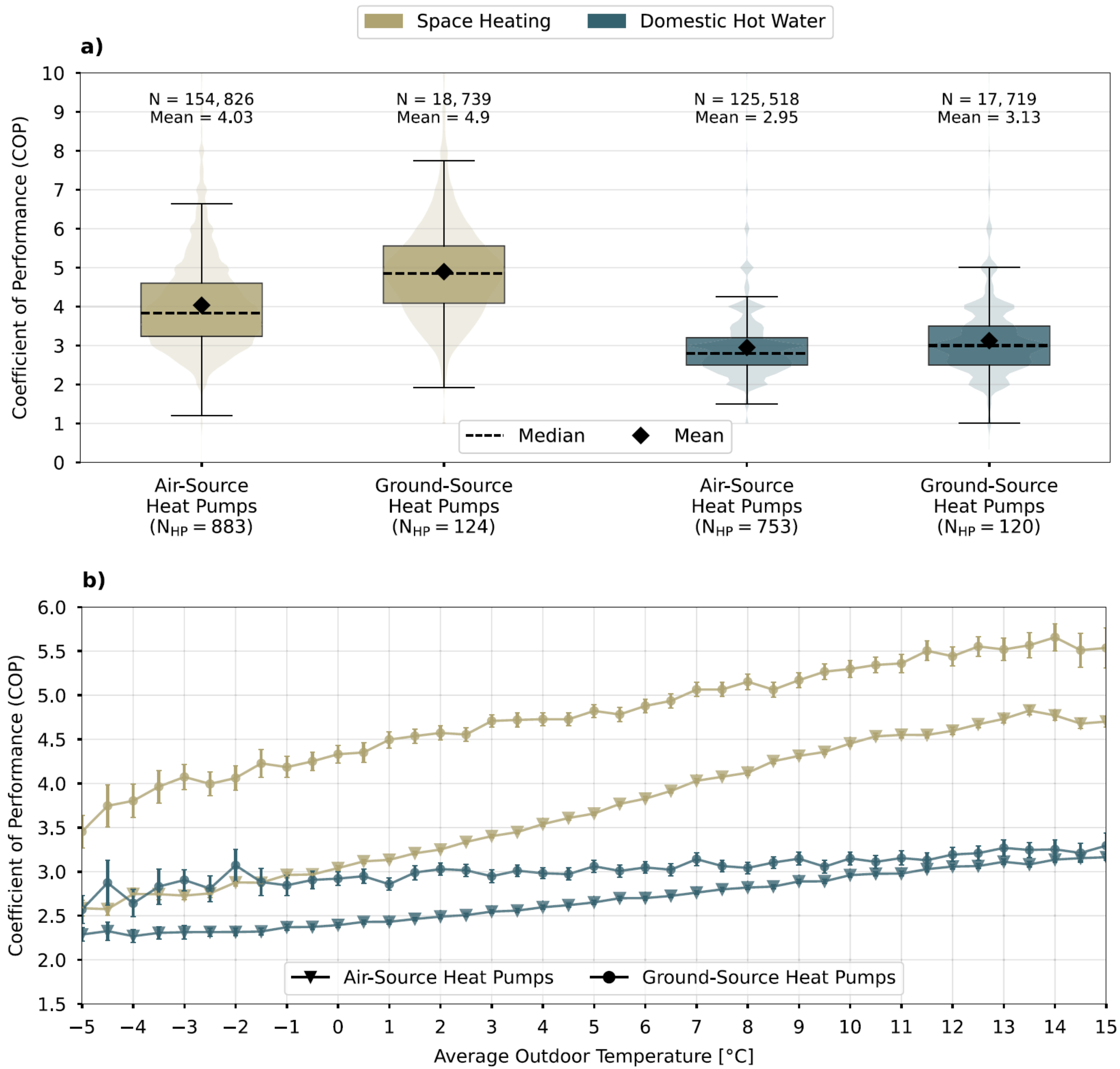
ASHP: Average Forecast V Actual Efficiencies by Region/Country



GSHP: Average SCOP V Actual Efficiencies by Region/Country



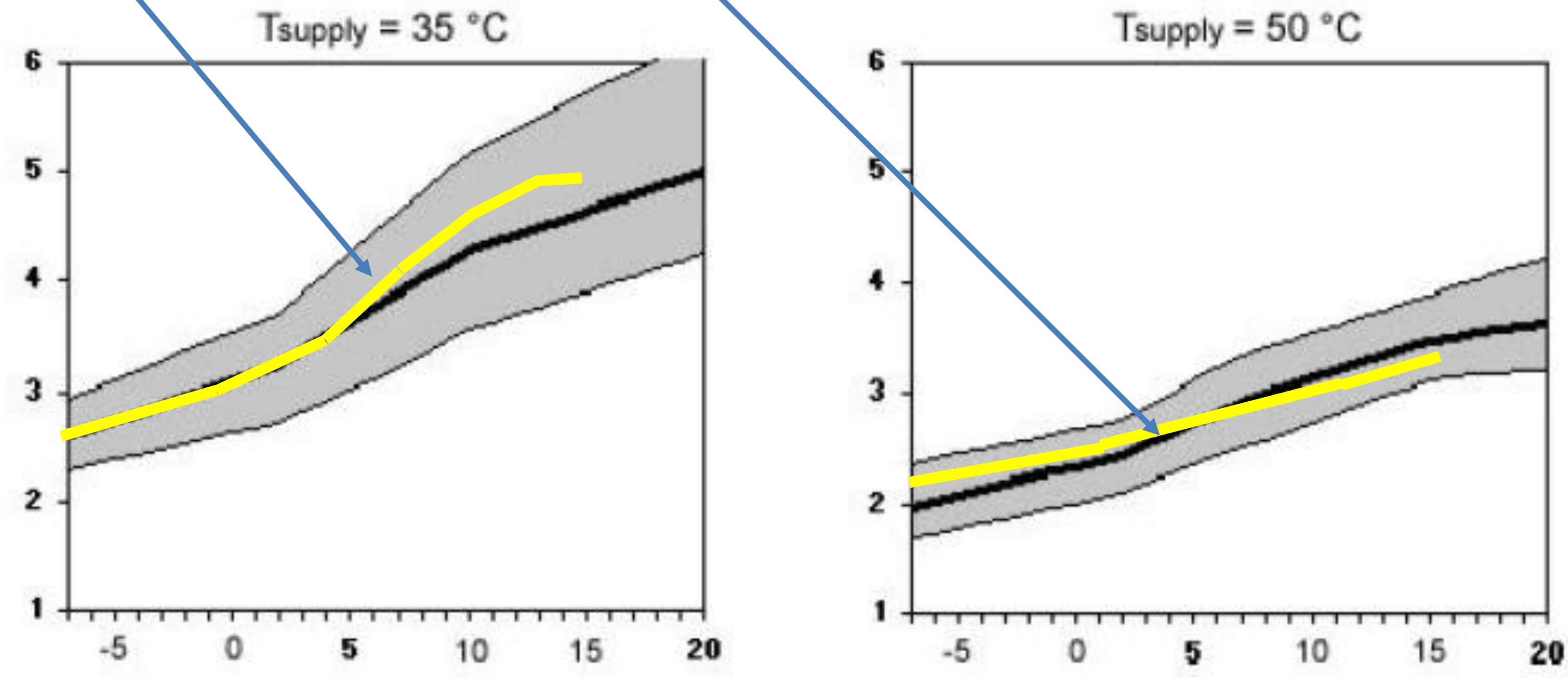
Uno studio in campo sulle PDC in Europa centrale



https://doi.org/10.1038/s41467-025-58014-y

Prestazioni di PDC aria-acqua)

