IEA - Annex 54

CETIAT Project PR5 :
Low GWP refrigerants

Studies shared with the Annex 54

11/06/2024

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Summary

- Experimental evaluation of R410A, R407C and R134a alternative refrigerants in residential heat pumps

- Experimental and numerical study of heat transfer in evaporation and condensation with R410A, R32 and R454B in a finned tube heat exchanger

- Design and study of a prototype of heat pump using 150 g of propane

Experimental evaluation of R410A, R407C and R134a alternative refrigerants in residential heat pumps

Drop-in tests to replace :

- R410A in a 10 kW A/W reversible HP → R459A, R454B, R447A, HPR2A and R32
- R407C in a 3 kW (W/A) reversible HP → R454C
- R134a in a split Heat Pump Water Heater (w/ 200 liters tank) → R1234yf and R513A

➢ More than 100 performance tests were made

Experimental evaluation of R410A, R407C and R134a alternative refrigerants in residential heat pumps

Drop-in tests

No changes were made to the heat pumps

Experimental procedure (3 steps)

Step 1: Refrigerant charge optimization

Step 2: Thermal performance assessment with alternative refrigerants

Step 3: Performance verification with the initial refrigerant

=> Step 2 : Thermal performance assessment

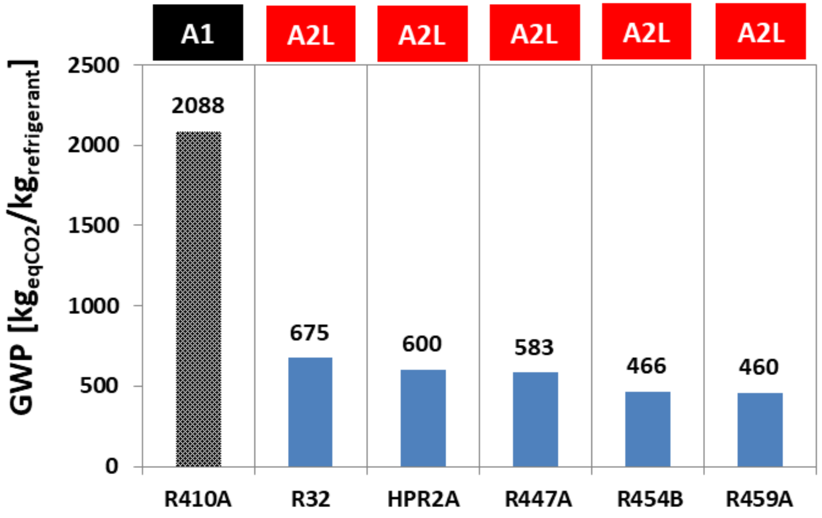
Air-to-water and water-to-air heat pumps: Tests in rating and operating limit conditions according to EN 14511 standard

Heat pump water heater: Tests consisted in heating-up the water in the tank followed by a hot water tapping. Measurements followed the EN 16147 standard recommendations

Experimental evaluation of R410A alternative refrigerants in residential heat pumps

- Refrigerant properties

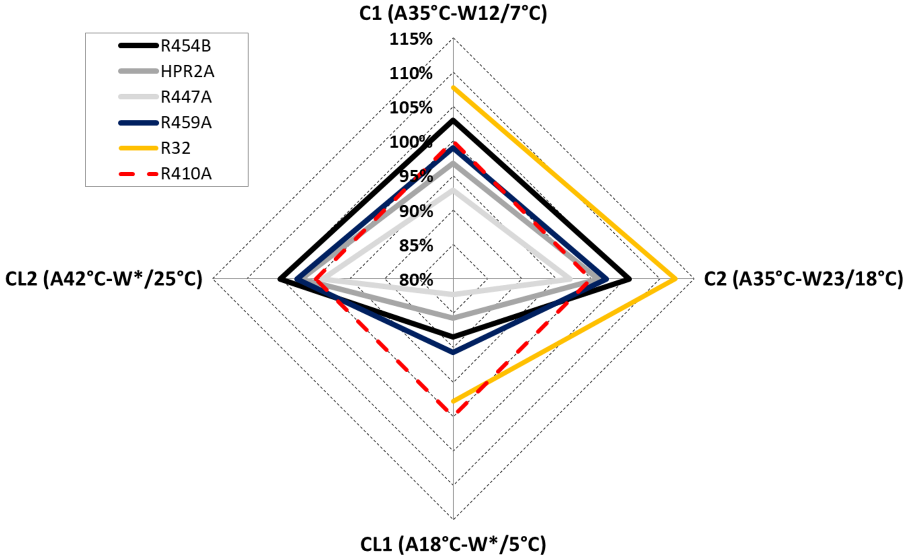
Refrigerant	Composition	Glide (K)
R410A	R32/R125 (50/50%w)	0.1
R32	R32 (100%w)	0
HPR2A	R32/R134a/R1234ze(E) (76/6/18%w)	4.1
R447A	R32/R1234ze(E)/R125 (68/28.5/3.5%w)	5.1
R454B	R32/R1234yf (68.9/31.1%w)	1.3
R459A	R32/R1234yf/R1234ze(E) (68/26/6%w)	1.9



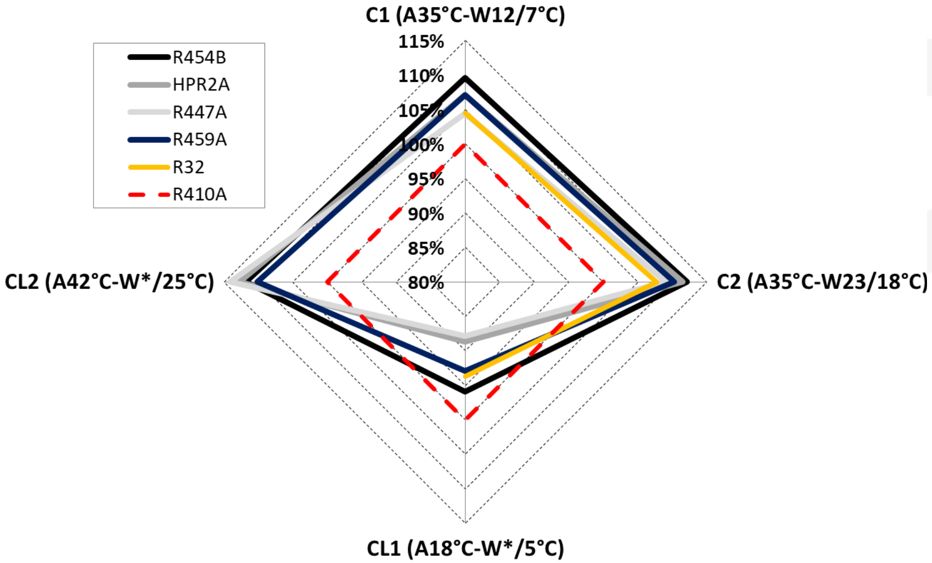
- Test conditions
  - ***Cooling mode***: 2 rating and 2 operating limit conditions
  - ***Heating mode***: 6 rating and 3 operating limit conditions
- **84 tests** have been carried out according to EN 14511

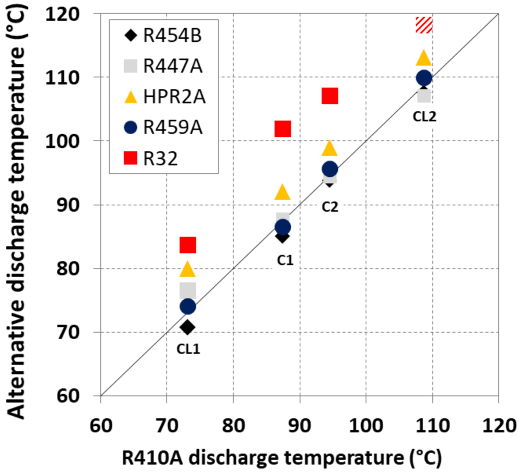
Experimental evaluation of R410A alternative refrigerants in residential heat pumps

Cooling capacity (ratio)



EER (ratio)





- ❑ R447A: Capacity -7.2% and EER +3.9%
- ❑ HPR2A: Capacity -3.6% and EER +5.0%
- ❑ R459A: Capacity -1.3% and EER +5.2%
- ❑ R454B: Capacity +0.5% and **EER +7.4%**
- ❑ R32*: **Capacity +5.9%** and EER +2.0%

