Background

- Low GWP refrigerants are coming for residential AC systems.
- Yet, there hasn’t been a consensus on the winning candidate.
- What’s the latest R&D and regulation efforts in bringing low GWP alternatives to residential AC?

AC leads the power consumptions in residential sectors.

Fig. source: [1]
Recent Reviews

- Comprehensive reviews focusing on **residential AC alternatives** are needed.

<table>
<thead>
<tr>
<th>Author</th>
<th>Focus</th>
<th>Highlights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dalkilic and Wongwises (2010)</td>
<td>Theoretical analysis R12, R22 and R134a replacement with mixtures from (R134a, R152a, R32, R290, R1270, R600 and R600a)</td>
<td>R290/R600a (40/60) best alternative for R12; R290/R1270 (20/80) best alternative for R22</td>
</tr>
<tr>
<td>Benhadid-Dib and Benzaoui (2012)</td>
<td>Briefing on refrigerant phasing history up to 2015.</td>
<td>Cover the basics of most refrigerants, and overview of regulation efforts.</td>
</tr>
<tr>
<td>Wang et al. (2012)</td>
<td>Alternative refrigerants for air conditioners, heat pumps, chillers, water heaters, ice makers and refrigeration equipment</td>
<td>AHRI led, industrial-wide cooperative program lasts years, covers dozens candidates</td>
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<tr>
<td>Bolaji and Huan et al. (2013)</td>
<td>Natural refrigerants: R717, HC, R718, R744</td>
<td>Reviewed potential application of major natural refrigerants, including oil compatibility</td>
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<td>McLinden et al. (2014)</td>
<td>62 candidates with critical temperatures within 300 to 400 K</td>
<td>Thermodynamic analysis indicate no ideal fluid</td>
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<tr>
<td>Sarbu (2014)</td>
<td>Candidates for air conditioning, heat pump and commercial refrigeration applications</td>
<td>Describes refrigerants selection based on properties</td>
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<tr>
<td>Mota-Babiloni et al. (2015)</td>
<td>Commercial refrigeration working fluids R404A, R507A and their substitutes: HC, Natural (CO2, NH3), HFC, HFO/HFC mixture</td>
<td>No universal solution: propane for low charge; low-GWP HFC or HFC/HFO mixture as drop-in or retrofit; CO2 for transcritical</td>
</tr>
<tr>
<td>Pham and Monnier (2016)</td>
<td>R410A interim replacements (R32 and other A2L HFO blends) and long term replacements (natural, HC)</td>
<td>Dedicated overview for R410A, different paths towards long term ultra-low-GWP</td>
</tr>
<tr>
<td>Domanski et al. (2017)</td>
<td>R410A and R404A candidates review</td>
<td>Comprehensive database search based on modeling and cycle analysis</td>
</tr>
<tr>
<td>Mota-Babiloni et al. (2017)</td>
<td>Focused on recent low-GWP investigations because of F-gas Regulation for applications of all sizes</td>
<td>Unique perspective looking into policy driven advancements in low-GWP research and commercialization</td>
</tr>
<tr>
<td>Harby (2017)</td>
<td>Hydrocarbon as replacements in refrigeration, AC and automobile AC</td>
<td>Comprehensive review of latest HC research efforts</td>
</tr>
<tr>
<td>Abas et al. (2018)</td>
<td>Major natural and synthetic refrigerants</td>
<td>A parametric quantification based model for natural refrigerant selection and optimization</td>
</tr>
<tr>
<td>Ciconkov (2018)</td>
<td>Historic overview of refrigerants transition up to now and future envisions, focusing on natural refrigerants and HFOs</td>
<td>Proposed direct phase-in of natural refrigerants instead of step by step phase down</td>
</tr>
</tbody>
</table>
R&D Progress – A1

- R744, GWP: 1
  - Pros: environmentally benign and stable
  - Cons: need major system redesigns to improve performance and reliability (high pressure)
  - R&D Gaps: mostly focused on applications other than residential

- R466A (49% R32, 11.5% R125, 39.5% R13I1), GWP: 730
  - Pros: non-flammable, similar properties of R410A
  - Cons: supply and cost associated with iodine in R13I1
  - R&D Gaps: need more performance and reliability studies
R&D Progress – A2L

• R32, GWP 675
• Performance: close to R410A (lower discharge T limits)
• Pros: low GWP, pure fluid, validated success in ductless units
• Cons: flammability, interim replacements
• R&D Gaps: safety study (for unitary systems)

