ANNEX 54 WORKSHOP
HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS

2024-05-15
Yunho Hwang

www.heatpumpingtechnologies.org
• Introduction: Annex 54 Heat Pumps with Low GWP Refrigerants, Yunho Hwang
• 150 Project – Update on final results about heat pump development, market data, and safety topics, Thore Oltersdorf
• Austria’s activities in IEA HPT Annex 54, Christian Köfinger
• Ecologic Assessment of Heat Pump Systems: Evaluation of the Refrigerant’s Impact, Christoph Höges
• Shape Optimized Air-to-Refrigerant Heat Exchangers for Low-GWP Refrigerants: Dehumidification & Acoustics Considerations, Vikrant Aute
ANNEX 54: OBJECTIVES

• Promoting the application of low-GWP refrigerants to accelerate the phase-down of high-GWP HFCs
• Developing design guidelines for optimized components and systems for low-GWP refrigerants
• 2022 member countries are Austria, France, Germany, Italy, Japan, Korea, Sweden, and US. (In 2023, six member countries.)
BACKGROUND: HIGH DEMANDS FOR HEAT PUMPS (US)

• The Inflation Reduction Act (IRA) of 2022 (US) targets reducing carbon emissions by roughly 40 percent by 2030.
• Nearly $9 billion was allocated for the home efficiency rebate programs. This could support up to 1.6 million households nationwide in upgrading homes and apartments to lower energy bills, including by installing up to 500,000 heat pumps and conducting deep building retrofits through insulation and electrical wiring.
• In sum, these programs will make these cost-saving upgrades more accessible for low- and moderate-income families toward deploying at least 12 million heat pumps by 2030.
Figure 17: Heat Pump sales in 21 European markets per type of technology

Source: EHPA (2023)
The US DOE challenges the industry to develop a cold climate commercial rooftop heat pump capable of operation to -15°F (-26°C) using a refrigerant with a GWP ≤ 150, with a stretch goal of 5.
BACKGROUND: HEAT PUMPS WITH LOW GWPS (EU)

• On 5 April 2022, the European Commission presented a proposal for a regulation on fluorinated GHGs (F-gases) that would repeal the current F-gas Regulation.
• The proposal aims to reduce F-gas emissions further than the existing quota system, gradually reducing the supply of hydrofluorocarbons (HFC) to the EU market to 2.4 % of 2015 levels by 2048.
• It would also ban F-gases in specific applications, and update the rules on implementing best practices, leak-checking, record-keeping, training, waste treatment, and penalties.
ANNEX 54: TASKS

• Task 1: Review of state-of-the-art technologies (Year 1: 2019-2021) (Latest low-GWP refrigerants; current components and system designs; Review of current standards and policies; thermophysical property and heat transfer characteristics; safety and flammability of refrigerants and safe use of flammable refrigerants)

• Task 2: Case studies and design guidelines for optimization of components and systems (Year 2-4: 2020-2022)

• Task 3: Review of design optimization and advancement impacts on LCCP reduction (Year 3-5: 2021-2023)

• Task 4: Outlook for 2030 (Year 5: 2022-2023)

• Task 5: Report and information dissemination (Year 5: 2023)
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS

• **AU**: identified low GWP refrigerants and provided an overview of the Austrian heat pump market and examples of low GWP refrigerants in applications.

• **DE**: summarized the heat pump market survey; integrated fluid screening and evaluated SCOP of HCs, HFOs, and mixtures.

• **IT**: reported a solar-assisted heat pump water heaters using CO$_2$; compared R410A alternatives for residential HPs: R32, R454B and R454C.

• **SE**: provided the Swedish HP market for residential and commercial units, shared case studies and design guidelines for a geothermal R290 HP for multifamily buildings (EBOX), a CO$_2$ HP system for commercial buildings, and an R290 HP and chiller for the process cooling and heating.

• **US**: reported the next-generation HX design framework and provided 5.3 kW condenser optimization for R32 and R454B.
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS

- Focused on: Task 2) case studies and design guidelines for optimizing components and systems, Task 3) Review of design optimization and advancement impacts on LCCP reduction, Task 4) 2030 outlook.

