Evaluation of lower-GWP refrigerants for residential heat pumps

---

Jaime Sieres // ChETE – Universidad de Vigo

Madrid, 11th november 2024

IEA HPT TCP Technology Collaboration Programme | SPAIN NATIONAL TEAM

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas | VICEPRESIDENCIA TERCERA DEL GOBIERNO MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO | IDAE

Research from different national projects

- Liquid-to-water heat pumps with lower-GWP refrigerants
  - Funded by the Spanish ‘Agencia Estatal de Investigación’,within the ‘Programa Estatal de I+D+i Orientada a los Retos de la Sociedad del Plan Estatal de Investigación Científica y Técnica y de Innovación 2013–20160, grant number ENE2016–79771–R
- Air-to-water heat pumps with lower-GWP refrigerants
  - Funded by the Spanish ‘Agencia Estatal de Investigación’,within the ‘Programa Estatal de I+D+i Orientada a los Retos de la Sociedad del Plan Estatal de Investigación Científica y Técnica y de Innovación 2017–2020, grant number PID2019-104762RB-I00/AEI/10.13039/501100011033

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
AGENCIA ESTATAL DE INVESTIGACIÓN

Motivation

- Liquid-to-water heat pumps (domestic sector):
  - Variable speed compressor technology
  - Plate heat exchangers
  - No liquid receiver (dependent of refrigerant charge)
  - R410A widely used

- Global Warming Potential (GWP)
  - GWP of R410A is 1924
  - International regulations limit or ban refrigerants with high GWP (ex. EU Nº517/2014)
  - Natural refrigerants
  - Blends: R452B ,R454B, R455A…
    - They show similar COP but lower capacities
    - Evaluation done at limited operating conditions