*R32 did not allow performing CL2 limit condition test – $T_{discharge}$ > 115°C

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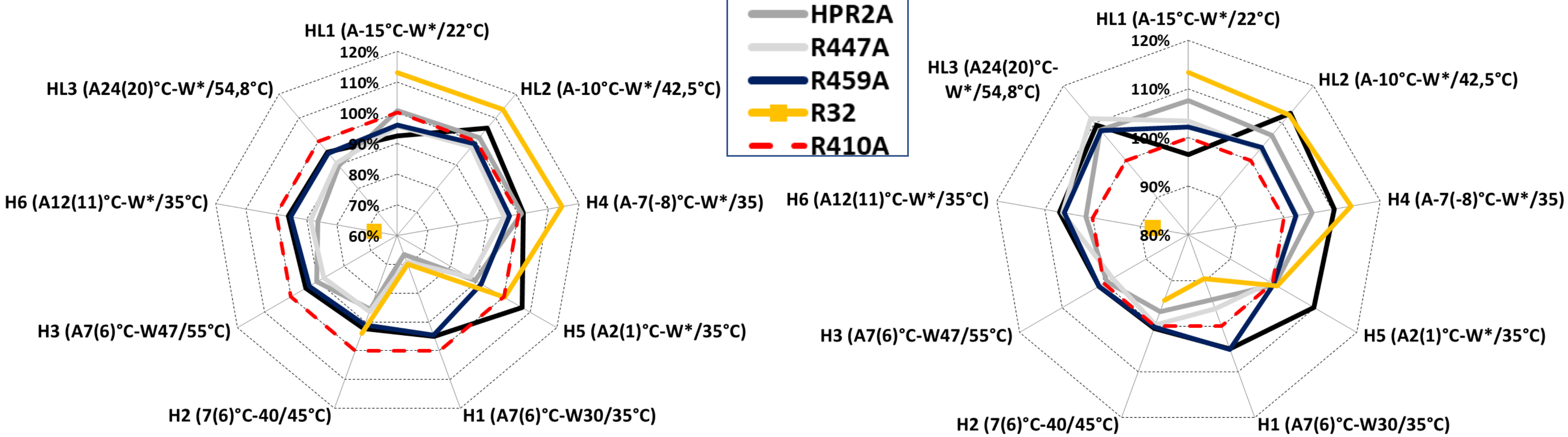
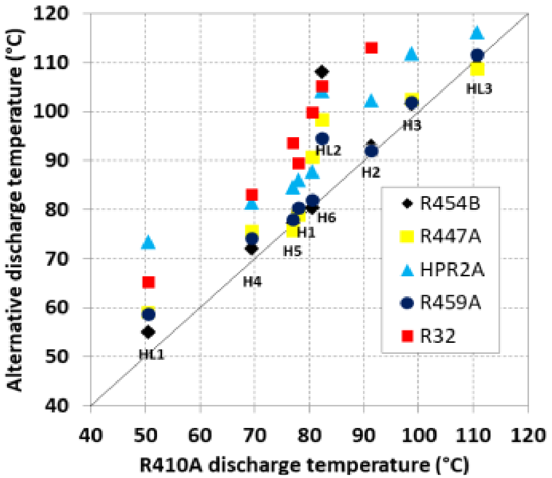
Experimental evaluation of R410A alternative refrigerants in residential heat pumps

Heating capacity (ratio) / COP (ratio)





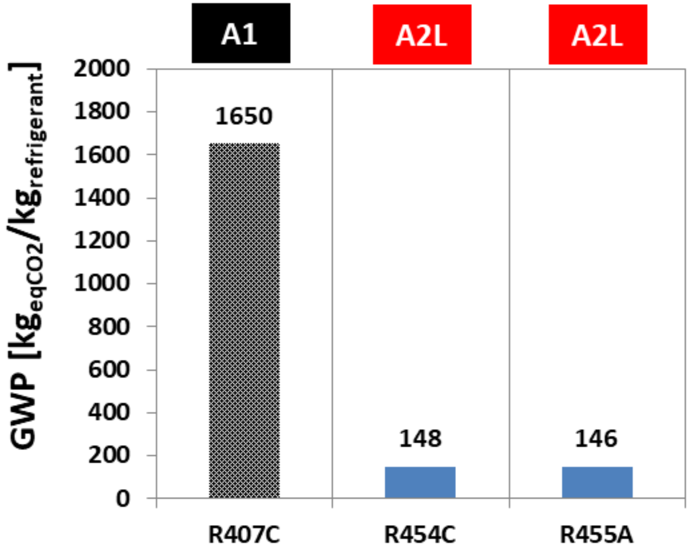
- ❑ R447A: Capacity -11.3% and COP +2.1%
- ❑ HPR2A: Capacity -9.9% and COP +2.2%
- ❑ R459A: Capacity -5.3% and COP +3.1%
- ❑ R454B: **Capacity -2.3%** and **COP +5.7%**
- ❑ R32*: Capacity -3.9% and COP +1.6%

*R32 did not allow performing 2 condition tests (H3 and HL3) – $T_{discharge}$ > 115°C

Experimental evaluation of R407C alternative refrigerants in residential heat pumps

- Refrigerant properties

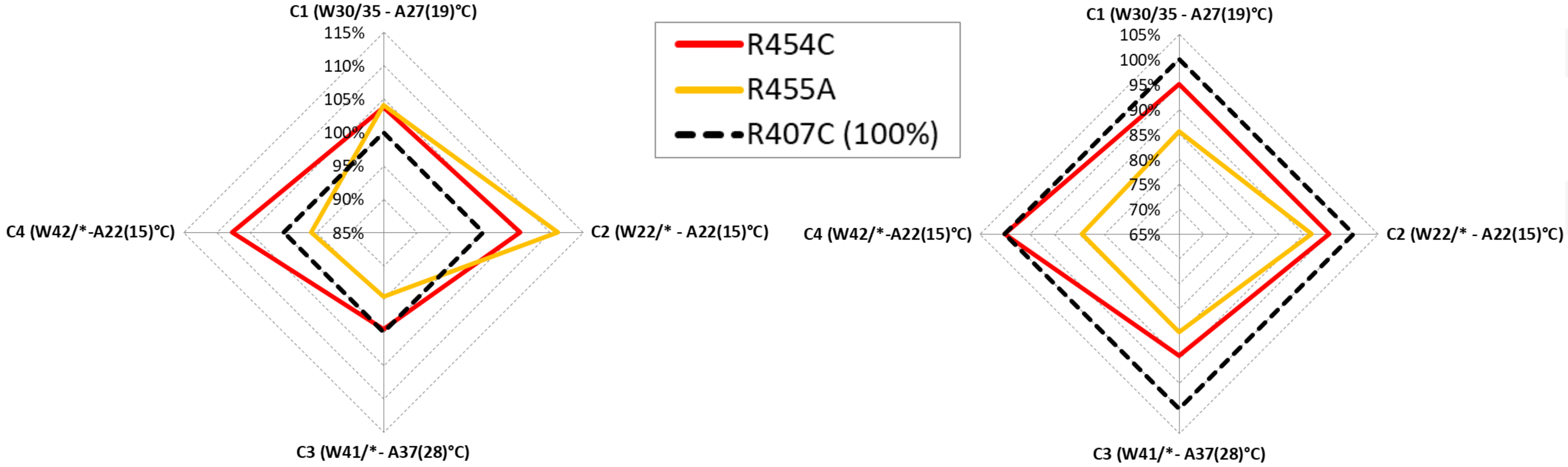
Refrigerant	Composition	Glide (K)
R407C	R32/R125/R134a (23/25/52%w)	7.0
R454C	R1234yf/R32 (78.5/21.5%w)	8.5
R455A	R1234yf/R32/R744 (75.5/21.5/3%w)	12.8

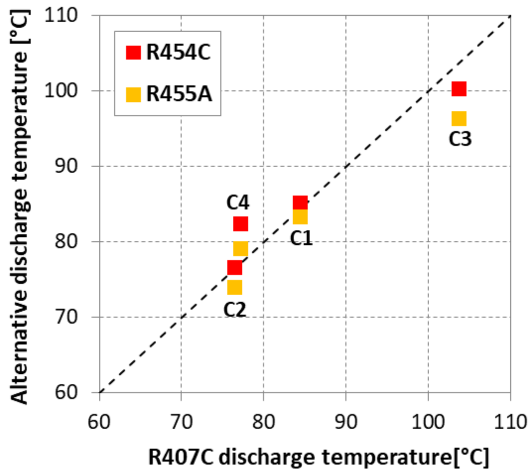


- Test conditions
  - ***Cooling mode***: 2 rating and 2 operating limit conditions
  - ***Heating mode***: 2 rating and 2 operating limit conditions
- **27 tests** have been carried out according to EN 14511