Dati medi pubblicazione di Nature



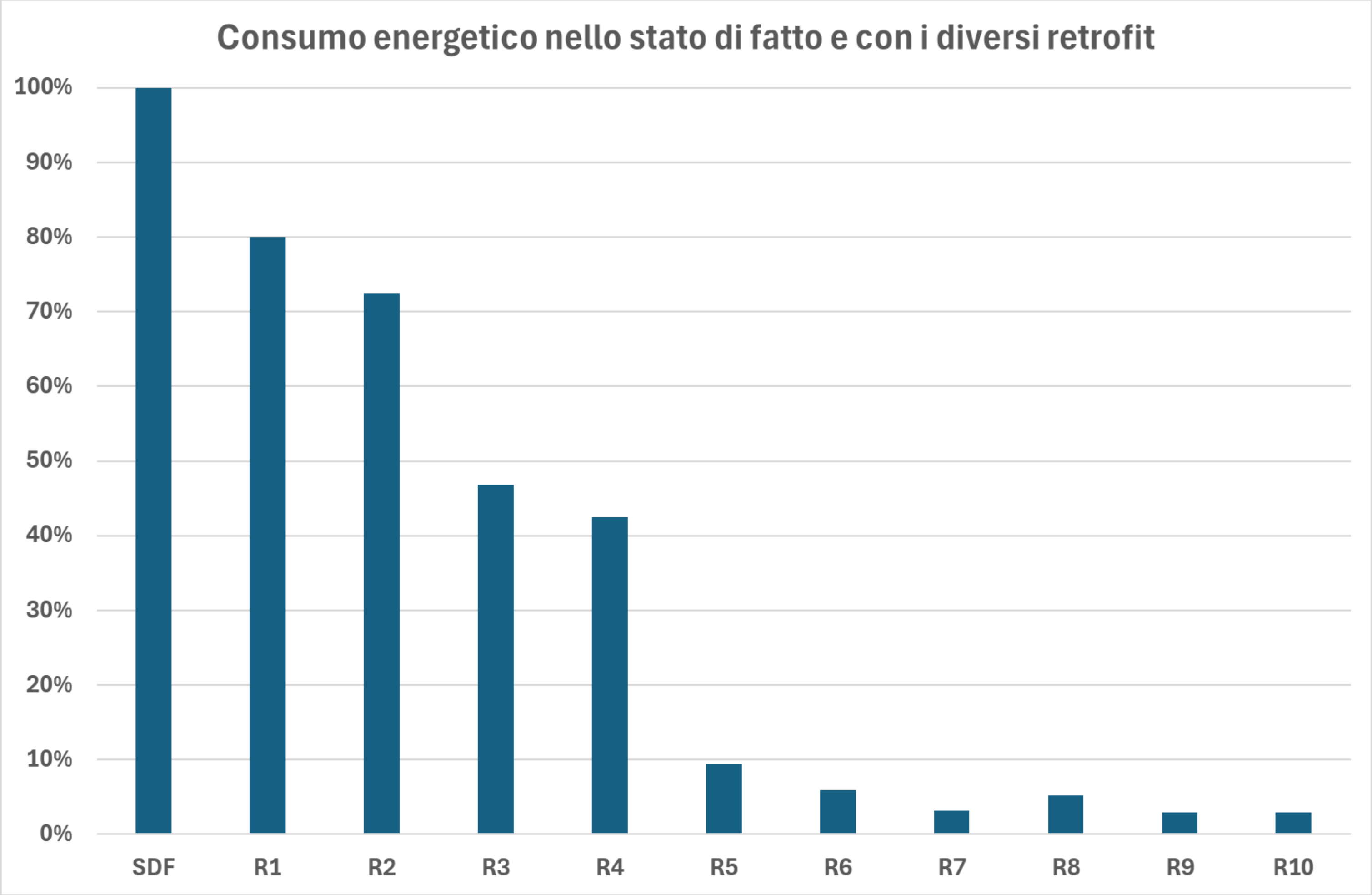
Dati statistici del laboratorio svizzero WTZ di Winterthur-Töss, in cui le line grosse rappresentano il valore medio testato e l’area grigia le dispersion dei dati misurati (circa attorno al 2000).

Analisi secondo metodo standardizzato

Archetipi:

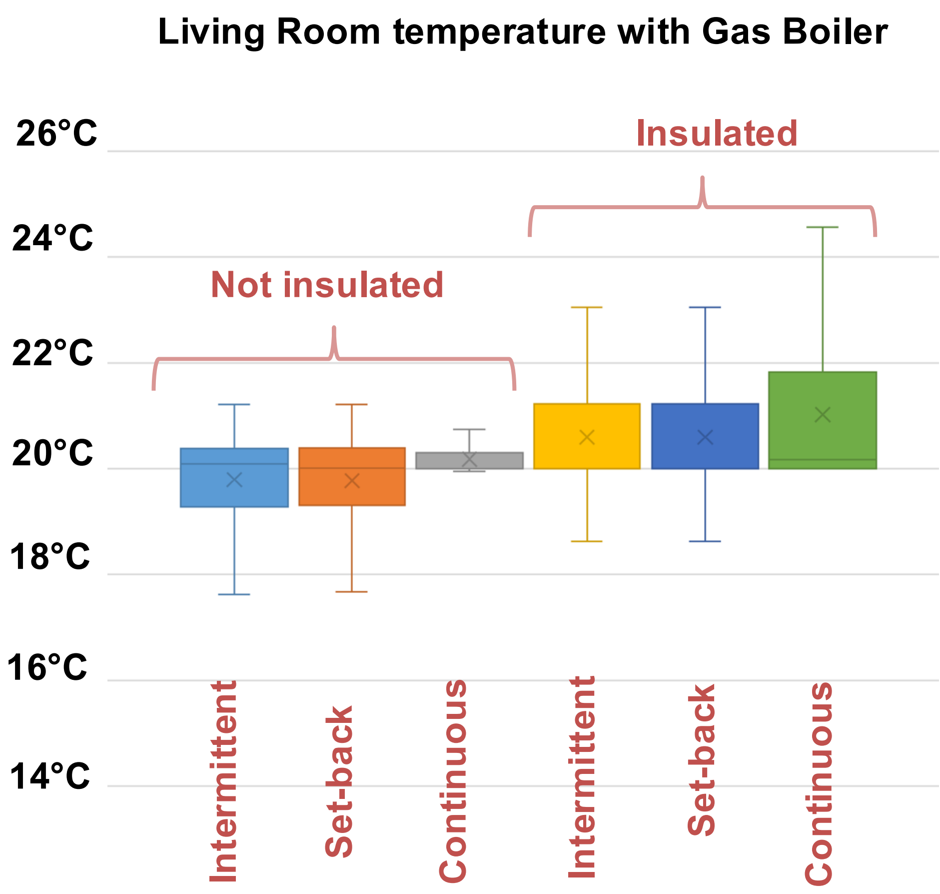
- **casa unifamiliare (Single Family House – SFH)**
- **casa a schiera (Terraced House – TH),**
- **casa plurifamiliare (Multi Family House – MFH)**
- **condominio (Apartment Block – AB).**