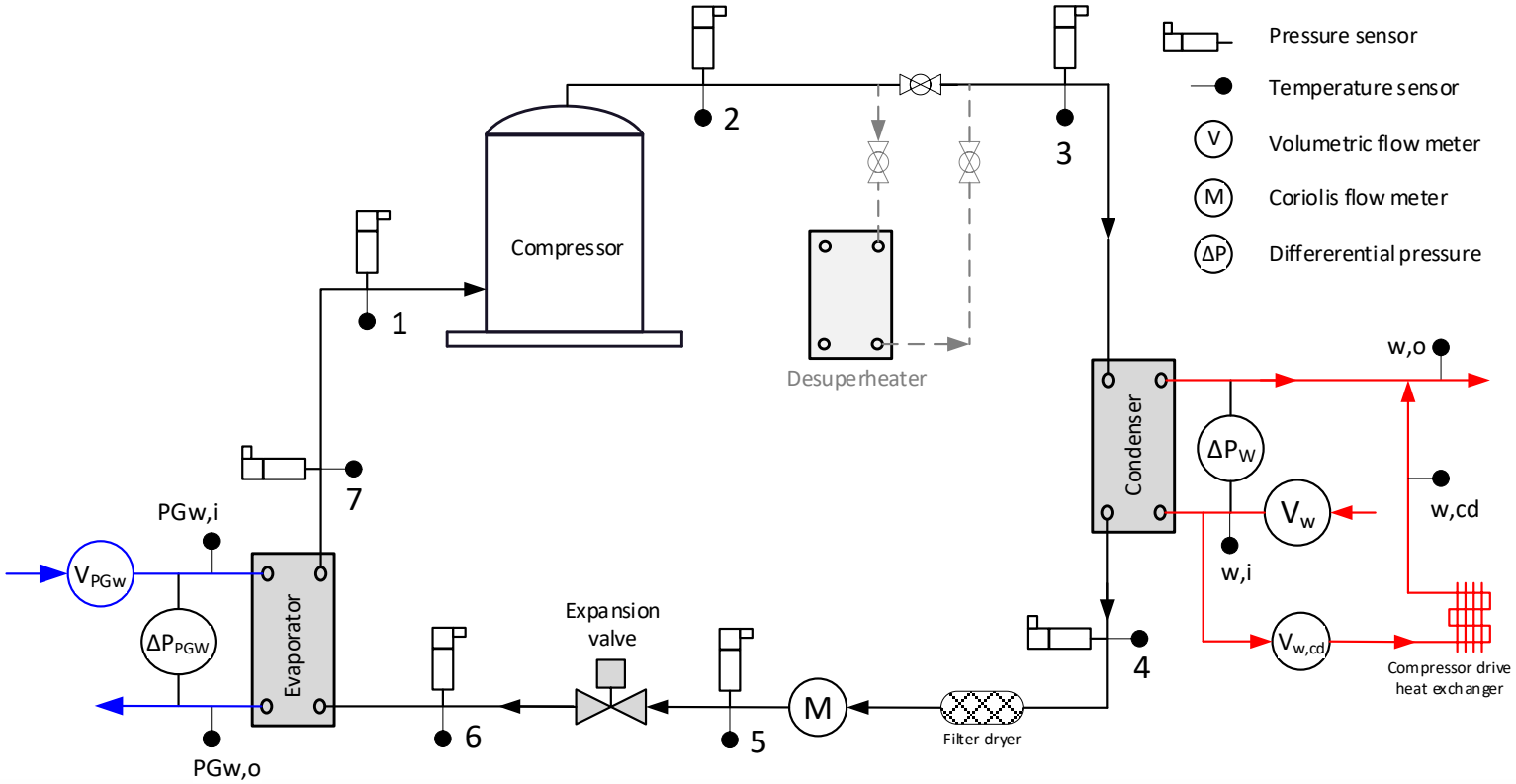
Outline

1. Refrigerants tested
2. Experimental set-up
3. Test conditions
4. Selected results
5. Conclusions and future work

Refrigerants tested

Property	R410A	R452B	R454B	R455A
Composition (wt%)	R32/R125 (50/50%)	R32/R125/R1234yf (67/7/26%)	R32/R1234yf (68.9/31.1%)	R1234yf/R32/R744 (75.5/21.5%/3%)
Molecular weight	72.6 kg/kmol	63.5 kg/kmol	62.6 kg/kmol	87.5 kg/kmol
Critical temperature	71.3 °C	77.1 °C	78.1°C	85.6°C
Boiling point @1 atm	-51.4 °C	-50 °C	-50.5 °C	-39.2°C
Heat of vap. @1 atm	19813 kJ/kmol	19806 kJ/kmol	19804 kJ/kmol	20501 kJ/kmol
Density sat. liq. @1 atm	1350 kg/m^3	1015 kg/m^3	1239 kg/m^3	1033 kg/m^3
Glide	0.1 K	1.3 K	1.5 K	12.8 K
GWP (AR4)	1924	675	466	146
ASHARE Safety Class.	A1	A2L	A2L	A2L

Experimental set-up



- Liquid-to-water HP for heating and DHW production
- Variable speed scroll compressor (Nmax = 7000 rpm)
- Brazed plate HX
- Electronic expansion valve
- Refrigerant R410A

Heat pump

Propylene-glycol water mixture tank

Water tank

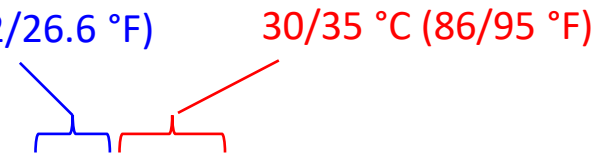
DHW tank

Experimental setup - Instrumentation

Variable	Instrumentation	Accuracy
Water and PGW volumetric flow rate	Electromagnetic flow meter	±0.2% reading
Water volumetric flow rate (compressor drive HEx)	Paddle-wheel flow meter	±(0.1 L×min^{-1}+2.5% reading)
Water and PGW temperatures	PT 100 Class B 1/10	±0.06 K
Water and PGW pressure drops	Differential pressure transducer	± 0.1% reading
Refrigerant temperatures	PT 100 Class A	±0.4 K
Refrigerant pressures (gauge): points 2-5	Pressure transmitter	±0.04 bar
Refrigerant pressures (gauge): points 6, 7 and 1	Pressure transmitter	±0.02 bar
Refrigerant mass flow rate and density	Coriolis flow meter	±0.1% reading
Atmospheric pressure	Digital barometer	±0.003 bar
Compressor and HP auxiliary electrical power	Power transducer	±0.5% reading