Experimental evaluation of R407C alternative refrigerants in residential heat pumps

Cooling capacity (ratio) / EER (ratio)





- R454C:
  - Cooling capacity: -0.5% to +7.7%
  - EER: -10.7% to 0.0%
- R455A:
  - Cooling capacity: -5.4% to +11.2%
  - EER: -15.5% to -8.4%

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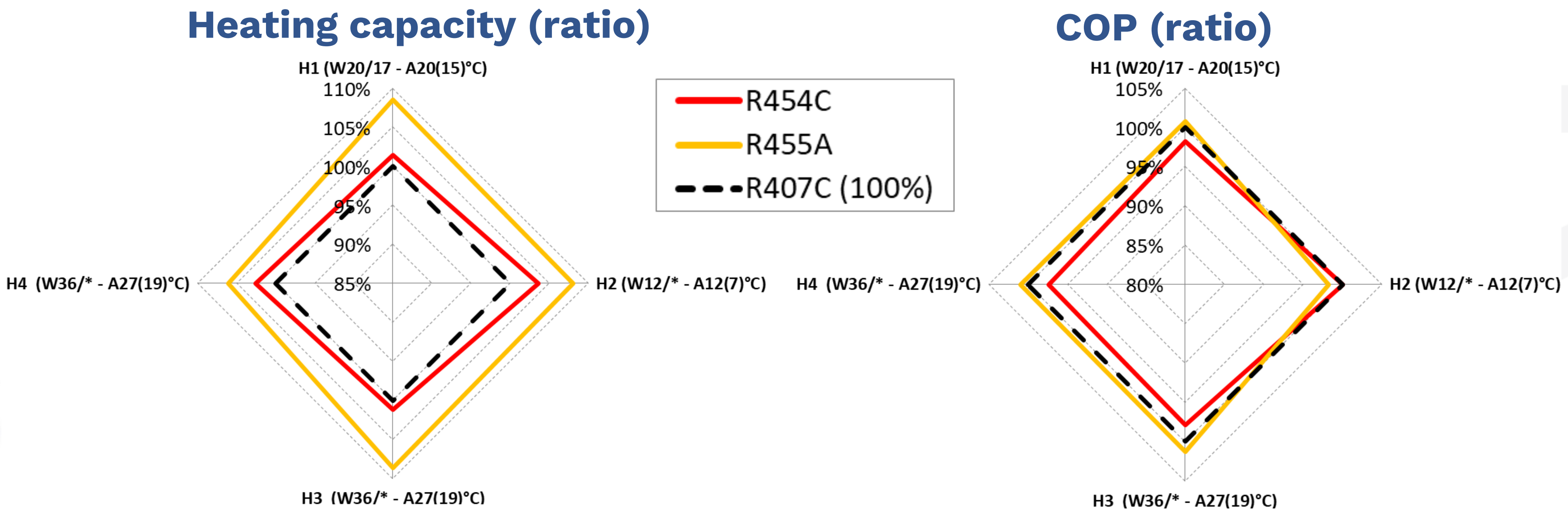
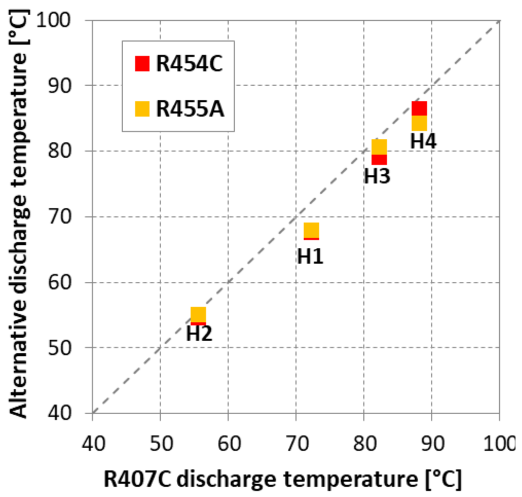
Experimental evaluation of R407C alternative refrigerants in residential heat pumps



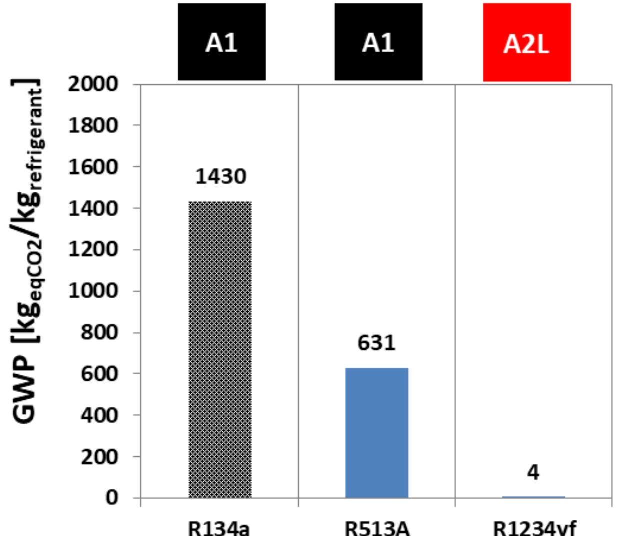


- R454C:
  - Heating capacity: +1.2% to +3.6%
  - COP: -2.6% to 0.0%
- R455A:
  - Heating capacity: +6.1% to +8.6%
  - COP: -1.8% to +1.3%

Experimental evaluation of R134a alternative refrigerants in residential heat pumps

- Refrigerant properties

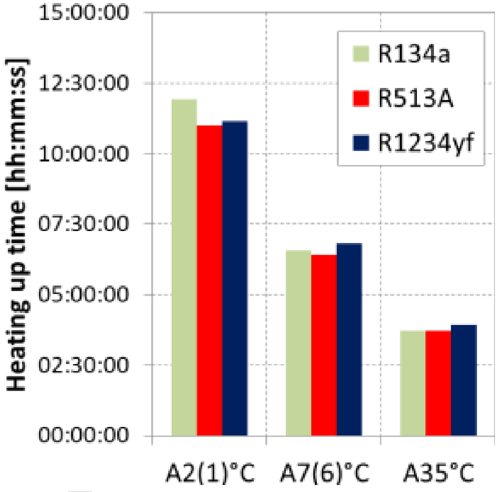
Refrigerant	Composition	Glide (K)
R134a	R134a (100%w)	0
R513A	R1234yf/R134a (56/44%w)	0
R1234yf	R1234yf (100%w)	0



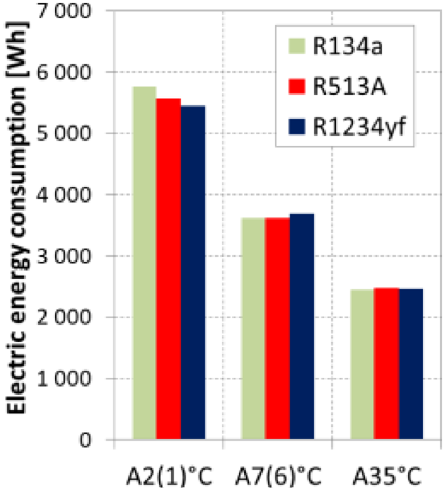
- Test conditions
  - 3 **outdoor air temperatures**: 2(1)°C, 7(6)°C, 35°C (dry(bulb))
  - **Phase 1**: Heating-up of the tank from 10°C to 60°C
  - **Phase 2**: Water tapping of 10 l/min (HP => off)
- 12 tests have been carried out, measurements followed the EN 16147 standard recommendations

Experimental evaluation of R134a alternative refrigerants in residential heat pumps