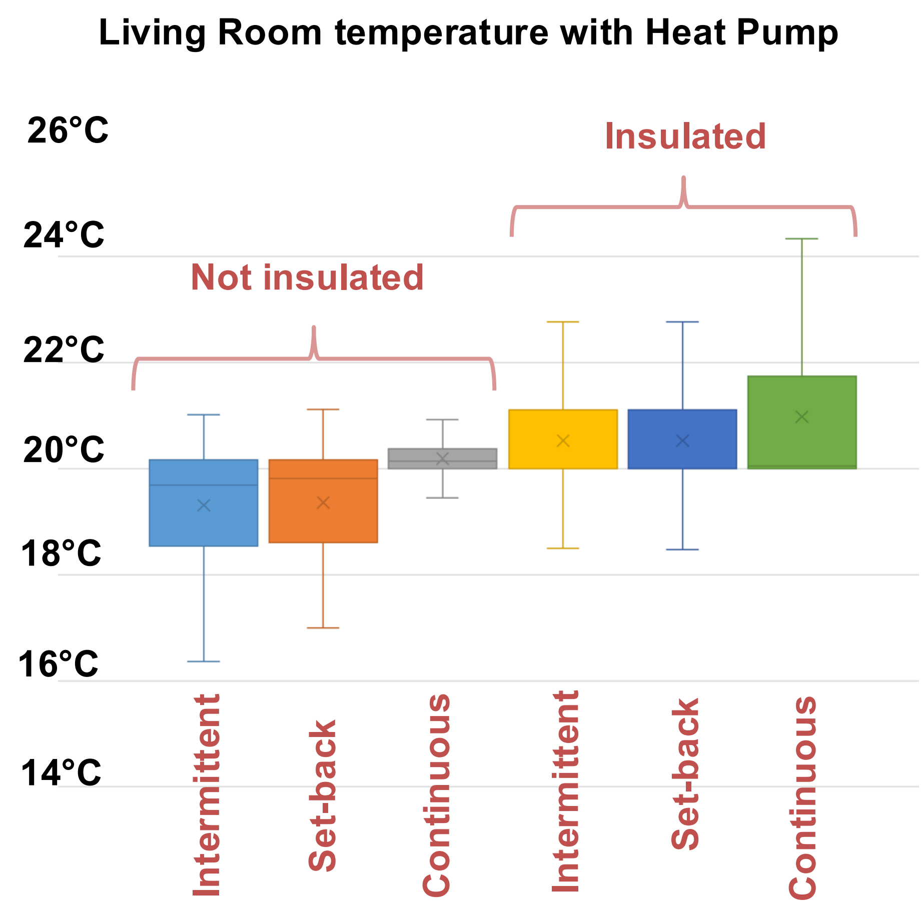
	Involucro opaco	serramenti	Ibrido	PDC	PV
SDF					
R1			X		
R2		X	X		
R3	X		X		
R4	X	X	X		
R5	X	X	X		X
R6	X	X		X	X
R7	X	X		X	X
R8	X	X		X	X
R9	X	X		X	X
R10	X	X		X	X



	SDF	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
SFH	F	E	E	B	B	A4	A4	A4	A4	A4	A4
TH S	G	F	F	D	D	A4	A4	A4	A4	A4	A4
TH E	G	G	F	D	D	A4	A4	A4	A4	A4	A4
MFH 12	F	F	E	C	C	An(A3/A4)	A4	A4	A4	A4	A4
MFH 16	F	F	E	D	D	An(A3/A4)	A4	A4	A4	A4	A4
AB S	F	F	E	D	D	An(A3/A4)	A4	A4	A4	A4	A4
AB E	F	F	E	D	D	An(A3/A4)	A4	A4	A4	A4	A4

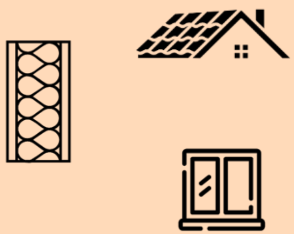
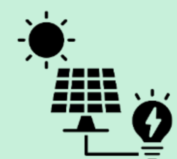
Analisi dinamica su un edificio terracielo