Test conditions

- Refrigerant charge sweeps
  - 50 grams increments (aprox.)
  - Undercharged – Overcharged conditions
  - Optimum charge determination
- Operating conditions
  - PGW and water temperatures: B0W35 and B0W45
  - Compressor speed: 25 – 100%
  - Degree of superheat: 2, 5 and 10 K

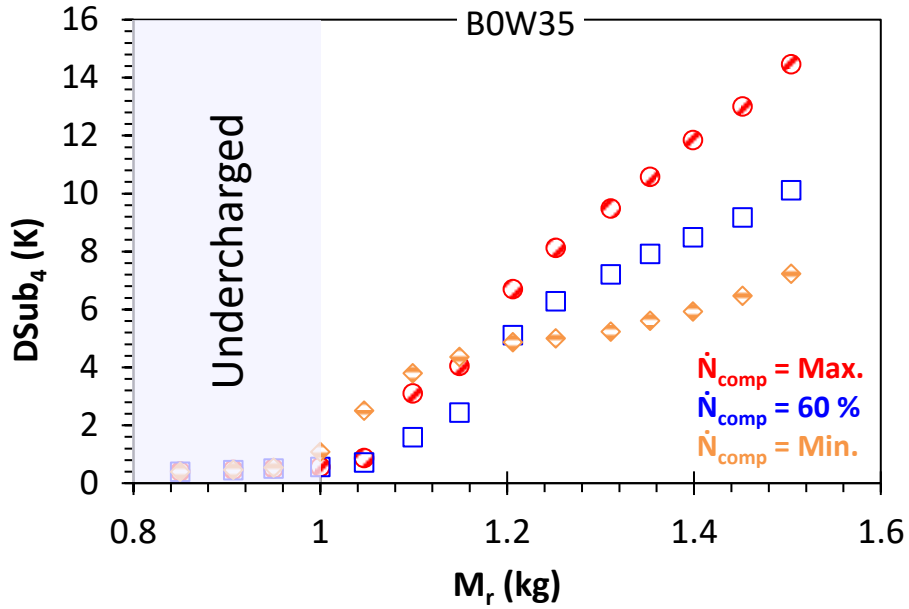


Select results – Optimum charge

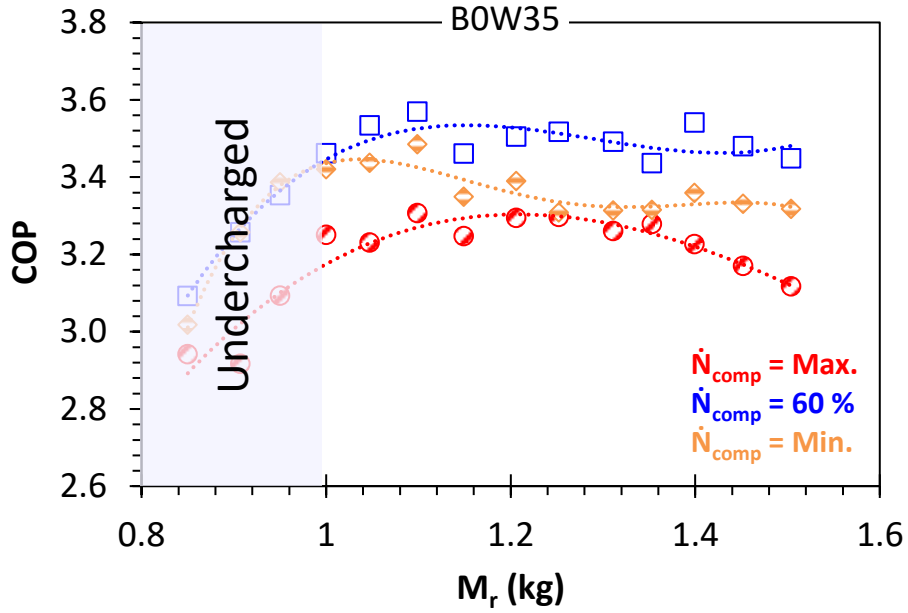
- Refrigerant: R410A (baseline)
- Optimum refrigerant charge
- Operating conditions
  - PGW inlet/outlet: 0/-3 °C (32/26.6 °F)
  - Water inlet /outlet: 30/35 °C (86/95 °F) and 40/45 °C (104/113 °F)
  - Compressor speed: 25 – 100%
  - Degree of superheat: 2, 5 and 10 K

