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

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Context

• The European F-gas regulation causes a shift towards refrigerants with no Ozone Depletion Potential (ODP) and Low Global Warming Potential (GWP)

• What is the biggest challenge for the EU?

The HFC Phase-down

- 2021: - 55%
- 2024: - 69%
What are the most promising Low-GWP refrigerants to replace the HFC commonly used in heat pumps?
Objectives

To assess and to compare the heat pump performance when “drop-in” tests are carried out with:

5 Low-GWP alternatives to R410A in a 10 kW air-to-water reversible HP
- R32, HPR2A, R447A, R454B and R459A

3 Low-GWP alternatives to R134a in a split HPWH having a 200L water tank
- R513A, R450A and R1234yf

2 Low-GWP alternatives to R407C in a 3 kW water-to-air reversible HP
- R454C and R455A
Experimental procedure

• **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 of the water in the tank followed by a hot water tapping. Measurements followed the EN 16147 standard recommendations
Tests of Low-GWP alternatives to R410A in a 10 kW air-to-water reversible HP

- Refrigerant properties

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

- 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

*For more details concerning the test conditions see the annex 54 report 2020
Tests of Low-GWP alternatives to R410A in a 10 kW air-to-water reversible HP

- **R447A**: Capacity: -17.7% to -1.0% and EER: -12.2% to +14.1%
- **HPR2A**: Capacity: -14.3% to +2.1% and EER: -11.3% to +12.7%
- **R459A**: Capacity: -9.3% to +2.7% and EER: -7.0% to +10.3%
- **R454B**: Capacity: -11.6% to +5.5% and EER: -4.1% to +12.1%
- **R32**: Capacity: -2.2% to +12.3% and EER: -6.4% to +7.8%

*R32 did not allow performing CL2 limit condition test – \( T_{\text{discharge}} > 115^\circ C \)
Tests of Low-GWP alternatives to R410A in a 10 kW air-to-water reversible HP

Heating capacity (ratio)

- **R447A:** Capacity: -30.8% to -2.4% and COP: -3.8% to +11.2%
- **HPR2A:** Capacity: -33.4% to +1.5% and COP: -5.8% to +8.1%
- **R459A:** Capacity: -8.9% to -0.9% and COP: +0.2% to +8.0%
- **R454B:** Capacity: -7.7% to +6.8% and COP: -3.5% to +12.7%
- **R32:** Capacity: -30.1% to +14.4% and COP: -12.7% to +13.9%

*R32 did not allow performing H3 rating condition & HL3 limit condition test – T_{discharge} > 115°C

- H1: Defrost periods occurred only for R32, HPR2A and R447A
Tests of Low-GWP alternatives to R407C in a 3 kW water-to-air reversible HP

• Refrigerant properties

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Composition</th>
<th>Glide (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R407C</td>
<td>R32/R125/R134a (23/25/52%w)</td>
<td>7.0</td>
</tr>
<tr>
<td>R454C</td>
<td>R1234yf/R32 (78.5/21.5%w)</td>
<td>8.5</td>
</tr>
<tr>
<td>R455A</td>
<td>R1234yf/R32/R744 (75.5/21.5/3%w)</td>
<td>12.8</td>
</tr>
</tbody>
</table>

• 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

*For more details concerning the test conditions see the annex 54 report 2020
Tests of Low-GWP alternatives to R407C in a 3 kW water-to-air reversible HP

- **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%
Tests of Low-GWP alternatives to R407C in a 3 kW water-to-air reversible HP

- **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%

Alternative discharge temperature [°C]

R407C discharge temperature [°C]
Tests of Low-GWP alternatives to R134a in a split HPWP having a 200 L water tank

- Refrigerant properties

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<th>Composition</th>
<th>Glide (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R134a</td>
<td>R134a (100%w)</td>
<td>0</td>
</tr>
<tr>
<td>R513A</td>
<td>R1234yf/R134a (56/44%w)</td>
<td>0</td>
</tr>
<tr>
<td>R450A</td>
<td>R1234ze(E)/R134a (58/42 %w)</td>
<td>0.5</td>
</tr>
<tr>
<td>R1234yf</td>
<td>R1234yf (100%w)</td>
<td>0</td>
</tr>
</tbody>
</table>

- 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)

- **16 tests** have been carried out, measurements followed the EN 16147 standard recommendations

*For more details concerning the test conditions see the annex 54 report 2020
Tests of Low-GWP alternatives to R134a in a split HPWP having a 200 L water tank

- **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%

- **R450A**:  
  - Heating-up: +12 min to +94 min  
  - COP: -5.2% to +1.8%
Conclusions

10 Low-GWP alternatives were evaluated with not less than 130 tests.

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

![Diagram showing the comparison of different refrigerants based on GWP values.]

- **R410A**
  - GWP = 2088 A1
  - Deal with the high discharge temperature

- **R407C**
  - GWP = 1650 A1

- **R134a**
  - GWP = 1430 A1

- **R454B**
  - GWP = 466 A2L

- **R459A**
  - GWP = 460 A2L

- **R32**
  - GWP = 675 A2L

- **R513A**
  - GWP ~ 631 A1

- **450A**
  - GWP ~ 604 A1

- **R454C**
  - GWP ~148 A2L

- **R455A**
  - GWP ~146 A2L

- **R1234yf**
  - GWP ~ 4 A2L

**And after...**

- R744 (A1), R290 (A3), R600a (A3), R1270 (A3), R717 (B2L) ??