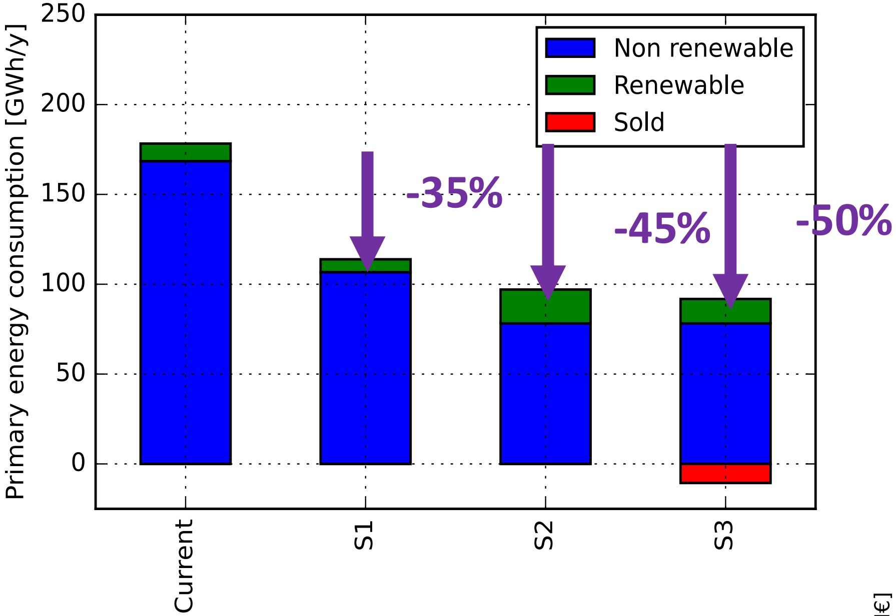




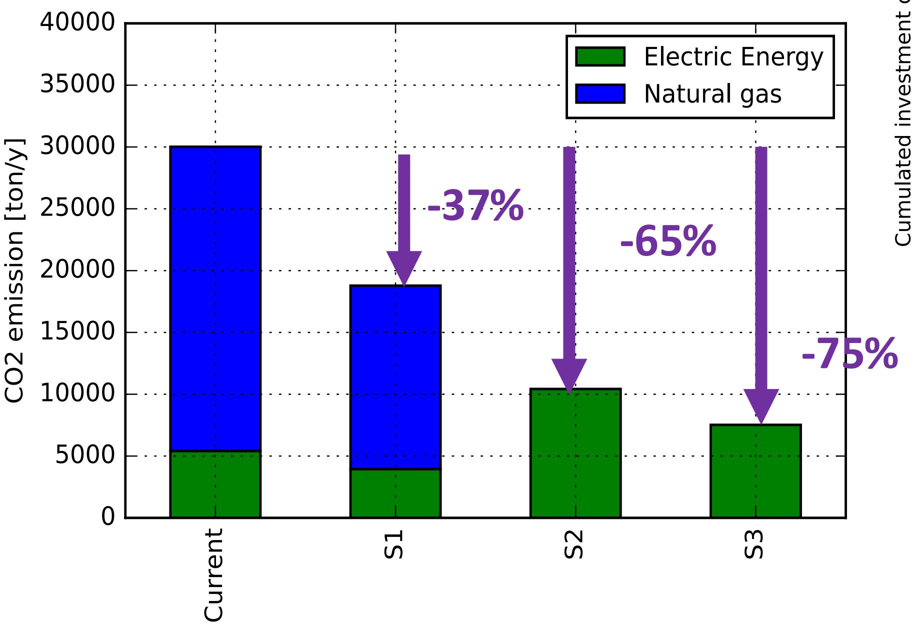
Lavoro in collaborazione con DAIKIN Europe

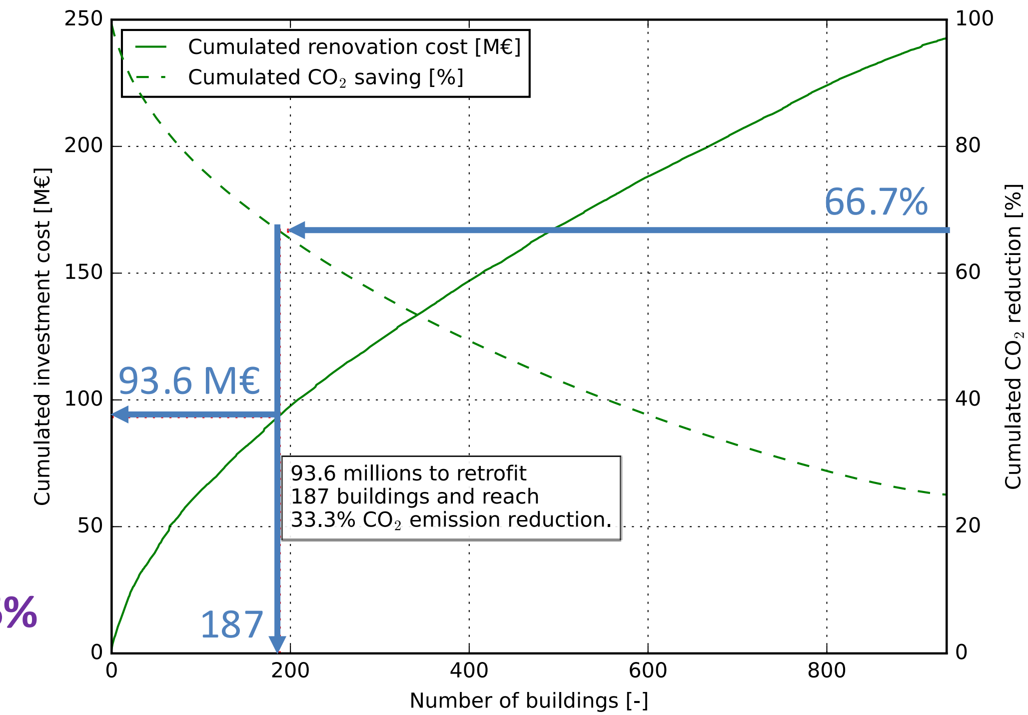
Scenari di riqualificazione

Scenario 1	Scenario 2	Scenario 3
	Scenario 1	Scenario 2
	+	+
		
$U_{muri,est} = 0.28 \frac{W}{m^2K}$		
$U_{tetto} = 0.24 \frac{W}{m^2K}$		
$U_{finestre} = 1.40 \frac{W}{m^2K}$		