Optimum charge – R410A

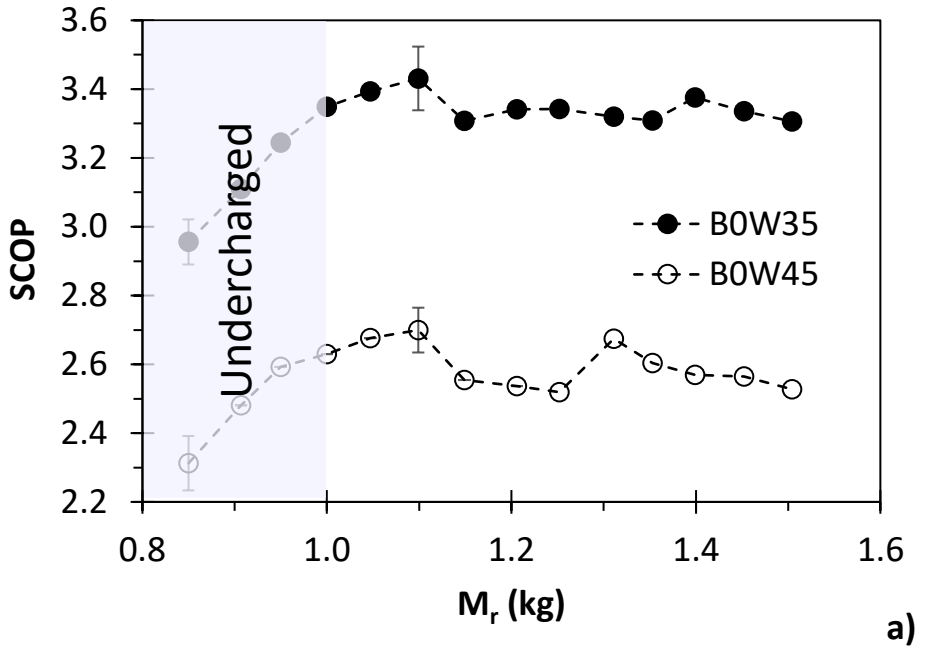
- COP drops for undercharged conditions
- COP stable if minimum charge is surpassed



- Charge that maximizes COP
- Optimum charge depends on compressor speed
- Optimum charge?