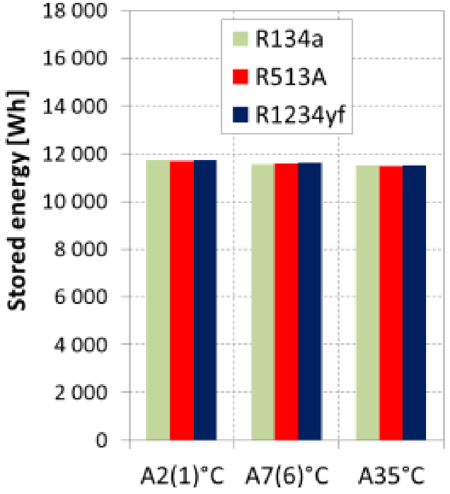
Heating-up time



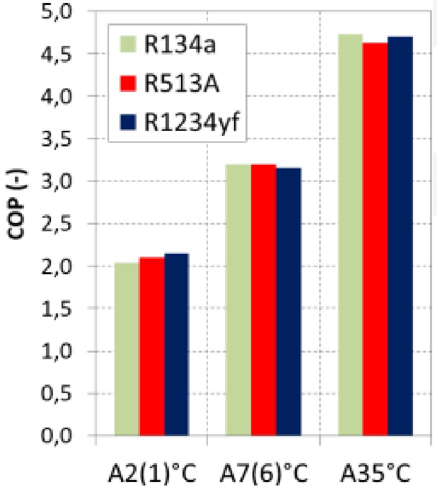
Electric energy consumption

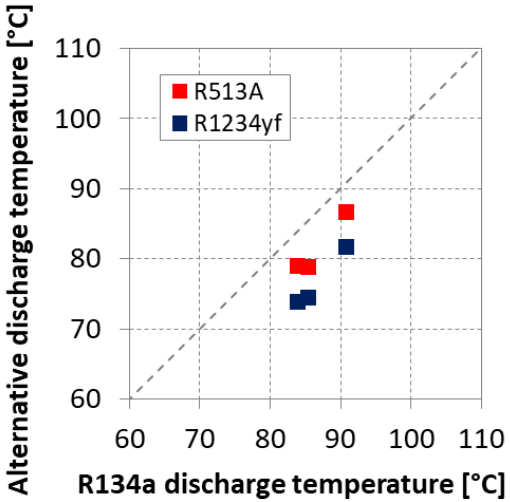


Stored energy



COP

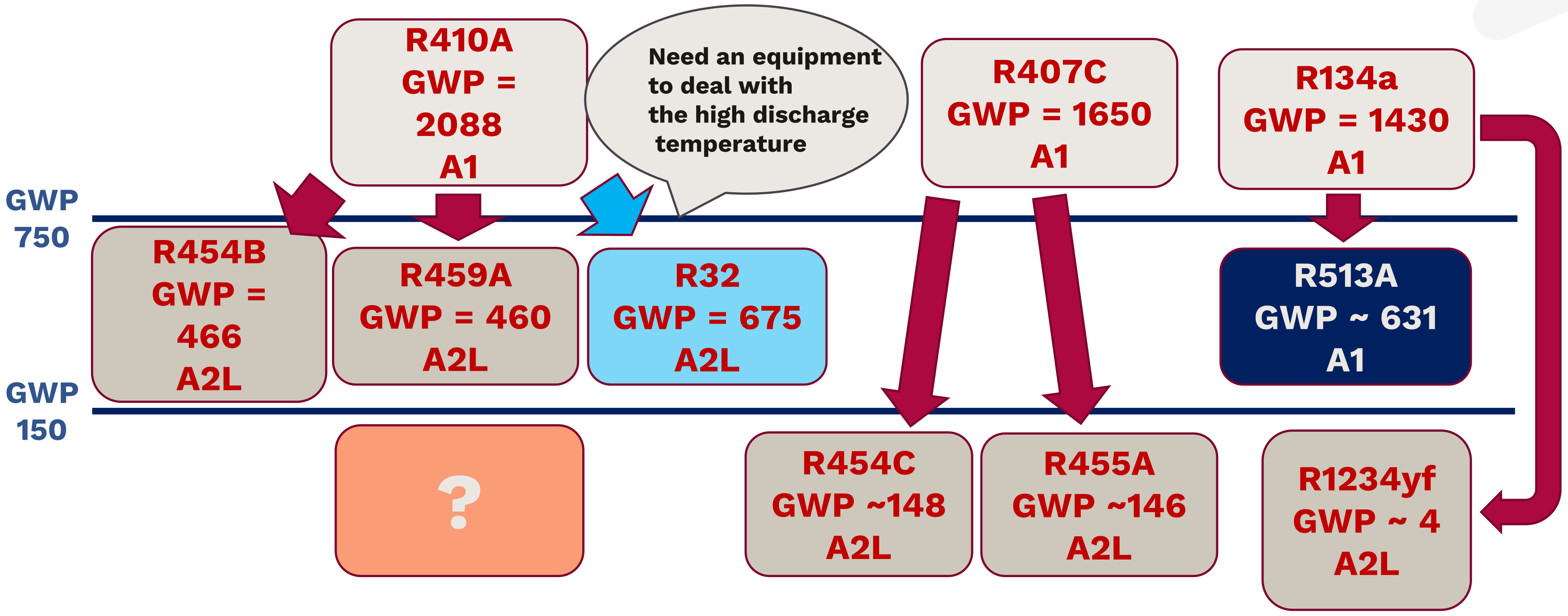




- R513A:
  - Heating-up: -55 min to 0 min
  - COP: -2.0% to +3.3%
- R1234yf:
  - Heating-up: -46 min to +14 min
  - COP: -0.6% to +5.9%

Experimental evaluation of R410A, R407C and R134a alternative refrigerants in residential heat pumps

What are the most promising Low-GWP refrigerants to replace in "drop-in" the HFC commonly used in heat pumps ?



Experimental and numerical study of heat transfer in evaporation and condensation with R410A, R32 and R454B in a finned tube heat exchanger

30 kW experimental setup was built to assess the heat exchanger performance

- 6 tests were carried out in evaporation and 5 tests in condensation
- The software EVAP-COND was used and the results were compared to the experimental results

a)

ROW DATA	
Number of rows	3
Number of tubes per row	32
Number of circuits	8
FIN DATA	
Fin type	Louver
Pitch	2,5 mm
Thickness	0,08 mm
Material	Aluminium
TUBE DATA	
Tube length	813 mm
Inner diameter	7,81 mm
Outer diameter	8,37 mm
Tube pitch	25,5 mm
Depth row pitch	20 mm
Inner surface	Smooth
Material	Copper

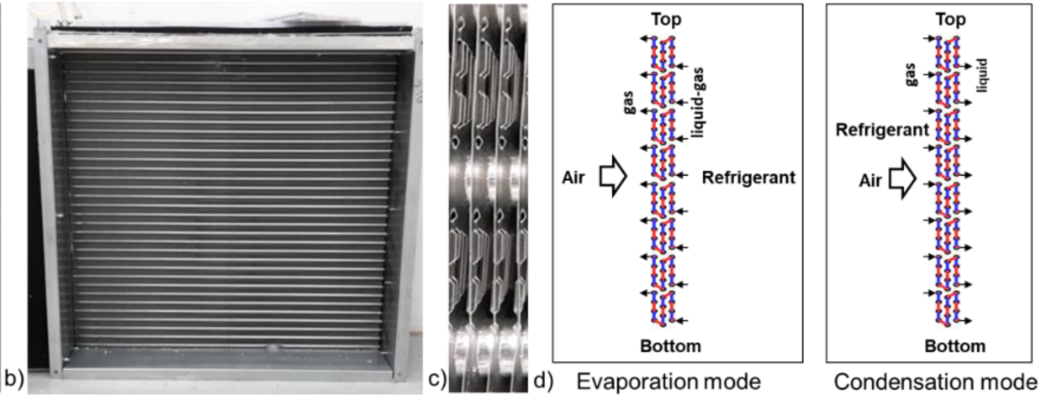


Figure 2: Main characteristics of the tested finned tube heat exchanger: a) Geometry characteristics; b) Overview photography; c) Fins close-up; d) Flow patterns

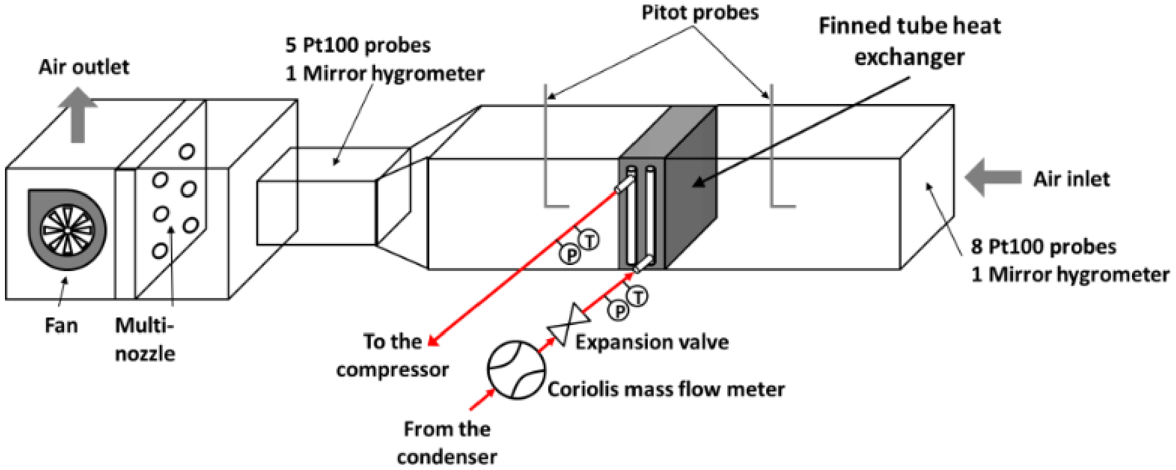


Figure 3: Schematic diagram of the installation and the instrumentation in evaporation mode

