IEA Heat Pump Annex 43:

*Fuel driven sorption heat pumps*

*For residential and small scale commercial heating applications*

Prof. Bob Critoph

University of Warwick

IEA National Teams Meeting for the UK Heat Pump Industry, DECC, 23rd September 2015
Contents:

• Background to Annex 43 - Fuel (Gas) Driven Sorption Heat Pumps

• State of the art and new developments
Reasons for gas driven heat pumps

- Buildings with radiators which might need higher temperatures
- Replacement of existing boilers, minimal change of existing system
- Grid balancing – inability of electricity grid to cope with an all-electric future
Scope
- Fuel driven sorption heat pumps for residential and light commercial
- Focus on heating mode, reversible allowed

Goals
- Identification of market opportunities and barriers
- Identification of the potential applications and importance in future energy systems
- Identification of market supporting measures
- Easy and sustainable market entrance and development
Participants

Current participants

- Germany (OA)
- Austria
- France
- Italy
- UK
- USA
- new 12/2014: Korea

Institutions

- ISE, Stiebel-Eltron, Bosch, SorTech
- Politecnico di Milano, CNR-ITAE
- University of Warwick, Delta EE
- GDF, GRDF, Boost heat
- AIT, University of Graz
- ORNL
- Korea Institute of Energy Research

Interest expressed from Poland and Sweden
Participating as observers
(Flowair/Gazuno and Climatewell)
Timeline:
Duration of the Annex: October 2013 – September 2017

Meetings:
1. Kick-off: October 2013 at Fraunhofer ISE in Freiburg, Germany – over 20 participants from 5 countries (7 Companies)
2. June 2014 at GDF in Paris, France – 21 Participants from 7 countries
3. November 2014 at Fraunhofer ISE, Freiburg, Germany 24 participants from 8 countries (Observers from Netherlands and Russia)
4. 9/10 June 2015 Vienna 18 Participants from 7 countries
5. ‘Friends of Sorption’ conference September 2015 – 115 delegates
Annex 43: Structure

Task A: Generic systems and system classification
Leader: ISE

Task B: Technology transfer
Leader: Uni Warwick

Task C: Field test and performance evaluation
Leader: Politecnico di Milano

Task D: Market potential study and technology roadmap
Leader: CNR-ITAE

Task E: Policy measures and recommendations, information
Leader: ISE
Work structure

A: Generic systems and system classification (ISE)

- WP1: Collection of technology and market relevant data
- WP2: Development
- WP3: System classification
- WP4: Development of generic systems and system boundaries
## Work structure

**A: Generic systems and system classification (ISE)**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>WP A1: Collection of technology and market relevant data (CR)</td>
<td>ISE, Polimi, Gdfs, DEE, AIT, TUG, ORNL</td>
<td>[progress bar]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP A2: Development of an enhanced system representation</td>
<td>ISE, Polimi, Vaillant, Stiebel, Bosch,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP A3: System classification</td>
<td>ISE, Polimi, Vaillant, Stiebel, Bosch,</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>WP A4: Development of generic systems and system boundaries</td>
<td>ISE, Polimi, Vaillant, Stiebel, Bosch,</td>
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<td></td>
</tr>
</tbody>
</table>
### WP1: Collection of technology and market relevant data

<table>
<thead>
<tr>
<th>Country</th>
<th>Responsible</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>TU Graz, AIT</td>
<td>2/3 completed</td>
</tr>
<tr>
<td>Germany</td>
<td>ISE</td>
<td>2/3 completed</td>
</tr>
<tr>
<td>Italy</td>
<td>Polimi</td>
<td>Chapters 1,2,4,6 completed</td>
</tr>
<tr>
<td>France</td>
<td>GdF - Suez</td>
<td>?</td>
</tr>
<tr>
<td>UK</td>
<td>Delta EE</td>
<td>Submitted</td>
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<tr>
<td>Benelux</td>
<td>GdF – Suez</td>
<td>?</td>
</tr>
<tr>
<td>Poland</td>
<td>Gazuno: As much as possible</td>
<td>End of June</td>
</tr>
<tr>
<td>Spain</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>Ed Vineyard / Kyle Glusenkamp (ORNL)</td>
<td>Submission end of July</td>
</tr>
<tr>
<td>Korea, Japan</td>
<td>? (will decide at the next meeting)</td>
<td>Submission end of July</td>
</tr>
<tr>
<td>EU Legislation</td>
<td>ISE, Vaillant, Bosch, Delta EE?</td>
<td></td>
</tr>
</tbody>
</table>
Work structure