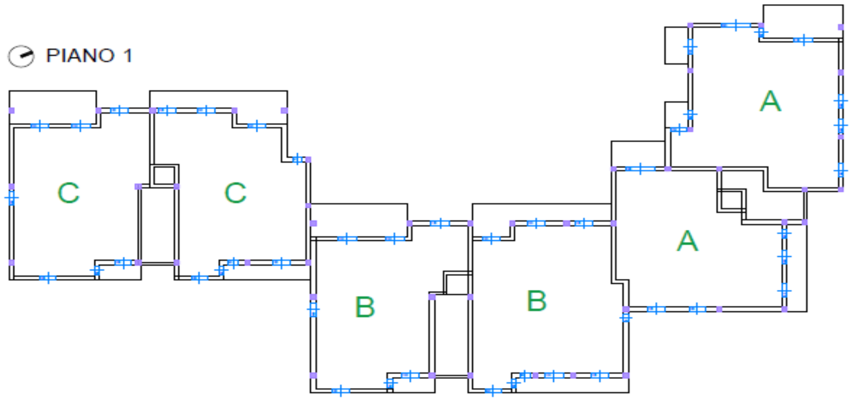


(-33% emissioni) per il **Climate City Contract (Padova)**





Utilizzo di pompe di calore distribuite con acqua di falda

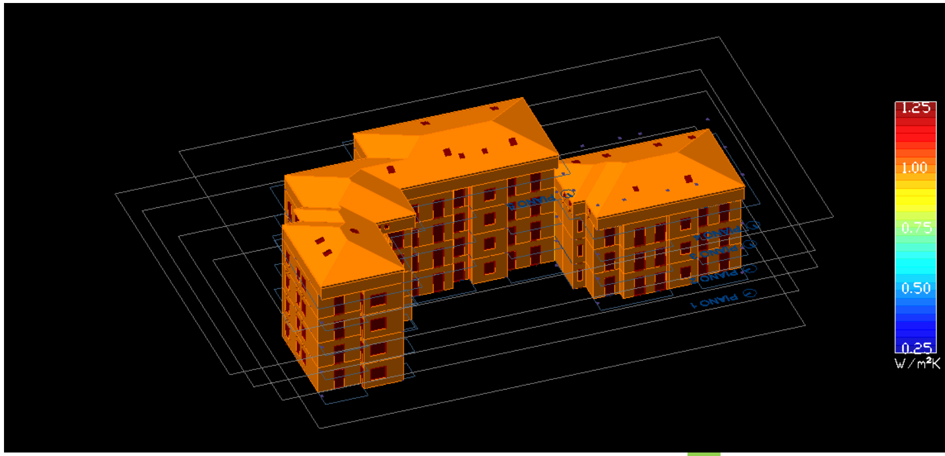


26 appartamenti totali

Superficie netta	2556	m^2
Volume netto	7305	m^3

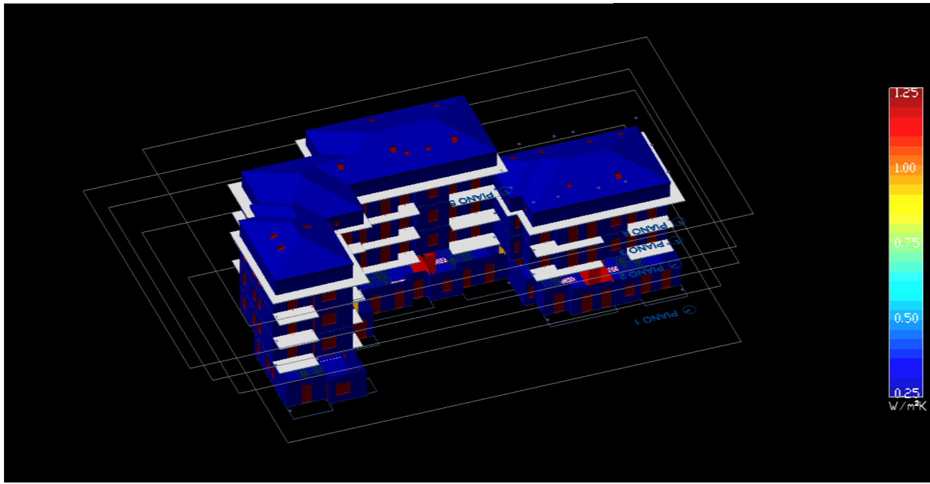
Lavoro in collaborazione con TEICOS ed ENEREN

Trasmittanza > 1 W/(m^2 K)
Classe E



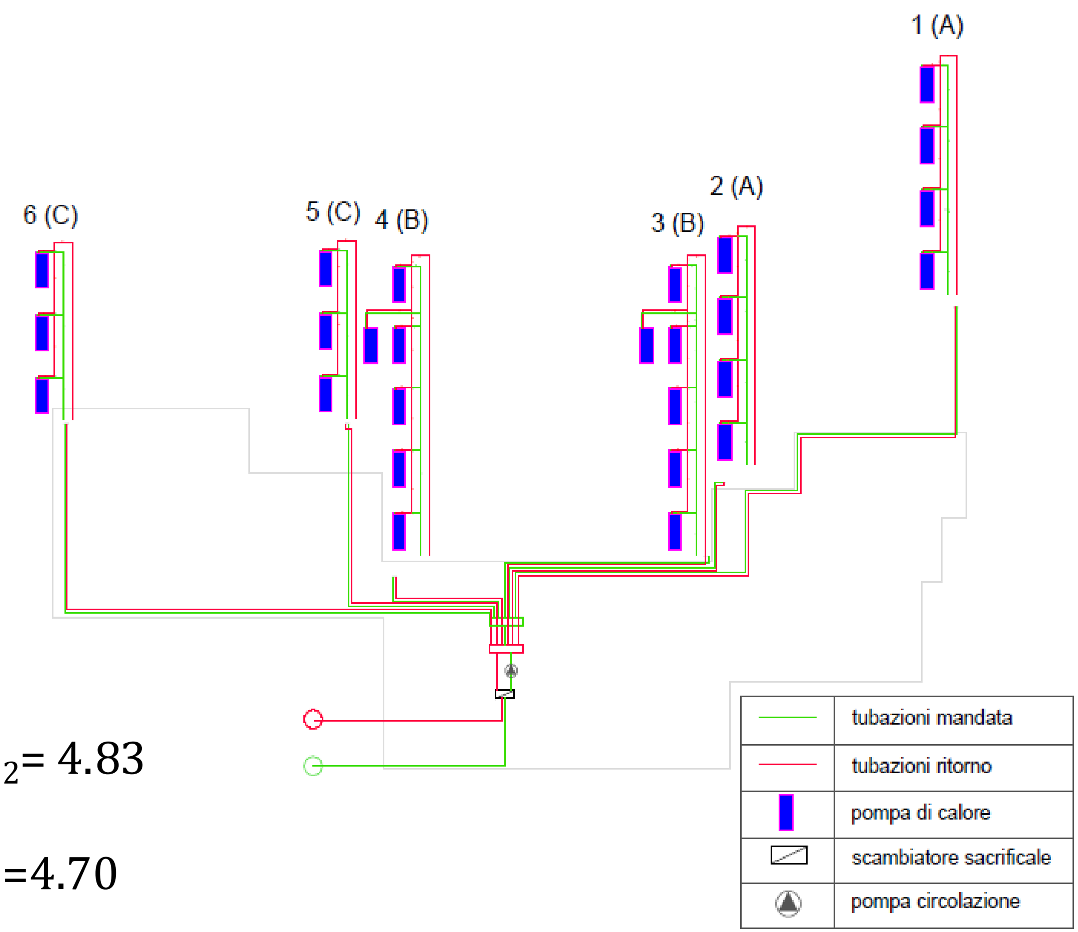
Cappotto termico

Trasmittanza < 0,3 W/(m^2 K)
Classe B



Soluzioni adottate:

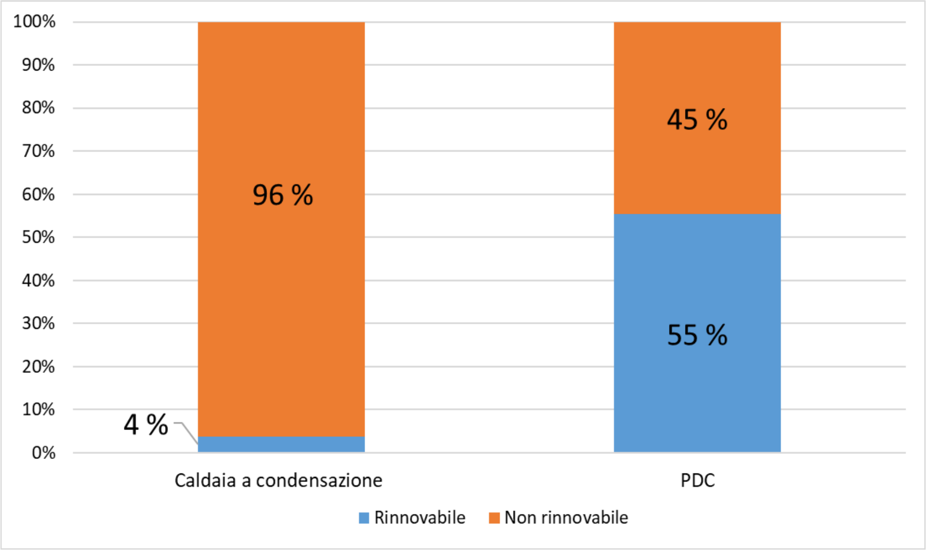
- **Isolamento a cappotto**
- **Sostituzione di caldaie autonome con pompe di calore**
- **Utilizzo di circuito ad acqua di falda sotto il cappotto per alimentare ogni PDC**
- **Sostituzione dei radiatori con fan-coil (distribuzione esterna)**

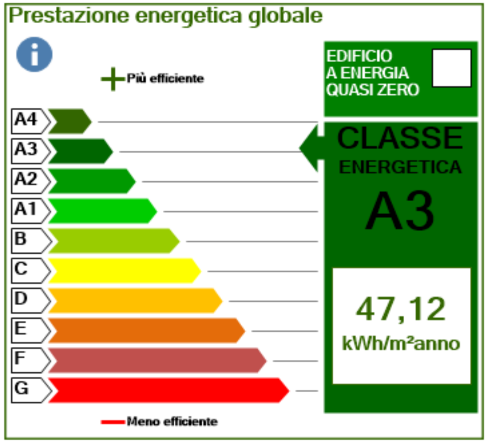


Inverno: 13 °C / 5 °C; COP_1= 4.43 COP_2= 4.83

Estate: 17 °C / 28 °C; EER_1=4.49 EER_2=4.70

Totale (ACS, caldo e freddo)

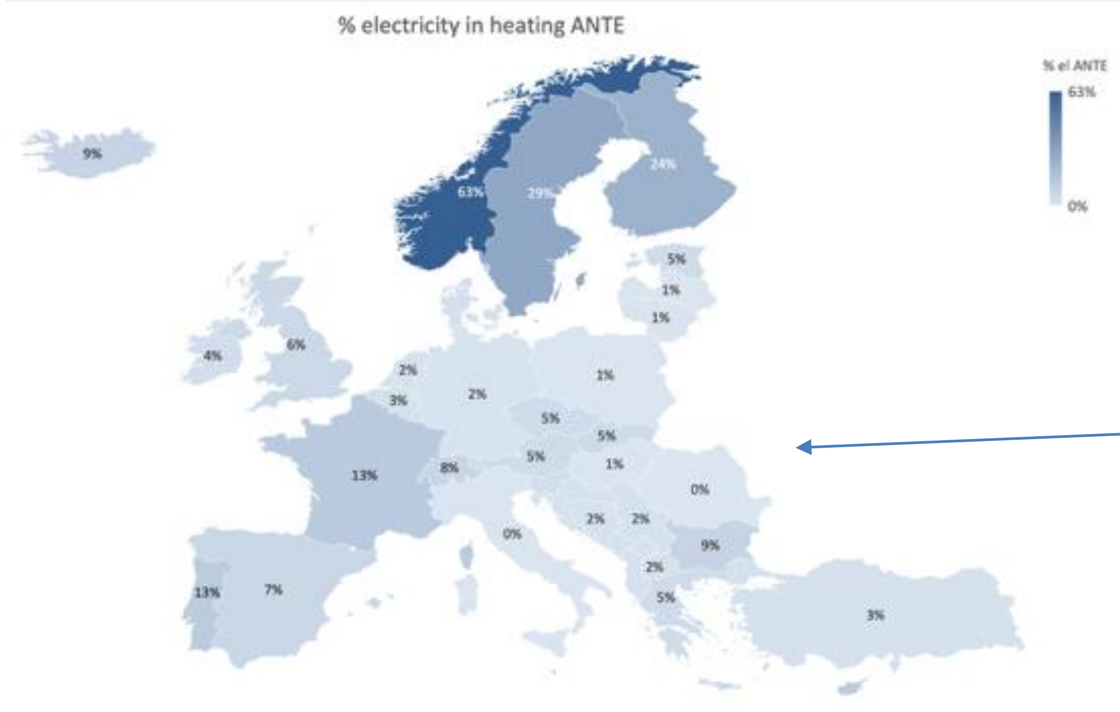




Con questa soluzione l'ACS viene prodotta sfruttando il calore di condensazione del raffrescamento (energia rinnovabile)

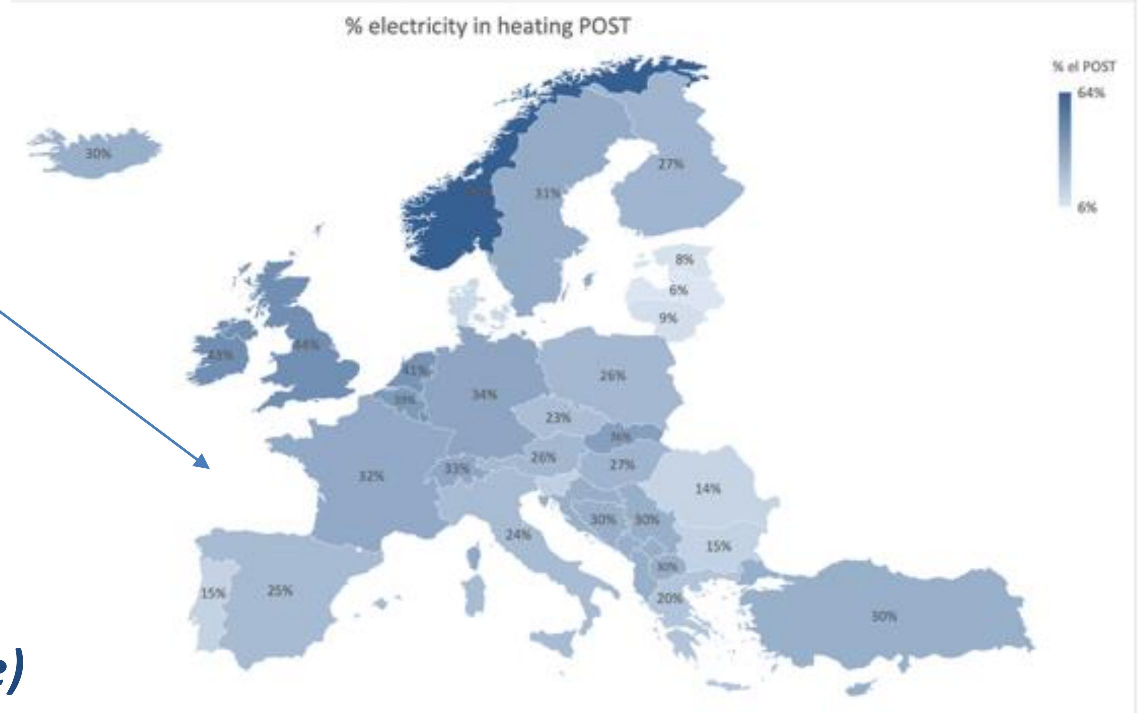
Certificato energetico solo con involucro e PDC. Senza PV