Experimental and numerical study of heat transfer in evaporation and condensation with R410A, R32 and R454B in a finned tube heat exchanger

Table 4: Main results measured on the refrigerant side in evaporation mode

Refrigerant	Run	Evaporating temperature (°C)		SH (K)	Cooling capacity (kW)	Pressure drop (kPa)
		Bubble point	Dew point			
R410A	1	2.2	1.4	16.6	12.2	22
	2	1.1	-0.3	17.6	14.3	36
	3	-0.7	-2.8	18.5	17.5	52
	4	3.4	2.6	11.7	11.9	20
	5	0.4	-1.0	15.1	14.1	37
	6	-0.5	-2.7	16.0	17.3	52
R454B	1	1.8	0.4	16.7	14.6	33
	2	0.5	-1.3	17.3	17.0	46
	3	-0.3	-3.3	15.6	20.8	69
	4	0.4	-1.1	15.2	14.3	36
	5	0.2	-1.8	15.2	17.1	47
	6	0.3	-2.7	14.6	20.6	69
R32	1	2.2	1.0	12.7	17.4	29
	2	-3.7	-4.7	20.9	21.1	59
	3	-3.5	-7.1	12.5	25.1	78
	4	2.2	1.0	11.0	17.5	29
	5	0.6	-1.4	12.4	20.6	46
	6	-1.7	-5.1	14.0	25.2	77

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Refrigerant	Pressure drop (kPa)
R410A	18
	18
	23
	21
R454B	16
	19
	20
	22
R32	16
	17
	20
	21

Experimental and numerical study of heat transfer in evaporation and condensation with R410A, R32 and R454B in a finned tube heat exchanger

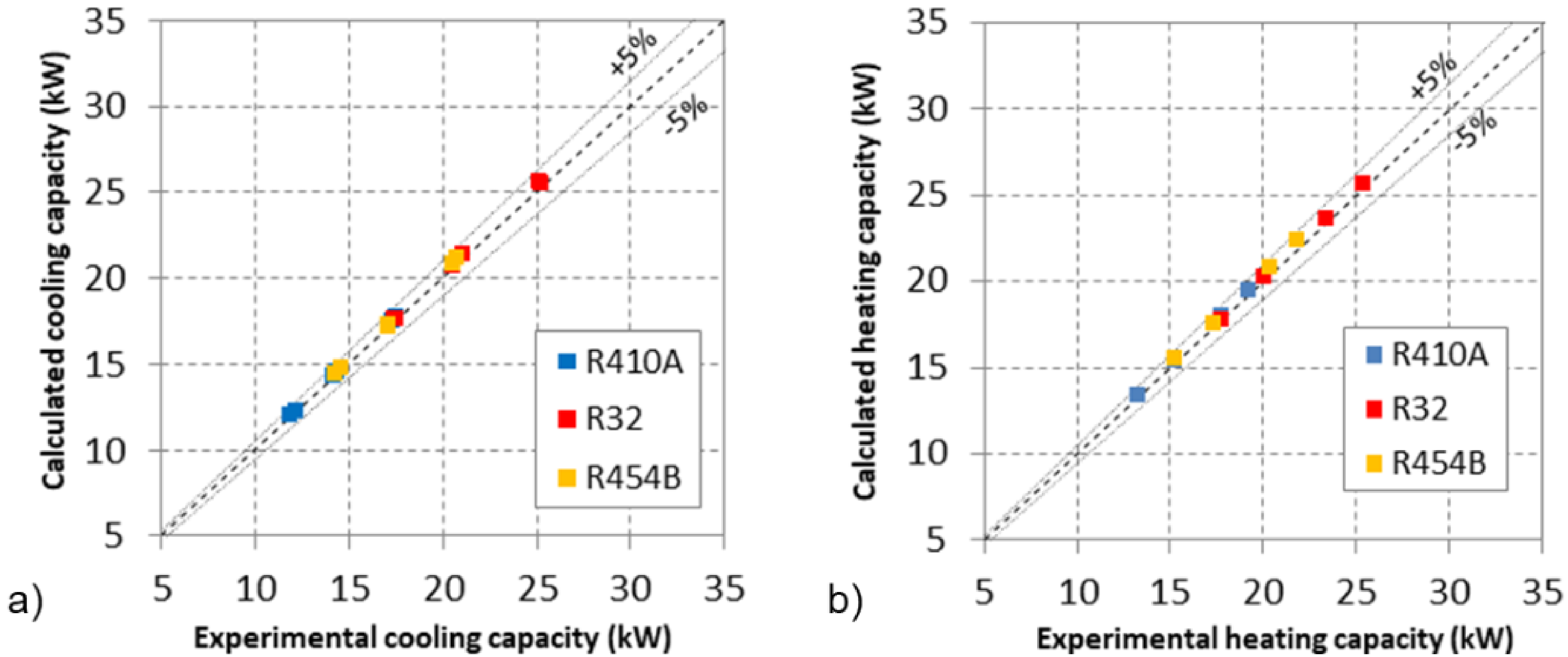


Figure 5: Calculated capacity versus experimental capacity of R410A, R454B and R32, for both modes: a) Evaporation mode; b) Condensation mode

Experimental and numerical study of heat transfer in evaporation and condensation with R410A, R32 and R454B in a finned tube heat exchanger