B: Technology transfer (Warwick)

- WP 1: link research and industry (workshops) (Warwick)
- WP 2: New materials (ISE)
- WP 3: New components/systems (CNR-ITAE)

Under WP1 i-STUTE, EHPA and Annex 43 hope to organise a gas fired heat pump workshop for industry in 2015/16.
Work structure

C: Field test and performance evaluation (Polimi)

- WP 1: Standardized Monitoring & Measurement Procedure
- WP 2: Test procedures on system level
- WP 3: Laboratory Tests
  (Warwick/Kiwa, reported 2014)
Work structure

D: Market potential study and technology roadmap (CNR-ITAE)

- Simulation study from Polimi evaluates different technologies in different climate zones, different building types and building standards
- Combine with market data and actual building stock for technology roadmap
D: Market potential study and technology roadmap (CNR-ITAE)

Simulation model:

Specifications

- Selection of ‘market ready’ RE technologies for heating
  - Condensing boiler (tank for DHW)
  - GAHP Air/Water (monovalent and bivalent)
  - EHP Air/Water (monovalent and bivalent)
D: Market potential study and technology roadmap (CNR-ITAE)

Simulation model:

- Selection of target building and climate
  - 150 m²
  - 2 building standards (renovated, incl. emission system underfloor heating / low temperature radiators)
  - 3 main locations (different climatic zones in Europe)
    - Athens
    - Strasbourg
    - Helsinki
  - more locations can be added later, although ...

2 (buildings) x 3 (locations) x 5 (plants) = 30 sims.
2 (buildings) x 3 (locations) x 9* (plants) = 54 sims.

* Including solar, w/s GAHP and EHP, hybrid
D: Market potential study and technology roadmap (CNR-ITAE)

Simulation model:

**Model capabilities**

<table>
<thead>
<tr>
<th></th>
<th>GAHP</th>
<th>EHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full load performances</td>
<td>GUE, AEF (experimental)</td>
<td>COP (manufacturer’s data)</td>
</tr>
<tr>
<td>Partial load</td>
<td>PL correction factor (experimental)</td>
<td>Cycle losses model (see Afjei, Type 201)</td>
</tr>
<tr>
<td>Defrosting</td>
<td>already accounted for in GUE measurement (EN12309-6)</td>
<td>COP correction (see Afjei, Type 201)</td>
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<tr>
<td>System control</td>
<td>Bivalent mode Set point T</td>
<td>Bivalent mode Set point T</td>
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**D: Market potential study and technology roadmap (CNR-ITAE) Workplan**

<table>
<thead>
<tr>
<th>Workpackages</th>
<th>Part.</th>
<th>2015</th>
<th>2016</th>
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<tr>
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<td>1 2 3 4</td>
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<tr>
<td>Specifications</td>
<td>Polimi ISE ?</td>
<td></td>
<td></td>
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<tr>
<td>TRNSYS models and tools (DSS)</td>
<td>ISE Polimi ?</td>
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<td></td>
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<tr>
<td>Energy simulations</td>
<td>Polimi ISE ?</td>
<td></td>
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<tr>
<td>KPI – UE average</td>
<td>Polimi ISE</td>
<td></td>
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<tr>
<td>EU HP Summit 2015</td>
<td>Polimi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KPIs - Country specific</td>
<td>Polimi ISE ?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Work structure

E: Policy measures and recommendations, information

- Dissemination
- Workshops for planners, installers and decision makers
- Develop recommendations for policies e.g. building codes and funding schemes
Contents:

- Background to Annex 43 - Fuel (Gas) Driven Sorption Heat Pumps
- State of the art and new developments
Technologies:

- Engines
- Sorption
  - Absorption
  - Adsorption
Absorption

Adsorption

Performance similar in principle
Refrigerants similar:

• Water
• Ammonia
• Alcohols
Existing products:

**Vaillant**

**Technical data of zeoTHERM VAS 106/4**

- Rated heat output range Heating 1,5-10 kW
- Rated heat output range d.h.w. 4,2-12,5 kW
- Adjustable flow temperature 20-75 °C
- Recommended max. flow temperature HC < 40 °C
- El. power consumption max. 100 W
- Appliance width 772 mm
- Appliance height incl. flue outlet 1.700 mm
- Appliance depth 718 mm
- Transport weight (without casing) 160 kg
- Operating weight 175 kg
- Integrated controller
  - zeolite module > no moving parts / no maintenance
Existing products:

Vaillant system:
- Water refrigerant, zeolite adsorbent
- Heat pump, solar collector, water storage tank
- Only intended for use with underfloor heating systems with Maximum output temperature of 40°C
- Claimed reduction of annual energy use of 18% compared with a condensing boiler.
- Initial system sale price was around €16,000.
- On market for three years
Existing products:

**Viessmann Gas-Fired Zeolite Compact Heating Appliance**

**Features at a glance**

- **Hybrid Heating Appliance:**
  - Heating Power Modulation: 1.6 to 10 kW (1 to 7)
  - Booster capacity for DHW: 15 kW
- **SGUE Heating (VDI 4650-2):** 135 % (Hi 35/28 °C)
- **SGUE Heating (VDI 4650-2):** 125 % (Hi 55/45 °C)
- **Ambient Heat Source:** 2013 GHS
  - From 2014 also Solar
- **Working pair completely environment friendly**
- **Installation, maintenance and service analog to condensing boiler compact units**
- **Gas-Fired Adsorption Heat Pump in the dimensions of Viessmann compact heating appliances**
- **Dimensions:** BxHxT: 600x595x1875 mm
- **Weight:** <170 kg (separable in two parts)

Launched 2014
Near market products:
Stiebel Eltron are developing a zeolite – water machine with help from Sortech and similar principal to Vaillant and Viessmann products.
Near market products:
Stiebel Eltron are developing a zeolite – water machine with help from Sortech and similar principal to Vaillant and Viessmann products.

New coated heat exchangers

- Aluminum heat exchanger using a fiber technology from Fraunhofer IFAM coated with zeolite
- Very high surface area in comparison to a lamellar heat exchanger
- Thus, more zeolite coated on the surface, with excellent thermal contact
- Considerable improvement of energy density proved by experiment
Existing products:

**Robur**

- Ammonia water absorption
- Air, water and ground source options
- DHW at 65°C (gross COP 1.24)
- 38 kW to radiators (supply temperature 50°C) COP of 1.52 (gross), 1.38 (net).
- Saving of about 40% in gas consumption compared to a condensing boiler.
- Single module 854(w) x 1256(d) x 1281(h).
- 18kW unit, is under development.
- The product is ‘badged’ by BDR Thermea and Bosch
- 40kW unit is c. £12,000.
Existing products:

‘Half sized’
Robur (17kW)
• Developed under Heat4U EU project
• 5 field tested
• Similar performance to large machine
• Now available on the market in Italy
• Manufacture in Germany 2016
• Cost??
Heat4U: Gas Absorption Heat Pump Solution for existing residential buildings

C. Bongs, E. Johann, P. Robinet, K. Lowe, J. Doroszkiewicz, M. Brune, A. Albers, G. Corallo, L. Tischer

**Heat Flow Rate - 14/02/14 (BritishGas)**

- **GUE\textsubscript{NCV} = 1.25**

- $P_{\text{in}}$ in kW

- $t$ in h

**Heat Flow Rate - 14/04/22 (BritishGas)**

- **GUE\textsubscript{NCV} = 1.25**

- $P_{\text{in}}$ in kW

- $t$ in h

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**Temperatures - 14/02/14 (BritishGas)**

- GHP
- SH
- DHW

- $T$ in °C

- $t$ in h

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**Temperatures - 14/04/22 (BritishGas)**

- GHP
- SH
- DHW

- $T$ in °C

- $t$ in h

---

**Modulation at higher part load**

- Start-up peaks for heating and DHW
- Steady-state performance at part load
- Heating supply temperature $\sim 55^\circ$C

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**Cyclic behavior at lower part load**

- Similar start-up peaks
- Supply temperature $\sim 38^\circ$C
- Performance indicator GUE\textsubscript{NCV} similar to modulation operation
Near market products: Bosch Thermotechnology

- System:
  - Gas driven absorption heat pump (NH$_3$/H$_2$O)
  - Max. 18 kW heat output
  - Solution recirculation in GEN and ABS
  - Solution cooled DEP
  - Second feed (rich solution) for REC