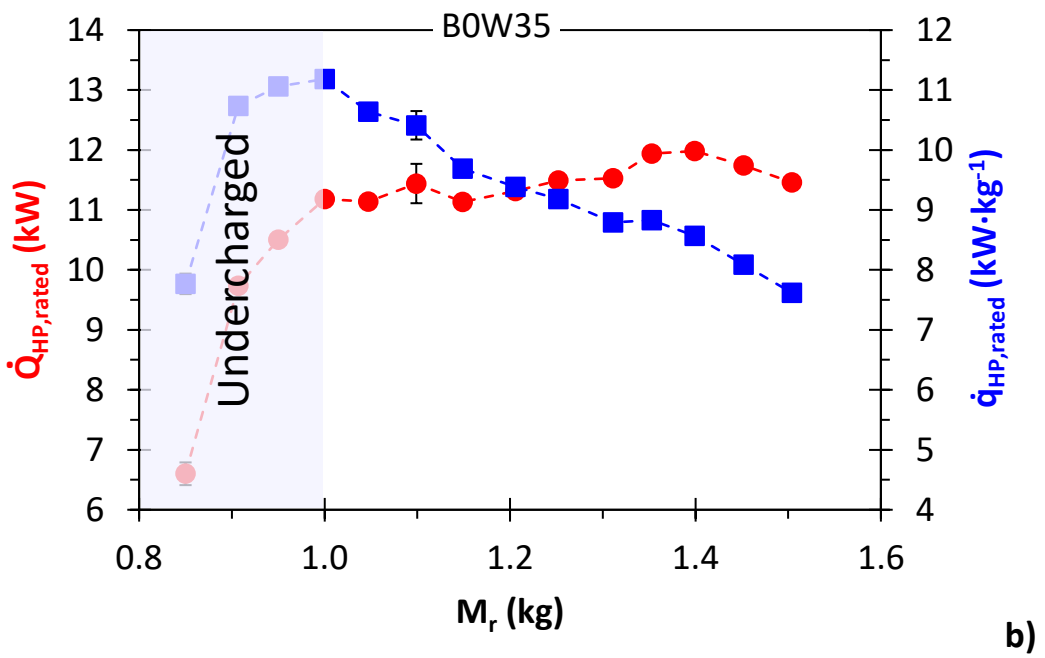


Optimum charge – R410A



- SCOP vs. charge
  - Considers the real behaviour of the unit during the heating season
- SCOP drops for undercharged conditions
- SCOP stable if minimum charge is surpassed

Optimum charge – R410A



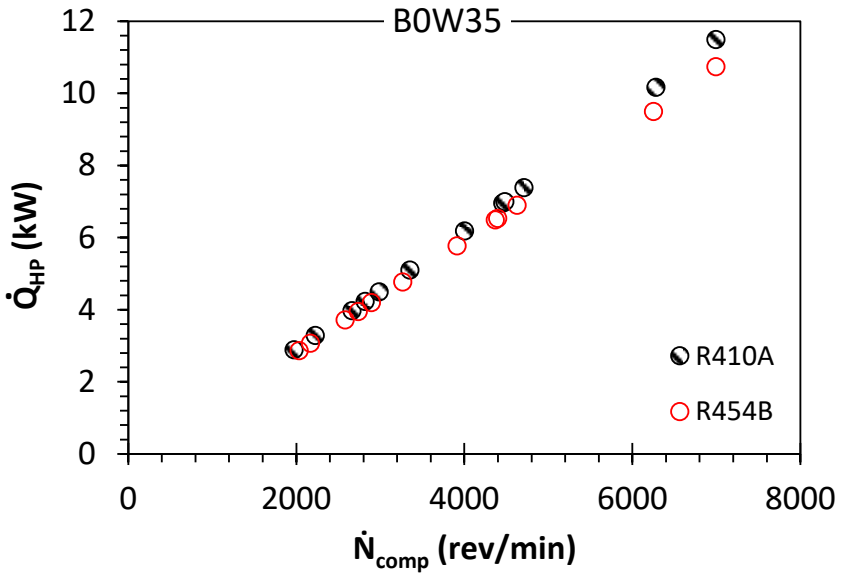
b)

- Rated heating capacity
  - $\dot{Q}_{HP,rated} = \dot{Q}_{HP@\dot{N}_{max}}$
  - Drops for undercharged conditions
  - Limited at high charges by compressor max. power

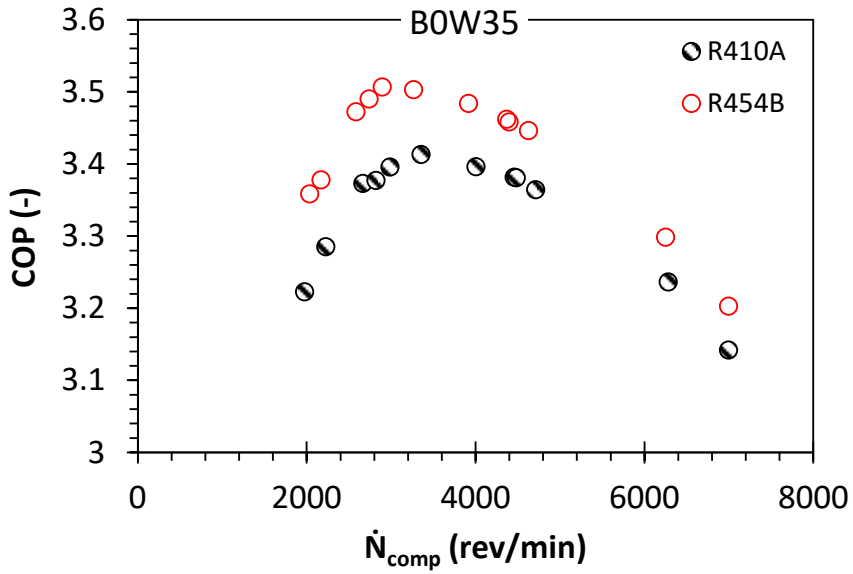
- Charge specific rated capacity
  - $\dot{q}_{HP,rated} = \dot{Q}_{HP,rated}/M_r$
  - Drops for undercharged conditions
  - Once a minimum charge is surpassed, $\dot{q}_{HP,rated}$ decreases with an increment of the refrigerant charge