Potenziale dei sistemi ibridi PDC+boiler in Europa



Copertura attuale di elettrico sui consumi finali di riscaldamento

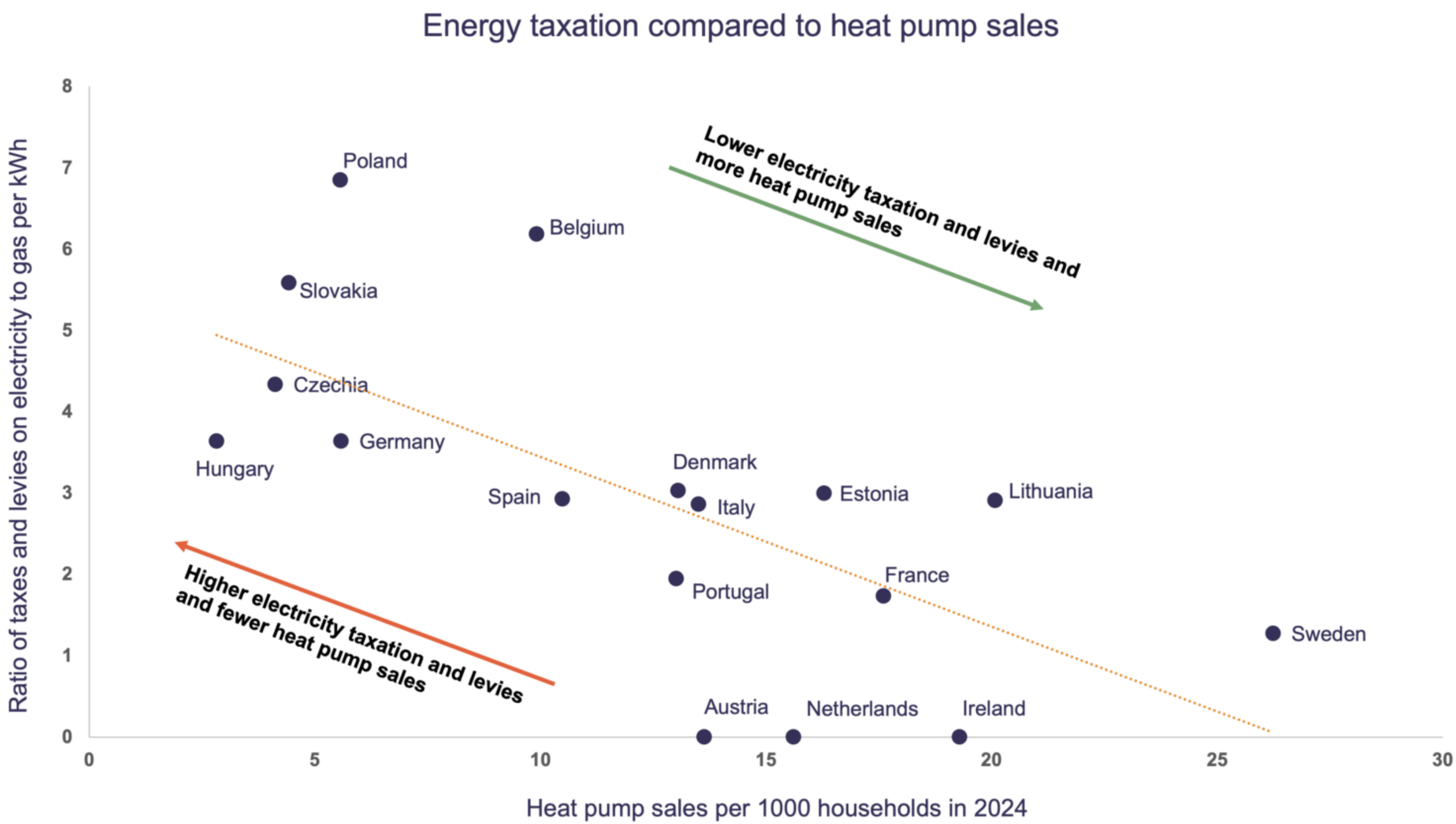
Copertura potenziale di elettrico sui consumi finali di riscaldamento



De Carli, Busato, Carnieletto, Mongelli (in corso di pubblicazione)

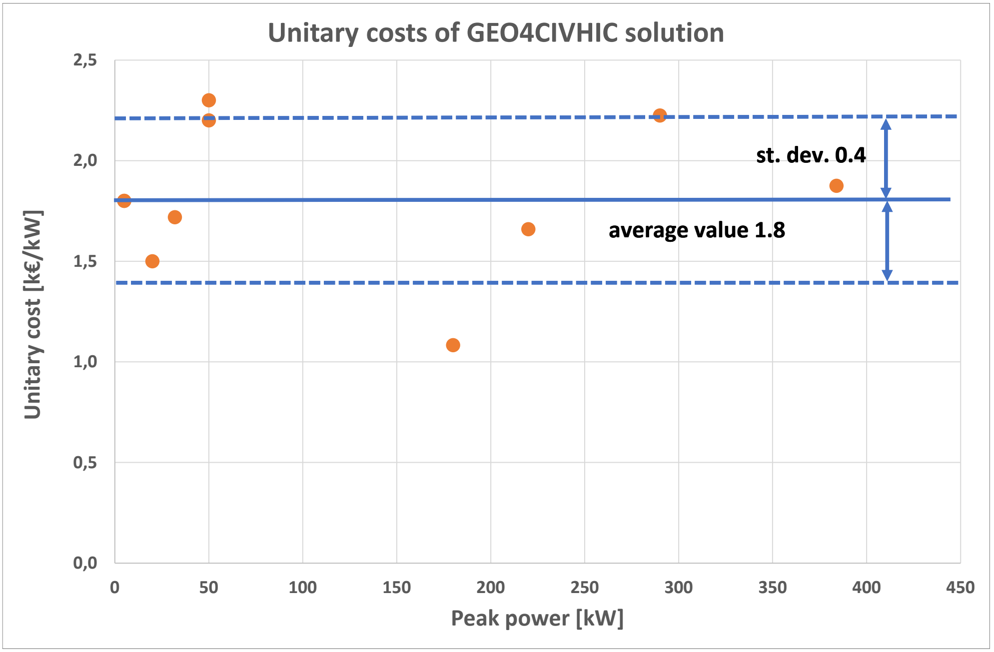
Mercato delle PDC e costo dell'elettricità