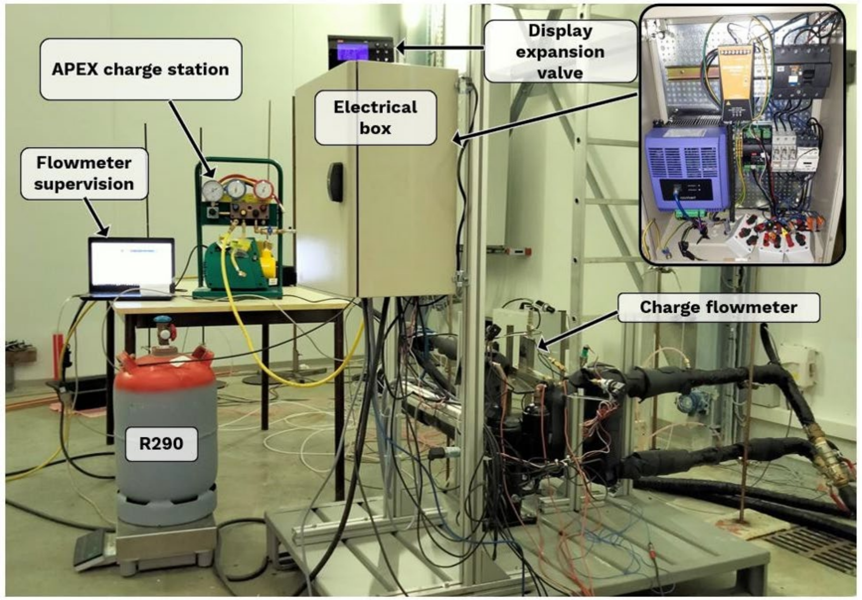
Conclusions

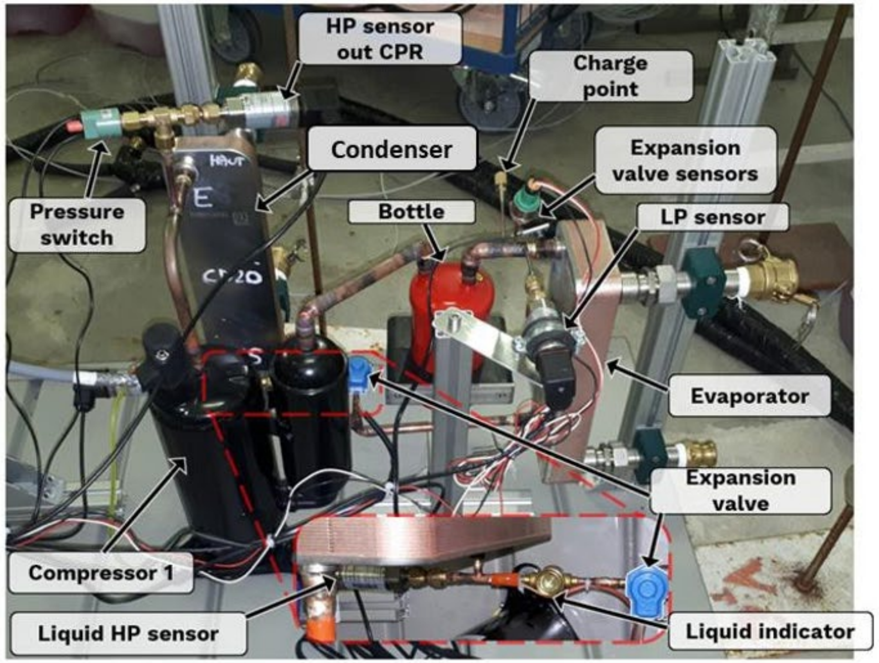
- 30 tests were carried out
- The differences between experimental and calculated capacities are less than 2.5% for all tests
- The temperature and pressure evolutions of the three refrigerants in the simulated circuit are also close to those observed during experimental tests.
  - ➢ EVAP-COND software can be a reliable tool for the simulation of finned tube heat exchangers
- The same design of finned tube heat exchanger can be used for R410A and R454B but a design optimization will be necessary with R32

Design and study of a prototype of heat pump using 150 g of propane

An R290 Brine/Water 5 kW Heat pump prototype was designed and built, it was used to study :

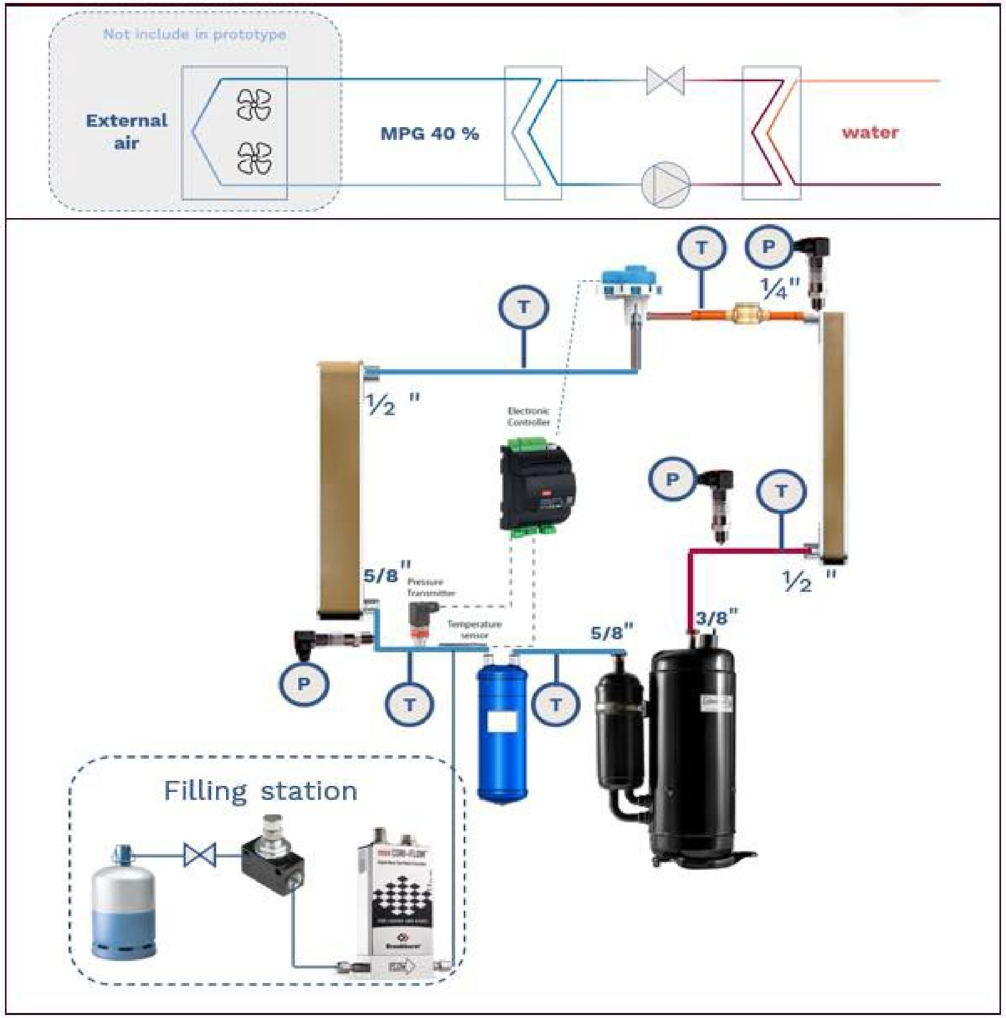
- Influence of superheating and compressor speed during charge optimisation
- Influence of evaporator, condenser size and compressor type on the optimal charge
- Seasonal performances analysis for 190 g and 90 g of R290





Design and study of a prototype of heat pump using 150 g of propane

- Smallest internal volume : water to water HP
- Designed to be used with an outdoor to brine heat exchanger
- Average climate heat pump
- Bivalence temperature of -10 °C
- Design capacity of 5 kW
- Medium temperature application (55 °C)
- Brine : MPG 40, 40 % at the source side



Design and study of a prototype of heat pump using 150 g of propane

- Test campaign & conditions

	Compressor	Evaporator	Condenser	Refrigerant charge optimization: Frq (Hz)	Refrigerant charge optimization: Superheating (K)	Seasonal performances (adapted from EN 14825)
Conf. 1	rotary	30 p.	20 p.	60	5, 10, 15	NO
				25	10	
				90	10	
Conf. 2	rotary	40 p.	20 p.	60	10	NO
Conf. 3	rotary	20 p.	20 p.	60	10	YES
Conf. 4	scroll	20 p.	20 p.	60	10	YES
Conf. 5	scroll	20 p.	30 p.	60	10	NO

	Air-to-brine heat exchanger (outdoor)		Brine heat exchanger (intermediary circuit)		Water heat exchanger (indoor)	
	Dry air temperature	Wet air temperature	Inlet temperature	Outlet temperature	Inlet temperature	Outlet temperature
Nominal conditions	7 °C	6 °C	4 °C	-1 °C	47 °C	55 °C
SCOP A	- 7 °C	- 8 °C	-10 °C	-15 °C	44 °C	52 °C
SCOP B	2 °C	1 °C	-1 °C	-6 °C	34 °C	42 °C
SCOP C	7 °C	6 °C	4 °C	-1 °C	28 °C	36 °C
SCOP D	12 °C	11 °C	9 °C	4 °C	22 °C	30 °C
SCOP E/F	- 10 °C	- 11 °C	-13 °C	-18 °C	47 °C	55 °C

Design and study of a prototype of heat pump using 150 g of propane

Impact of superheating

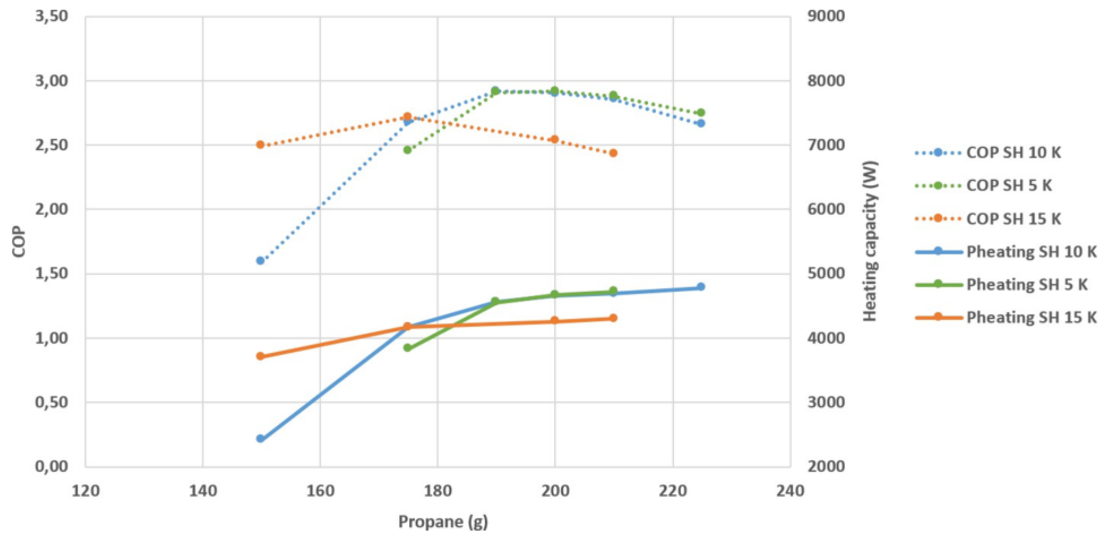


Figure 4-4: Charge optimization – Rotary compressor 60 Hz – Condenser 20 p – Evaporator 30 p EVAP 4 °C / -1 °C – COND 47 °C / 55 °C

- If SH ↗ then optimal charge ↘ but performances ↘
- Reducing below 10 K : no significant enhancement

Impact of compressor speed

The compressor speed does not seem to have any influence on the optimal charge with the low charges encountered (Figure 4-5).