- Measurements:
  - COP=1.3 - 1.9 depending on operating conditions
  - Knowledge of HEX behavior
  - Input for modelling

- Modelling:
  - Good agreement between measured and predicted COP (error $\leq$ 5 % in most cases)
Near market products:
Bosch Thermotechnology

- **Logatherm GWPS192-18 i**
- **Supraeco 9000i G**

**Buderus**

- Planned market introduction: 2016
- Heat source: geothermal/air
- Max. flow temperature: 70 °C
- Heat output (B0/W65): 18 kW
- Modulation range: 1:4
- Max. annual efficiency: 170%
- Heating system: mono-/bivalent

Source: Bosch Thermotechnology GmbH
Near market products:

**Viessmann Gas-Fired Absorption Heat Pump**

**Features at a glance**

- Wall mounted hybrid appliance:
  - Gas-fired absorption heat pump and a condensing boiler
- Seasonal heating GUE > 1.4 (55/45 °C)
- Seasonal heating GUE > 1.3 (65/50 °C)
- High modulation range (1.6 to 14 kW)
- Dimensions: BxHxT: 600x595x900 mm
- Weight: <90 kg
- Low noise
- Installation & Maintenance comparable to condensing boilers
Near market products:

Projects in USA:

ThermoLift Inc – Vuilleumier Cycle
  • Funded by DOE, etc
  Data from 2015 Building Technologies Office Peer Review,

ORNL – Absorption and Adsorption for water heating
  • DOE laboratory
  Slides from US Activities in Sorption Heat Pumps, Ed Vineyard, Kyle Gluesenkamp
  4th Expert Meeting, Vienna, June 9 2015,
The Natural Gas Heat Pump and Air Conditioner

2015 Building Technologies Office Peer Review

Heat from Burner
(15 kW)

Combined Heat Delivered
(25 kW)

FREE Heat from Ambient
(10 kW)

ThermoLift, Inc.
Paul Schwartz, CEO
pschwartz@tm-lift.com
DE-FOA-0000823
Thermally Driven Cycles (Vuilleumier & Stirling)

- Mechanical Compressor
- Thermal Compressor
- Stirling Process
- Vuilleumier Process
ThermoLift 4 Phase Process (Patent Pending)

Novel displacer system incorporating electronic controls:

- Enables independent and discontinuous motion.
- Thermodynamic advantages based on ability to control gas flow differently.
- This advancement was unachievable with mechanically-linked displacers in previous Vuilleumier devices.
- Enables customization and optimization at partial load conditions and for cooling applications.
ThermoLift first developed a benchtop proof-of-concept for the novel independent mechatronic design. A complete heat pump prototype was designed, simulated, and built by late 2014.

ThermoLift began testing and generated numerous iterations and simulations develop improved components.
Comparison to State-of-the-Art

![Graph showing efficiency (COP) vs. outside temperature (°F) for different systems: ThermoLift – Next Generation, ThermoLift – Demonstrator, ThermoLift Simulation, DOE Target Heat Pump Performance, Leading Gas-fired Heat Pump, Electric Heat Pump, Condensing Boiler.]
Manufacturing Failure ➔ Timeline Setback

Damage following de-compression

Un-zipped cold regenerator

Complete braze failure
Projects in USA:

ThermoLift Inc – Vuilleumier Cycle
• Funded by DOE, etc
  Data from 2015 Building Technologies Office Peer Review,

ORNL – Absorption and Adsorption for water heating
• DOE laboratory
  Slides from US Activities in Sorption Heat Pumps, Ed Vineyard, Kyle Gluesenkamp
  4th Expert Meeting, Vienna, June 9 2015,
Gas Sorption Systems Under Development

• Water heating
  – Commercial NH$_3$/H$_2$O (A.O. Smith/ORNL/SMTI)
  – Residential NH$_3$/H$_2$O (SMTI)
  – Residential H$_2$O/IL, membrane-based (GE/ORNL/UF)
  – Residential NH$_3$/carbon (ORNL)

• Space heating
  – Residential NH$_3$/H$_2$O (SMTI)
The Payback Period Challenge in the US (water heating)

- National average retail energy prices:
  - Electricity ~0.10 $US/kWh
  - Natural gas ~14 $US/MMBtu (0.53 $/m³, 0.05 $/kWh_{thermal})

- Average new *residential* storage water heater

| Electric HPWH | 2.35 | $1,050 | $530 | 3.8 year |

9,000,000 units shipped/year, most at minimum efficiency level.

