DEVELOPMENT OF THERMOTAR R290 DUCTED SPLIT AND ROOFTOP AIR-CONDITIONING UNITS

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Vienna

Daniel Colbourne
d.colbourne@re-phridge.co.uk
### Current products

<table>
<thead>
<tr>
<th></th>
<th>Rooftop</th>
<th>Ducted split</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model number</strong></td>
<td>EPAC-036-</td>
<td>CV036-</td>
</tr>
<tr>
<td><strong>Nominal capacity</strong></td>
<td>10.5 kW</td>
<td>10.5 kW</td>
</tr>
<tr>
<td><strong>R22 charge</strong></td>
<td>1300 kg</td>
<td>1360 kg</td>
</tr>
<tr>
<td></td>
<td>EPAC-048-</td>
<td>CV048-</td>
</tr>
<tr>
<td><strong>Nominal capacity</strong></td>
<td>14 kW</td>
<td>14 kW</td>
</tr>
<tr>
<td><strong>R22 charge</strong></td>
<td>1775 kg</td>
<td>1815 kg</td>
</tr>
<tr>
<td></td>
<td>EPAC-060-</td>
<td>CV060-</td>
</tr>
<tr>
<td><strong>Nominal capacity</strong></td>
<td>17.5 kW</td>
<td>17.5 kW</td>
</tr>
<tr>
<td><strong>R22 charge</strong></td>
<td>2210 kg</td>
<td>2265 kg</td>
</tr>
</tbody>
</table>
General approach for safe products

- Safety standards
- Product info
- Risk assessment
- Training
Development sequence

Analysis of baseline model (with R290) → Charge reduction & performance optimising → Leaks control and safety system → Leak tightness → Addressing sources of ignition → Risk assessment

Field trials → User guidance → Compliance with safety standard(s)
Establish possible failure modes

Steady operation: compressor on; evaporator blower on

Thermostat satisfied → LLSV closes → LP switches
Compressor terminates → Leak from evap → Leak sensor activates → Blower on

Thermostat satisfied → LLSV closes → LP switches
Compressor terminates → Leak from cond → Leak sensor activates → Blower on

Thermostat satisfied → LLSV closes → LP switches
Compressor terminates → Leak from floor → Leak sensor activates → Blower on

Steady operation: compressor on; condenser fan on

Thermostat satisfied → LLSV closes → LP switches
Compressor terminates → Leak from cond → Leak sensor activates → Blower on
## Charge reduction

<table>
<thead>
<tr>
<th></th>
<th>Rooftop</th>
<th>Ducted split</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R22 charge</strong></td>
<td>1300 g</td>
<td>1360 g</td>
</tr>
<tr>
<td></td>
<td>1775 g</td>
<td>1815 g</td>
</tr>
<tr>
<td></td>
<td>2210 g</td>
<td>2265 g</td>
</tr>
<tr>
<td><strong>R290 charge</strong></td>
<td>(590 g)</td>
<td>(610 g)</td>
</tr>
<tr>
<td></td>
<td>(800 g)</td>
<td>(820 g)</td>
</tr>
<tr>
<td></td>
<td><strong>990 g</strong></td>
<td><strong>1010 g</strong></td>
</tr>
</tbody>
</table>
Evaluating leak amount, mass flow and control

<table>
<thead>
<tr>
<th>System operation</th>
<th>Condition</th>
<th>Released mass [g]</th>
<th>Mass flux [g/min/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low side</td>
<td>High side</td>
<td>Low side</td>
</tr>
<tr>
<td>State on(i)</td>
<td>Compr on, LP switch off</td>
<td>540</td>
<td>990</td>
</tr>
<tr>
<td></td>
<td>Compr on, LP switch off, LLSV closes</td>
<td>540</td>
<td>990</td>
</tr>
<tr>
<td></td>
<td>Compr off, LLSV closed</td>
<td>330</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>Following pump-down</td>
<td>100</td>
<td>890</td>
</tr>
<tr>
<td></td>
<td>Compr off</td>
<td>990</td>
<td>990</td>
</tr>
<tr>
<td>State off(i)</td>
<td>Compr oil de-gassing</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

![Graphs showing mass flow and internal pressure over time](image)
Evaluating leak amount, mass flow and control

Tests with 5 mm\(^2\) leak orifice at ducted split AHU evaporator

Leak amount: 340 g
Average mass flow: 125 g/min
Average mass flux: 25 g/min per mm\(^2\)
For “large” indoor unit leak hole: 1.5 g/min