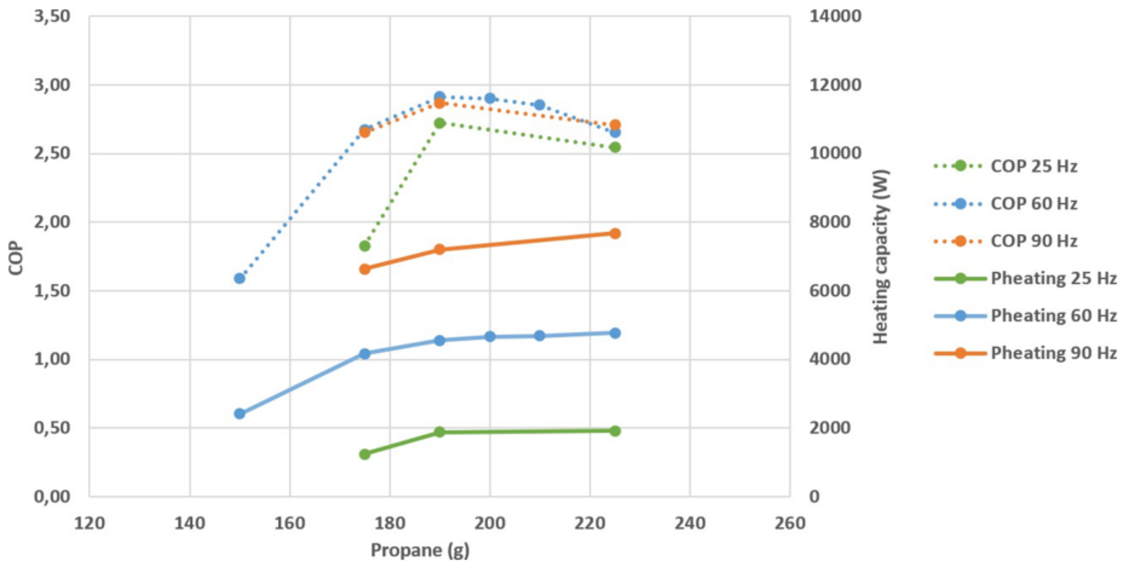


Figure 4-5: Charge optimization – Rotary compressor – Condenser 20 p – Evaporator 30 p – Superheating 10 K EVAP 4 °C / -1 °C – COND 47 °C / 55 °C

Design and study of a prototype of heat pump using 150 g of propane

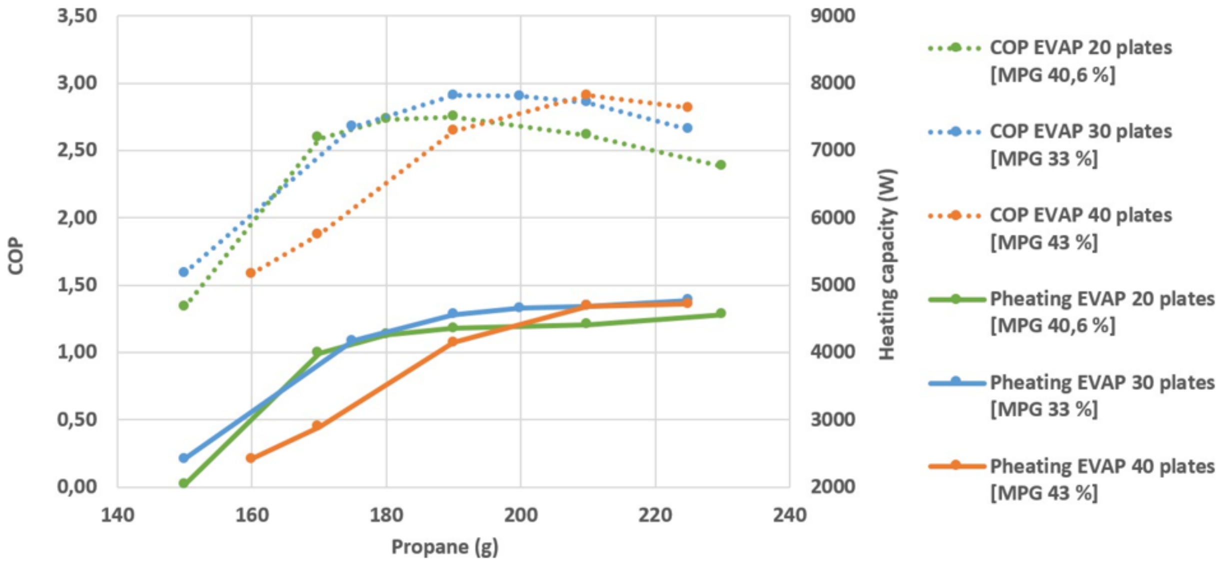


Figure 4-6: Charge optimization – Rotary compressor 60 Hz – Condenser 20 p – Superheating 10 K EVAP 4 °C/ -1 °C (or 3 °C/ 0 °C) – COND 47 °C / 55 °C

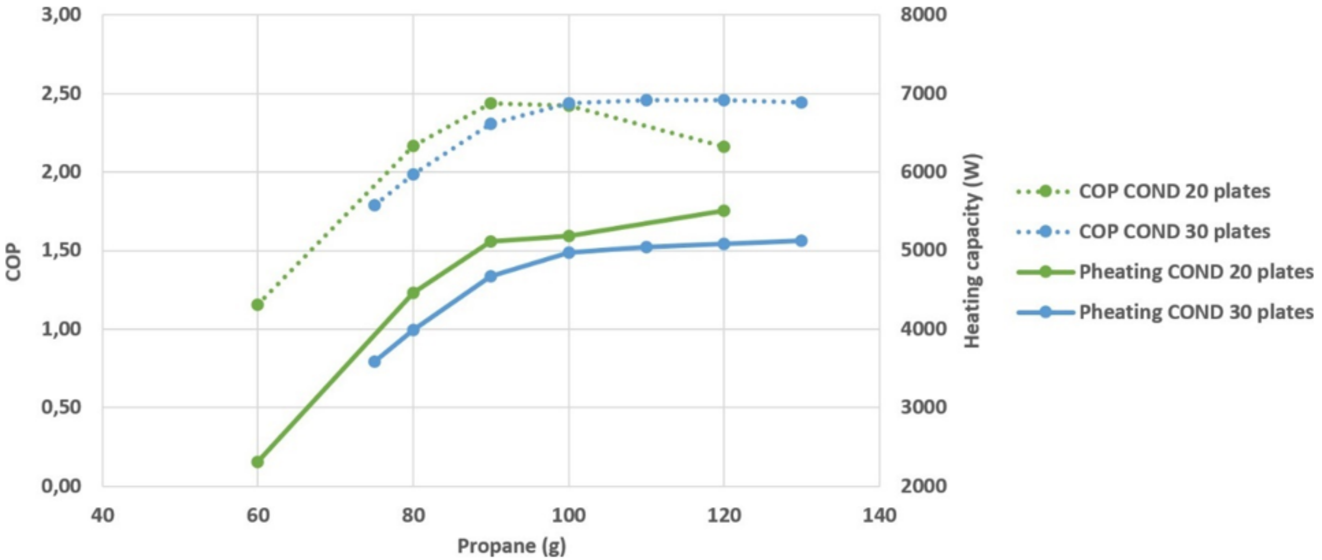


Figure 4-7: Charge optimization – Scroll Compressor 60 Hz – Evaporator 20 p – Superheating 10 K EVAP 4 °C/-1 °C – COND 47 °C/55 °C