R454B vs R410A – Drop in performance

- Heating capacity
  - Up to 6% lower with R454B

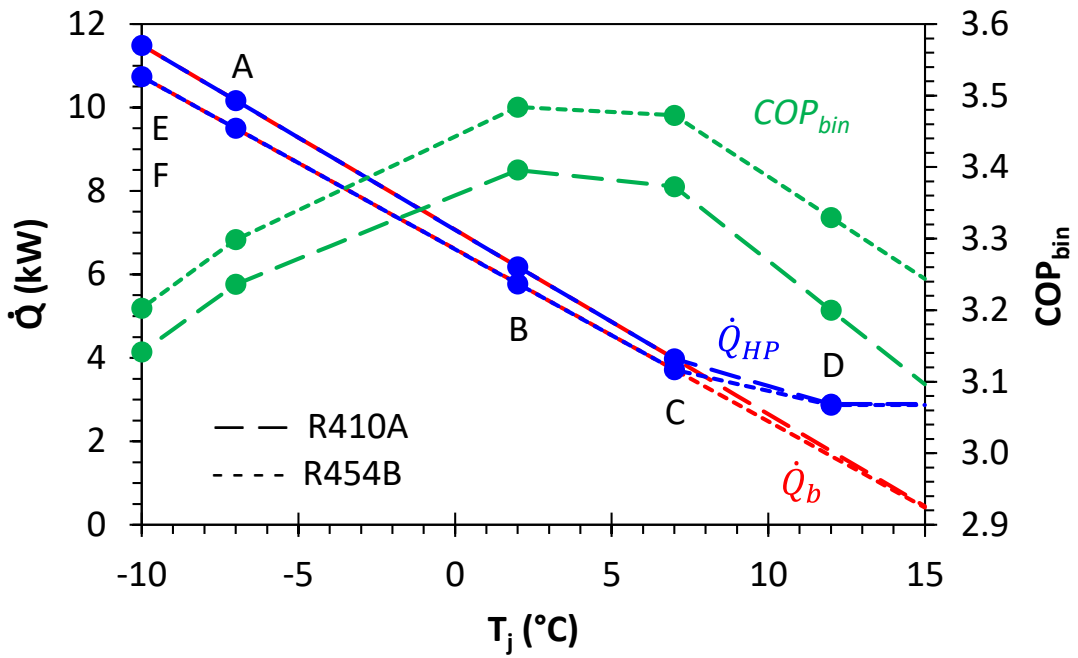


- COP
  - Higher with R454B (but for lower Q_{HP})