Target is 3 year pb with excess capital cost of $300 over non-condensing gas.

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Data source: US Department of Energy Technical Support Documentation, 2009
Stone Mountain Technologies, Inc.

SMTI: “Thermal compressors for sustainable heating”

Development Status:

- Residential Water Heater –
  - 6 Field Test Units Installed

- 80,000 Btu/hr GAHP –
  - Three Alpha Prototypes Under Test

- 140,000 Btu/hr GAHP –
  - Under Development
# SMTI Residential HPWH

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cycle COP</td>
<td>1.6</td>
</tr>
<tr>
<td>EF</td>
<td>1.3</td>
</tr>
<tr>
<td>First Hour Rating</td>
<td>60 – 80 gallons</td>
</tr>
<tr>
<td>Heating output</td>
<td>~10 kBtu/hr (~3 kW)</td>
</tr>
<tr>
<td>Emissions</td>
<td>10 ng NO\textsubscript{x}/J (projected based on GTI laboratory testing)</td>
</tr>
<tr>
<td>Installation</td>
<td>Indoors or semi-conditioned (garage)</td>
</tr>
<tr>
<td>Venting</td>
<td>½” – 1” PVC</td>
</tr>
<tr>
<td>Gas piping</td>
<td>½”</td>
</tr>
<tr>
<td>Estimated consumer cost</td>
<td>&lt;$1,800</td>
</tr>
<tr>
<td>Ammonia charge</td>
<td>&lt;25% allowed by ASHRAE Standard 15</td>
</tr>
</tbody>
</table>

*Patent Pending © SMTI 2015*
Residential Space Heating

Heating COP rated at ambient - 47°F (8.3°C)
hydronic - 100/120°F (37.8/48.9°C):

$\text{COP}_{\text{cycle}} = 1.65$
$\text{COP}_{\text{gas}} = 1.45$ (including combustion losses)
$\text{COP}_{\text{hp}} = 1.40$ (including parasitic)

- 140 kBtu/hr (40 kW)
- Gas-Fired, Air to Water Heat Pump
- Condensing
- 4:1 Modulation
- SCAQMD NOx Compliant
- Outdoor Installation
- GWP = 0
- 550 Watts at 100% fire

Forced air configuration
R&D projects:
Sorption Energy

Change in product concept over time of project:

Where has the rest of the hardware gone?
R&D projects:
Sorption Energy

Fits into standard wall-mounted casing

Box-for-box exchange for old boiler

Key competitive advantage
- other gas-fired heat pumps too large for wall mount

Retrofit market >90% of annual sales
R&D projects:
Cooll BV (Netherlands)

Carbon – Ammonia thermal wave adsorption, similar to Sorption Energy. No details available.
R&D projects:

boostHEAT (France)

“As compared to the latest generation of condensation boilers, the consumption should be reduced by 45 to 60% in low temperature mode (35°C) and by 25 to 40% in medium and high temperature mode (55 to 65°C)”

Thermally driven compressor using CO$_2$ refrigerant.
Will probably need two stages of compression.
Summary of heat pump products/developments:

<table>
<thead>
<tr>
<th>NH₃ - H₂O absorption</th>
<th>Silica gel / zeolite - H₂O adsorption</th>
<th>NH₃ – carbon / salts adsorption</th>
<th>Reciprocating machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More mature technology</td>
<td>• Water ref. does not extract heat</td>
<td>• Similar to NH₃ - H₂O but</td>
<td>• Potentially good / superior</td>
</tr>
<tr>
<td>• Good COP</td>
<td>below 5°C</td>
<td>slightly lower COP</td>
<td>COPs</td>
</tr>
<tr>
<td>• Physically large</td>
<td>• Needs gas backup</td>
<td>• Potential to be compact and</td>
<td>• Complex</td>
</tr>
<tr>
<td>• Toxic refrigerant (outdoor unit only?)</td>
<td>• LT output</td>
<td>low-cost</td>
<td>• Costly?</td>
</tr>
<tr>
<td>Robur</td>
<td>Vaillant</td>
<td>Sorption Energy Cooll</td>
<td>ThermoLift boostHEAT</td>
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<tr>
<td>Bosch</td>
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<td>SMTI</td>
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</table>
Thank you for your attention

• Any questions?
• Time for coffee??