- If evaporator size ↘ then optimal charge ↘ but performances ↘

- If condenser size ↗ then optimal charge ↗,
- It can also help to manage the variation in temperature condition without liquid receiver

Design and study of a prototype of heat pump using 150 g of propane

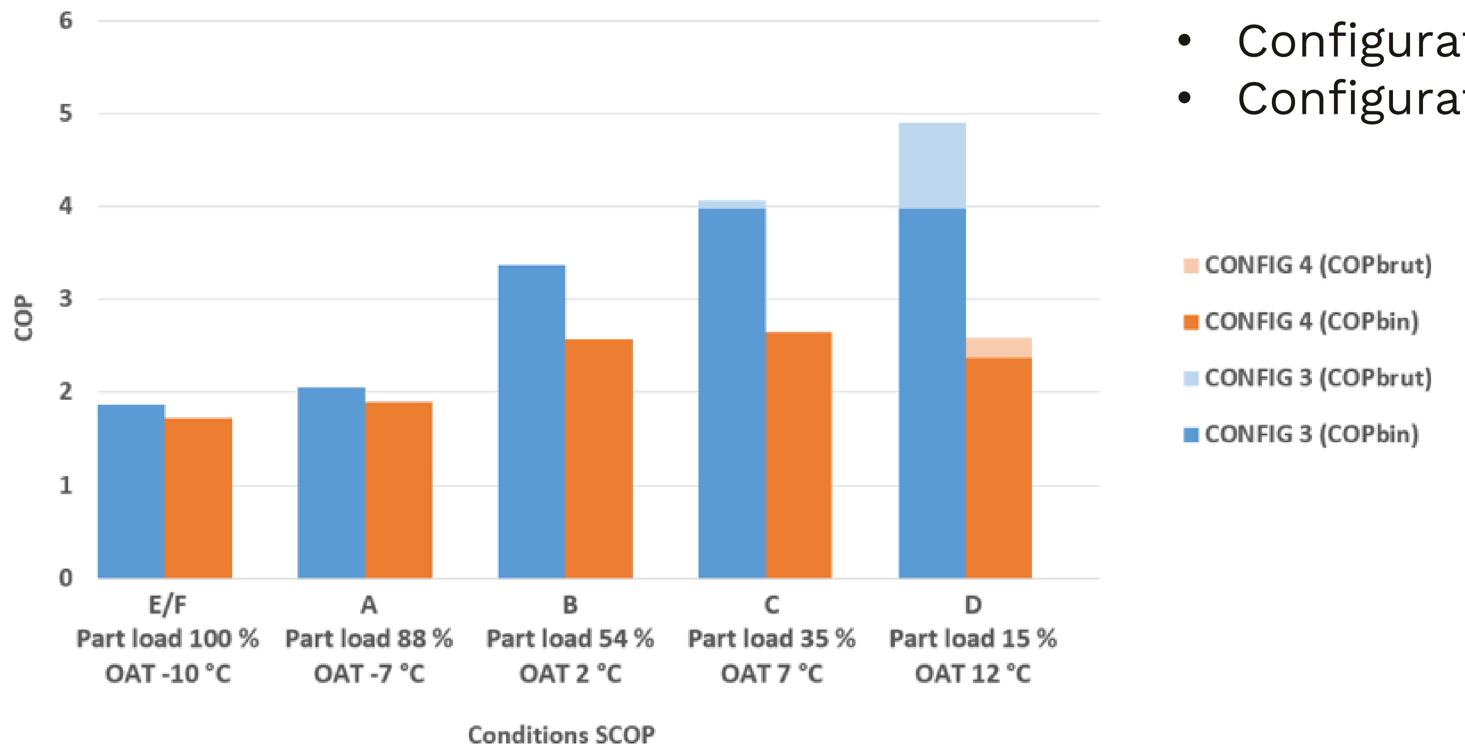


Figure 4-12: Seasonal performance analysis

- Configuration 3 : 190 g of R290
- Configuration 4 : 90 g of R290

Configuration 3 :

- higher condensation temperatures due to overcharging for conditions E/F and A
- higher minimum compressor speed causing ON/OFF cycling for conditions C and D

BUT : better overall performances

Design and study of a prototype of heat pump using 150 g of propane – Conclusions

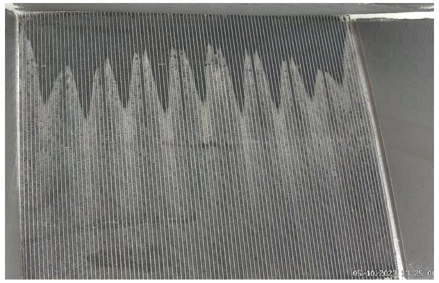
	Overview of the charge optimization results
Conf. 1	Good operation + optimal charge around **200 g**
Conf 2.	Bad operation + optimal charge around **210 g**
Conf 3.	Good operation + optimal charge around **190 g**
Conf 4.	Good operation + optimal charge around **90 g**
Conf 5.	Good operation + optimal charge around **110 g**

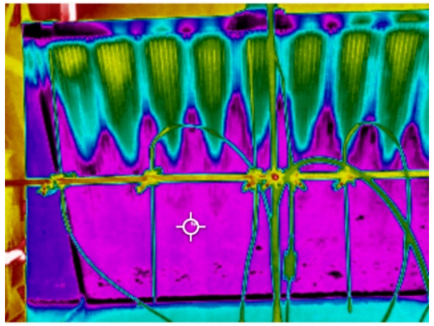
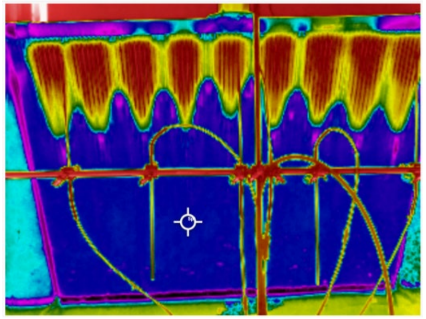
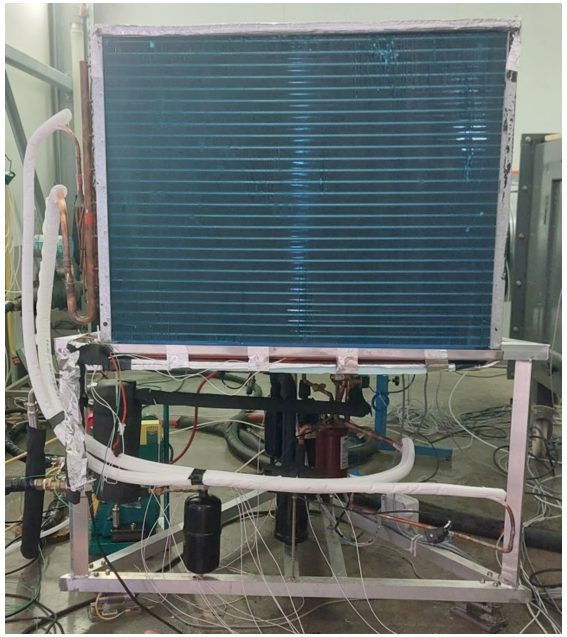
Overall conclusions

- Drop-in replacement solutions were studied and are/can be used
- Simulation tools gives relevant results and can allow to find replacement fluid candidates
- R&D for the components and system design is needed :
    - To improve performances
    - To reduce mass of refrigerant (for flammable fluid)

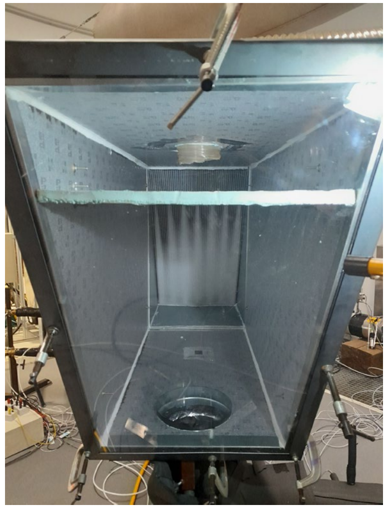
Other CETIAT's work on low GWP refrigerants

- Design and tests of an R290 air/water heat pump (5-10 kW) with R290 to study the frosting behavious of a micro-channel evaporator



- Design and tests of an R290 air/water reversible heat pump indoor packaged unit using a mix of fresh and recirculated air



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