<table>
<thead>
<tr>
<th>Task</th>
<th>AU</th>
<th>FR</th>
<th>DE</th>
<th>IT</th>
<th>JA</th>
<th>KO</th>
<th>SW</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lit. Review</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Case study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Design opt.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. 2030 outlook</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>5. Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>v</td>
<td>v</td>
</tr>
</tbody>
</table>
Zach et al. (2022, Austria) identified low GWP refrigerants. They provided an overview of the Austrian HP market until 2030 and examples of low GWP refrigerants in applications other than domestic HPs.

The Austrian HP market will increase from about 31,000 systems in the heating sector in 2021 to about 80,000 to 100,000 systems in 2030.

Verdnik et al. (2022, Austria) provided design guidelines for the optimization of components and systems of R-290 heat pumps.

**SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS (AU)**

- Refrigerant leakage and end-of-life refrigerant losses as well as indirect CO$_2$e emissions from (electrical) energy consumption during the systems’ lifespan and TEWI

<table>
<thead>
<tr>
<th>System</th>
<th>Refrigerant leakage [kg CO$_2$e]</th>
<th>End-of-life refrigerant losses [kg CO$_2$e]</th>
<th>Indirect CO$_2$e emissions (energy consumption) [kg CO$_2$e]</th>
<th>TEWI [kg CO$_2$e]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A baseline system</td>
<td>15,828 (27.0%)</td>
<td>22,423 (38.3%)</td>
<td>20,282 (34.7%)</td>
<td>58,533</td>
</tr>
<tr>
<td>Charge optimized R290 system</td>
<td>3 (0.0%)</td>
<td>5 (0.0%)</td>
<td>16,572 (100.0%)</td>
<td>16,581</td>
</tr>
</tbody>
</table>
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS (DE)

- Oltersdorf (2022, Fraunhofer ISE) reported the most recent findings on the German HP market development, technical trends, and characteristics of the market-available HPs.
- Hoges (2022, RWTH Aachen Univ.) investigated HCs and HC mixtures in residential HPs and concluded the HC mixture was only beneficial in the internal heat exchanger cycle.
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS

- Vering (2022, RWTH Aachen Univ.) provided the overview of suitable heat pumps depending on the refrigerant (from the bottom), SCOP evaluation.
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS

- Azzolin (2022, U Padova) reported a 5 kW capacity solar-assisted heat pump water heater working with CO₂.
Codella (2022, Chemours) compared R410A alternatives: R32, R454B and R454C.
Palm (2022, KTH, Sweden) provided the details of the Swedish HP market from smaller residential units to larger residential and commercial units.

He shared case studies and design guidelines for optimizing components and systems, including a geothermal R290 HP for multifamily buildings, a CO$_2$ system for heating & cooling the commercial building, and an R290 HP and chiller for the process cooling & heating.

![Water to water heat pump]

**SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS (SE)**

- \[\text{Compressor speed} = 2835 \text{ rpm}\]
- \[T_1=40^\circ\text{C}\]
- \[T_{\text{evap, water, in}} \approx 7.5^\circ\text{C}\]
SUCCESS STORIES/ACHIEVEMENTS/KEY FINDINGS (US)

- Wang (AHRI, 2022) reported leakage and ignition testing from PTAC and mini-split systems with R-290 and R-452B in a whole room scale.
- Nawaz (ORNL, 2022) experimentally investigated the performance of the R-290 in a heat pump water heating application and concluded that R-290 is a feasible alternative for residential HPWHs.
Aute (2022. U. of Maryland) reported the next-generation HX design framework and provided 5.3 kW condenser optimization for R32 and R454B.
ANNEX ACTIVITIES SINCE LAST EXCO REPORT

• Hosted workshops:
  – Hosted workshop on October 10, 2022, during the Chillventa
  – During the workshops, experts from ANNEX54 participating member countries presented low-GWP refrigerants utilizing technologies for residential heat pumps (air-to-air, water-to-water, and solar source heat pumps), and heat pump water heaters. Details of workshop presentation materials are available from the ANNEX54 website.

• Prepared and submitted 2022 country reports for Tasks 2, 3 & 4.