R454B vs R410A – Drop in performance

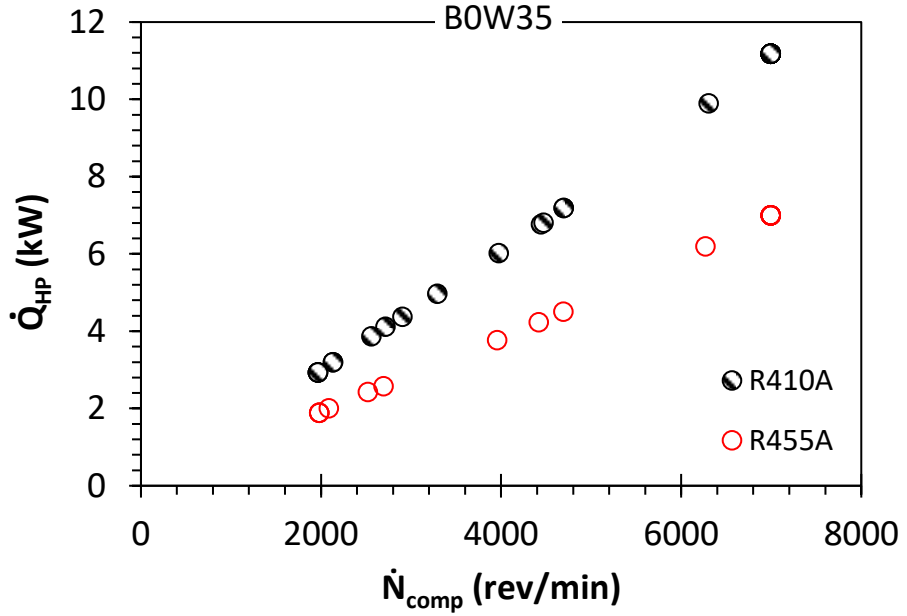
- SCOP calculation (EN 14825)



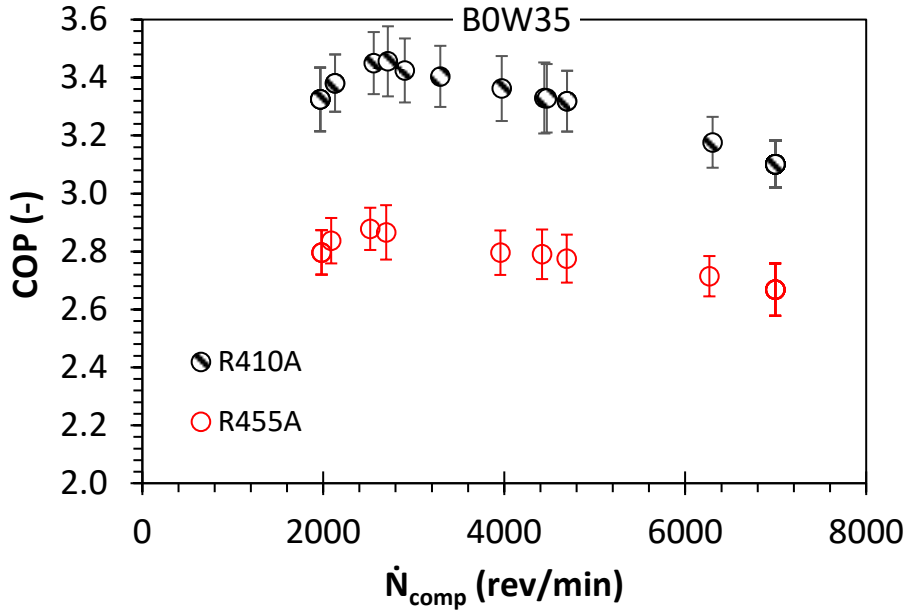
Parameter	R410A	R454B
$\dot{Q}_{design}$ (kW)	11.49	11.49
$\dot{Q}_{HP,rated}$ (kW)	11.49	10.74
Q_b (kWh)	23736	23736
E_{on} (kWh)	7103	6949
***SCOP*$_{on}$**	**3.342**	**3.416**

R455A vs R410A – Drop in performance

- Heating capacity
  - Up to 35% lower with R455A



- COP
  - Up to 25% lower with R455A



Conclusions and future work

- Lower-GWP refrigerants evaluation for domestic heat pumps
  - Charge optimization based on SCOP and $\dot{q}_{HP}$
  - R452B and R454B showed similar performance to R410A
    - R452B and R454B have GWP > 150
  - R455A has GWP < 150 but
    - Lower $\dot{Q}_{HP}$ and COP than R410A
- Ongoing research in air-to-water HP
    - Liquid-to-water and Air-to-water HP using propane
    - Low-diameter coils for reducing refrigerant charge


HEAT PUMPS IN SPAIN
NATIONAL WORKSHOP
11TH NOVEMBER 2024
CIEMAT / Madrid
Ongoing Spanish Team activity on HPT

Thank you!