• A2L mixtures, GWP: ~200 to ~700)
• Representatives: R452B (67% R32 + 26% R1234yf + 7% R125); R454B (68.9% R32 and 31.1% 1234yf); R446A (29% R32 + 3% R600 + 68% R1234ze); R447A (68% R32 + 3.5% R125 + 28.5% R1234ze(E))…
• Performance: on par with R410A with variations
• Pros: lower GWP than R32
• Cons: flammability, interim replacements, not validated in the market
• R&D Gaps: need to find convincing advantages over R32 and R466A

R&D Progress – A3

• A3, GWP < 100
• Representatives: R290, R161
• Performance: slightly lower than R410A but can be improved with system redesigns
• Pros: ultra-low GWP (ultimate replacements)
• Cons: flammability, costs with associated product redesigns
• R&D Gaps: ways to handle flammability without sacrificing performance and cost
  • Safety precautions
  • Secondary loop
  • Novel designs (On-going efforts)
Comparison

- R466A, R32, R452B / R454B and R290 remain the top replacements of R410A for now, considering balances among the GWP, performances and property similarities.

Fig. source: [16]
Regulation Progress – USA

- Refrigerants
  - ASHRAE Standard 34: refrigerant classification
  - EPA SNAP: identify acceptable substitutes (environmental aspect)

- System
  - ASHRAE 15: refrigerant system safety (subcommittee 15.2 for residential application)
  - UL → IEC: safety of household appliances

- Building & Local Codes

Code Adoption Process

- ASHRAE Standard 34 Designation and Safety Classification
- EPA SNAP Approval Significant New Alternatives Policy Program
- In compliance with Safety Standards
  - Refrigeration Systems: ASHRAE Standard 15
  - Equipment: relevant UL/EN/ISO Standards
- Adopted by Model Building Codes
  - State and Local Codes

Fig. source: [17]
Novel Unitary System Design

- Propose a novel design, enabling safe flammable refrigerant usage while ensuring performance advantages over R410A
  - The APF can be increased by up to 45% as compared to the existing design based on simulations.
  - Refrigerant charge can be reduced by 54%.

System Schematic

COP Comparison vs. Ambient Temperature (Top); Performance Comparison in Different Climates (Bottom)

<table>
<thead>
<tr>
<th>City</th>
<th>Refrigerant</th>
<th>Single stage cycle without economizer</th>
<th>Single stage cycle with economizer</th>
<th>Two-stage cycle with economizer</th>
<th>Changes (UP%)</th>
<th>Energy savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore</td>
<td>R290</td>
<td>4.84</td>
<td>5.79</td>
<td>6.31</td>
<td>31</td>
<td>23</td>
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<tr>
<td></td>
<td>R32</td>
<td>4.80</td>
<td>5.72</td>
<td>6.31</td>
<td>31</td>
<td>23</td>
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<tr>
<td>Miami</td>
<td>R290</td>
<td>4.09</td>
<td>4.11</td>
<td>4.45</td>
<td>7</td>
<td>8</td>
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<tr>
<td></td>
<td>R32</td>
<td>4.02</td>
<td>4.04</td>
<td>4.42</td>
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<td>8</td>
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<tr>
<td>Houston</td>
<td>R290</td>
<td>4.25</td>
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<td>5.05</td>
<td>20</td>
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<tr>
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<td>R32</td>
<td>4.19</td>
<td>4.59</td>
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<tr>
<td>Chicago</td>
<td>R290</td>
<td>5.14</td>
<td>6.78</td>
<td>7.41</td>
<td>45</td>
<td>31</td>
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<tr>
<td></td>
<td>R32</td>
<td>5.12</td>
<td>6.71</td>
<td>7.42</td>
<td>45</td>
<td>31</td>
</tr>
</tbody>
</table>
2nd Year Work – Component Optimization

• Objective:
  • A comprehensive review of latest R&D progress on component optimizations using low-GWP refrigerants in residential AC
  • Performance, charge and cost comparisons of various novel HX designs aiming for low GWP refrigerants in residential AC

• Expected outcome:
  • An report covering latest R&D progress, clarifying research trends of component optimizations for residential AC refrigerant replacements (On-going, 30+ review completed)
  • A quantitative comparison of various novel HX designs. Guidelines on future high performance, low charge HX designs for residential AC
Conclusions

• We have completed a review of recent R&D and regulation progress on low GWP refrigerants for residential AC.
• R466A is the most promising non-flammable immediate replacements, though more performance and reliability studies are necessary.
• R32 remains in strong position over other A2L mixtures with proven market success, other than unitary systems.
• The ultra-low-GWP replacements are still an open question.
• Existing efforts to promote interim refrigerants mostly focus on product safety re-designs.
Thanks!
References


9. Pham HM, Monnier K. Interim And Long-Term Low-GWP Refrigerant Solutions For Air Conditioning 2016:11.