• Online survey conducted for 2022 and 2023 activities
### ACHIEVED ACTIVITIES: WORKSHOPS

- **Annex 54 hosted the workshop during the Chillventa**

<table>
<thead>
<tr>
<th>Workshop name</th>
<th>Date</th>
<th>Presenter</th>
<th>Title of presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Pumps for Low-GWP Refrigerants During The Chillventa</td>
<td>10/10/22</td>
<td>Yunho Hwang</td>
<td>Introduction: Heat Pumps with Low GWP Refrigerants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thore Oltersdorf (ISE Fraunhofer, Germany)</td>
<td>Recent findings and outcome of the market development and some projects for heat pumps in Germany</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Christian Vering (RWTH Aachen, Germany)</td>
<td>From the Bottom to the Top: Sustainable Heat Pumps in Residential Buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fabrizio Codella (Chemours, Italy)</td>
<td>Low GWP HFO Refrigerants for residential Heat Pumps to enable a safe and sustainable European building renovation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wissam Rached (Honeywell, International)</td>
<td>Honeywell's refrigerant Solstice® N71 (R-471A)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vikrant Aute (U. of Maryland)</td>
<td>Potential Benefits of Shape Optimized Air-to-Refrigerant Heat Exchangers for New Lower-GWP Refrigerants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marco Azzolin (U. of Padova)</td>
<td>Use of R-744 in a solar assisted heat pump for residential heating applications</td>
</tr>
</tbody>
</table>
PLANNED ACTIVITIES

• Organizing workshops to present Annex 54 activities during the HPC in May 2023 and the ICR in August 2023.

• Expert meetings are planned during the workshops
SUMMARY

• In 2022, we achieved considerable progress in three areas: 1) Task 2: case studies and design guidelines for optimizing heat pump systems using low GWP refrigerants. 2) Task 3: a review of design optimization and advancement impacts on life cycle climate performance (LCCP) reduction. 3) Task 4: 2030 Market projection.

• The work can be a valuable reference for researchers, engineers, and policymakers across the HVAC industry.
ANNEX 54 WEBSITE

All presentation materials, meeting agenda, minute and attendee list are available from ANNEX54 website.

https://heatpumpingtechnologies.org/annex54/

Heat pump systems with low GWP refrigerants

This annex aims at promoting low GWP refrigerant application to accelerate phase down of high-GWP HFCs by developing design guidelines of optimized heat pump components and system for low-GWP refrigerants through the review of available low-GWP refrigerants, their properties and applicable standards, safety and flammability of refrigerants, and safe use of flammable refrigerants:

- Optimization of heat pump components and system for low-GWP refrigerants;
- Analysis of the LCCP impact by the current design and optimized design with low-GWP refrigerants;
- Market opportunity study for heat pumps with low-GWP refrigerants and low-GWP refrigerants availability for 2030. Target applications are air-conditioning and heat pump systems for residential and commercial buildings.
• Mei, Z., Y. Hwang*, J. Kim, Thermodynamic analysis and LCCP evaluation of kangaroo heat pump cycle for electric vehicles, Energy, Accepted on July 29, 2022.
• Lin, L., L. Gao, M. Kedzierski, Y. Hwang, A general model for flow boiling heat transfer in microfine tubes based on a new neural network architecture, Energy and AI, Accepted on March 10, 2022.
Recent findings and outcome of the market development and some projects for heat pumps in Germany OLTERSDORF T., Chillventa Congress 2022, Heat Pumping Technologies, 10.10.2022.

LC150 - Propan-Kältekreise mit deutlich reduzierten Füllmengen, SCHNABEL L., Kongress Energieforschung für Industrie und Gewerbe, Berlin, Germany, 17./18.05.2022.


Entwicklung und Rolle von Propanwärme pumpen, SCHNABEL L., Berliner Energietage, Fachbereich 3.11 Wärme pumpen für Bestandsgebäude, Berlin, 03.05.2022.


CONTACT

• Operating Agent: Dr. Yunho Hwang, Center for Environmental Energy Engineering, University of Maryland, USA.

• yhhwang@umd.edu