Bassi costi del rapporto tra costi elettricità/gas porta a una maggiore vendita di PDC per famiglie

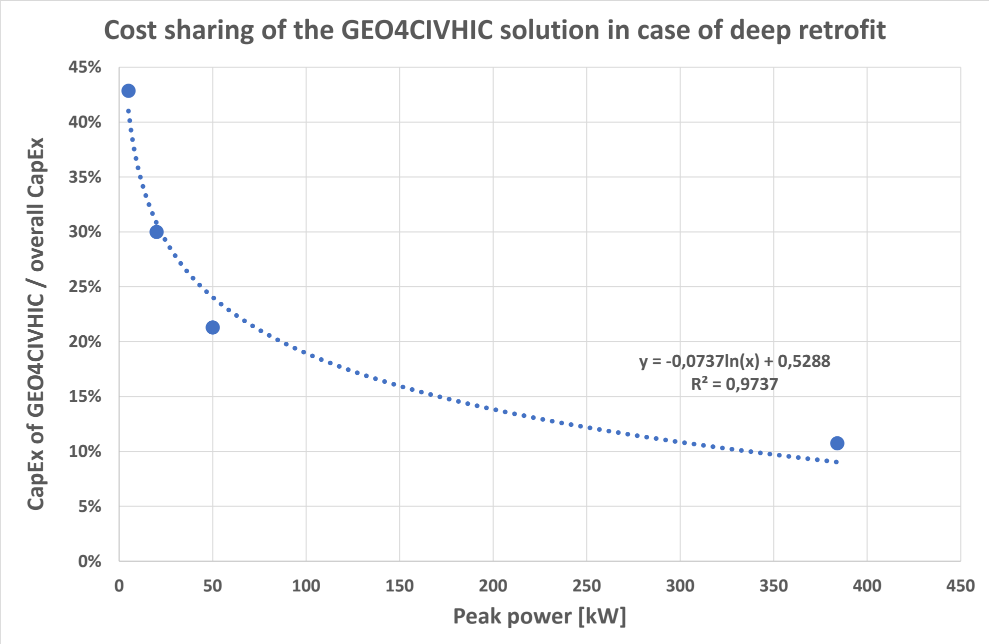


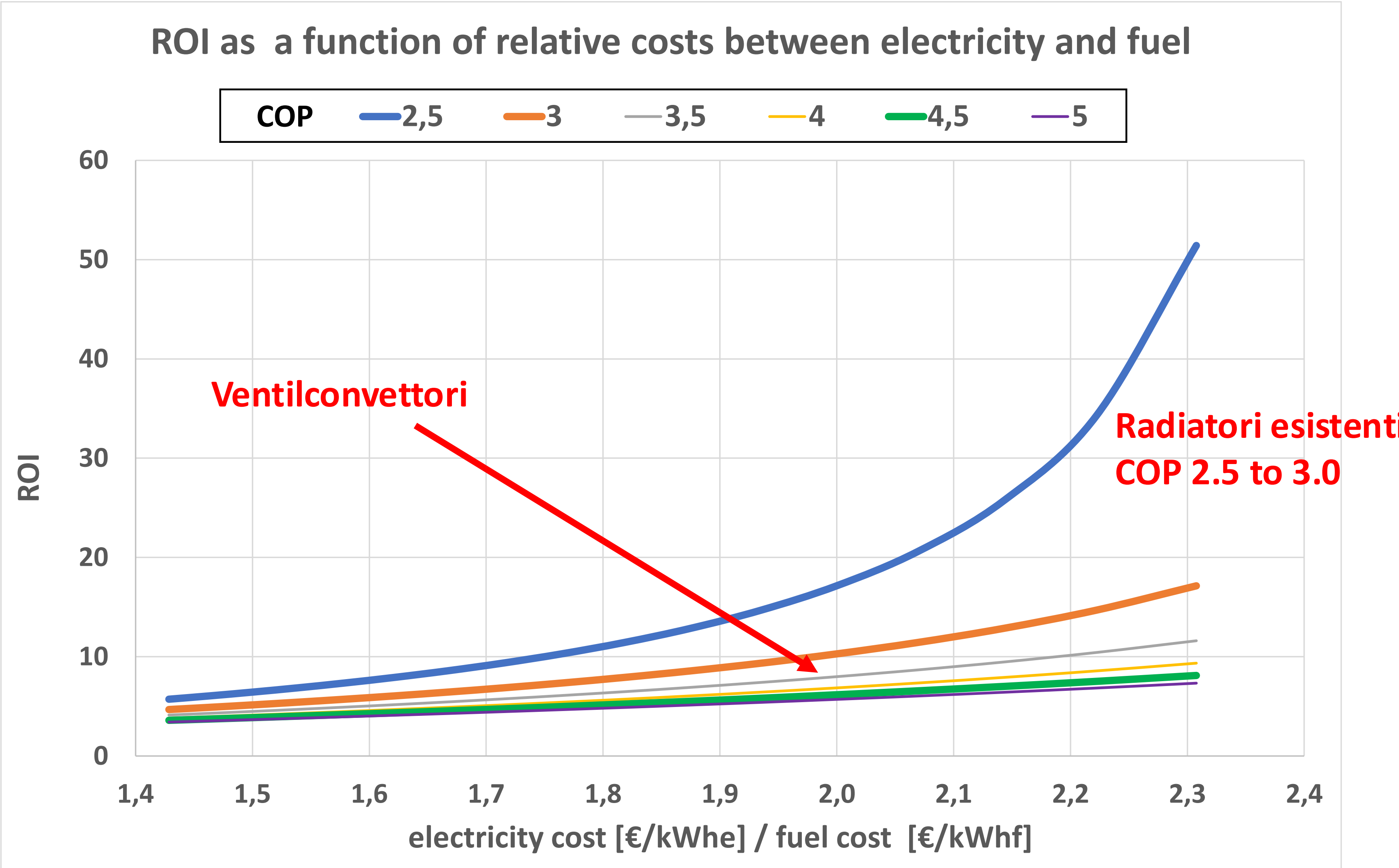
Source: EHPA

Analisi di costi con PDC geotermiche (GSHP)



Progetto Horizon GEO4CIVHIC





ROI as a function of relative costs between electricity and fuel
COP
2,5
3
3,5
4
4,5
5
60
50
40
30
20
10
0
ROI
1,4
1,5
1,6
1,7
1,8
1,9
2,0
2,1
2,2
2,3
2,4
electricity cost [€/kWhe] / fuel cost [€/kWhf]
Ventilconvettori
Radiatori esistenti
COP 2.5 to 3.0

GEO 4 CIVHIC

Grazie dell'attenzione