Leak amount: 65 g
Average mass flow: 40 g/min
Average mass flux: 10 g/min per mm\(^2\)
For “large” indoor unit leak hole: 0.5 g/min
Identifying hazardous area/zoning

Characterise
- Releasable mass and leak rate
- Extent of flammable zone

For locations
- Inside AHU
- Inside cond unit
- Around cond unit
- Beyond supply duct
- Beyond return duct

Implement mitigations
- Minimum airflow
- Shut off valves
- Min heights
- Min room/area size
Zoning inside housing
Zoning beyond condenser/ing unit

Test no. 52

Concentration [kg/m³]

- #4: in front cond 0.5m
- #5: in front cond 0.5m
- #9: in front cond 0.5m
- #6: below cond, 0.5m
- #7: below cond, 0.5m
- #10: below cond, 0.5m
Zoning beyond air handling unit

- New model with internal elevation

Graph showing:
- Max mean floor conc [g/m^3]
- Plenum chamber elevation [m]

Data points:
- Split AHU
- Packaged
Zoning beyond duct outlets

- **#5**: 1st RH vent, mid
- **#11**: 1st LH vent, mid
- **#7**: 2nd RH vent, mid
- **#8**: 2nd LH vent, mid

Average concentration [g/m³]

- **#6**: 1st RH vent, -0.45m
- **#10**: 1st LH vent, -0.45m
- **#4**: 2nd RH vent, -0.45m
- **#12**: 2nd LH vent, -0.45m

Closed off return duct
Zoning beyond duct outlets
Zoning beyond duct outlets
Zoning beyond duct outlets

Position along outlet:

-0.2 m  +0.2 m

Local concentration [g/m³]
Additional mitigation

1st LOD

2nd LOD

Leak starts

Airflow initiated

Layer dispersed within 15 seconds

Leak stops

3rd LOD

500g R290, 90 g/min, 1260 m³/h
Eliminating potential sources of ignition
Risk assessment

Uncertainty → increasing knowledge → Certainty

Higher risk → Risk analysis → Risk quantification → Mitigation features → Implementation

Lower risk

Leak of refrigerant

Primary consequence (jet fire, flash fire, explosion)

Presence of ignition source

Secondary consequence (thermal damage, secondary fire, overpressure damage, injury)

Refrigerant mixture with air

Active ignition source

Ignition

(same space and time)

Increasing knowledge
## Risk assessment

<table>
<thead>
<tr>
<th>Ignition location</th>
<th>Ignition frequency ( \text{y}^{-1} )</th>
<th>TI ( \text{s(kW/m}^2\text{)}^{4/3} )</th>
<th>OP ( \text{kPa} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within/by condensing unit</strong></td>
<td>1.1E-15</td>
<td>30</td>
<td>1.1 (DS), 1.2 (RT)</td>
</tr>
<tr>
<td><strong>Cond install area</strong></td>
<td>5.8E-06</td>
<td>60</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Inside/by AHU</strong></td>
<td>3.4E-16</td>
<td>30</td>
<td>14.0 (DS), 17.8 (RT)</td>
</tr>
<tr>
<td><strong>Occupied space (return duct)</strong></td>
<td>1.5E-07</td>
<td>200</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Occupied space (supply duct)</strong></td>
<td>1.5E-07</td>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Inside ducting</strong></td>
<td>4.9E-11</td>
<td>20</td>
<td>4.5</td>
</tr>
</tbody>
</table>

### Preliminary results

- **Barbecue**
- **Cooker (oven, grill, hob)**
- **Microwave**
- **Patio heaters**
- **Heating appliances**
- **Central (+water) heating**
- **Lights**
- **Dishwasher**
- **Fridge/freezer**
- **Tumble dryer**
- **TV**
- **Washing machine**
- **AC&HP (USA)**

The results are categorized as:
- **Un acceptable**
- **Broadly tolerable**
- **Broadly acceptable**
- **Negligible**
Compliance with safety standards

NTC 6228: Sistemas de refrigeración y bombas de calor. Requerimientos de seguridad y medioambientales.

EN 378: Refrigerating systems and heat pumps. Safety and environmental requirements
Summarising remarks

- Followed conventional sequence of steps for addressing flammability hazard in safe design
- Extensive testing and evaluation
  - Releasable refrigerant quantity, concentration development from leak, effectiveness of mitigation measures
- Appraised with flammability QRA, applied standards
- Products considered to be “safe”
Thank you for your attention!

Primer fabricante de equipos con refrigerante 290 en América.