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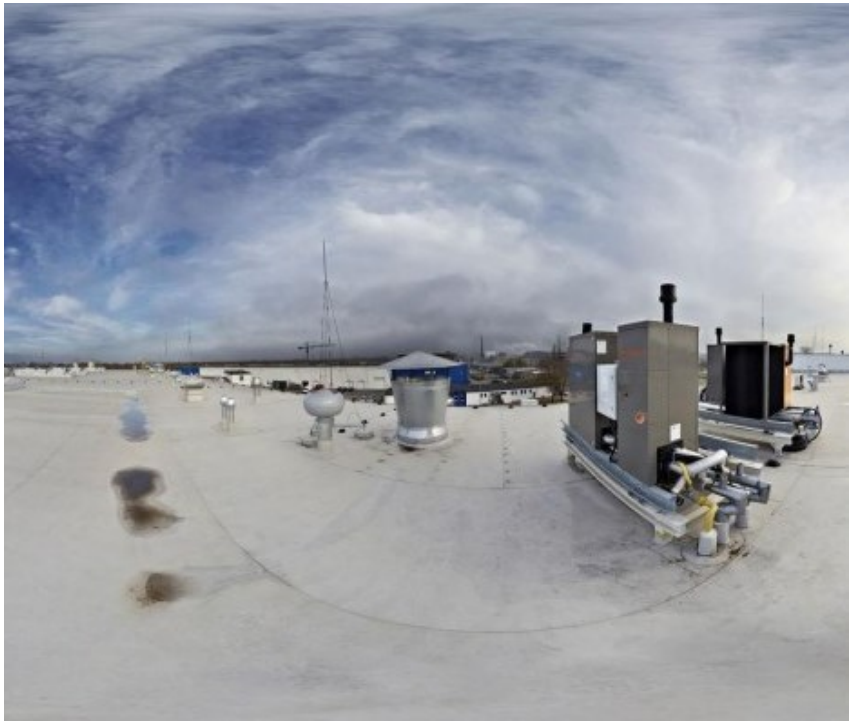
Gas heat pump development and performance evaluation - IEA HPT Annex 43



Source: Flowair

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Nuremberg, 20 October 2015

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Outline

- Fuel driven sorption heat pumps: goals for the development
- Examples of appliance development from Annex 43
- Status in standardisation of performance evaluation
- Conclusions and prospects

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Reasons for broader implementation of FSHPs

Most of the forecasts for markets with traditionally high percentage of gas heating systems predict an important role of FSHPs in the future heating and DHW market in the mid-term.

Reason for such predictions:

- Technology readily available with a good potential for improvements
- Quick introduction of RE in a conservative market
- Well suited for retrofit – large impact in a short time period
- Diversification of final energy sources / relief for the electricity grid

However:

- Only a few products with limited capacity range on the market
- Technology awareness level low, both among professionals and users
- Competitive products emerging (e.g. hybrid heat pump)

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Development goals

- Decrease of life-cycle costs
  - Introduction of novel production processes
  - Usage of less cost-intensive components
  - Control optimisation and hybridisation
  - Increase of the seasonal PER
- Size reduction
  - Enhancement of mass and heat transport through novel designs
  - Whole system optimisation
  - Optimisation of ambient heat exchangers
- Diversification of heat energy sources
  - Development of new working pairs

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Market acceptance (additional goals for the development)

- FSHPs are marketed mostly as „efficient gas boilers“ or „the next generation in gas heating“
- Being well suited for the delivery of heat in higher temperature areas and needing smaller heat sources, the predominant application is retrofit and/or boiler replacement:
  - Raise awareness through good practice -> monitoring!
  - Easy boiler replacement -> installation, connections, operation
  - Heat source -> high density areas, e.g. noise!

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Robur K18: Technology and application

http://www.heat4u.eu

- Gas absorption heat pump (GAHP) based on water/ammonia solution with nominal capacity of 18 kW_{th}
- The goal was to develop an appliance for detached or semi-detached existing family houses
- The focus was on the improvement of thermodynamic and seasonal efficiencies by increasing the modulation range, compact design, silent operation and integrated controls
- The prototypes were measured in two laboratories and monitored at locations in Germany, France, UK and Poland

Source: ROBUR

Source: ROBUR

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Robur K18: Performance

- Laboratory testing according to EN 12309 at Polimi and Fraunhofer ISE
- Aim:
  - Verification of the appliance performance
  - Evaluation of the EN 12309 test methods
- All methods covered by the standard used:
  - Steady state characterisation
  - Transient tests with defrost cycles
  - Cycling tests for operating conditions below the modulation range

T_{air}	$T_{w\ out}$	Q_h	PLR	GUE target	GUE achieved
7.0	50.0	16.89	100%	1.50	**1.53**
7.0	35.0	19.15	100%	1.65	**1.74**

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Sorption Energy: Concept

- UK is the largest European market for domestic gas appliances with ~11 million installed units, ~1.5 million units sold annually, ~85% retrofit
- Concept: box-for-box exchange for conventional gas boiler, air source
- Goal: 30-40 % reduction in gas consumption

Source: University of Warwick

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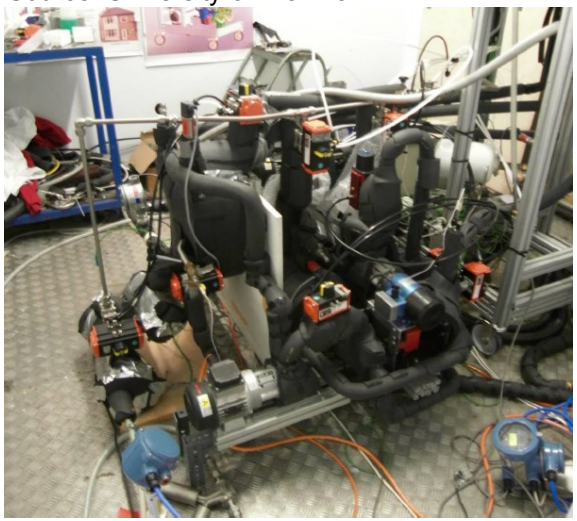
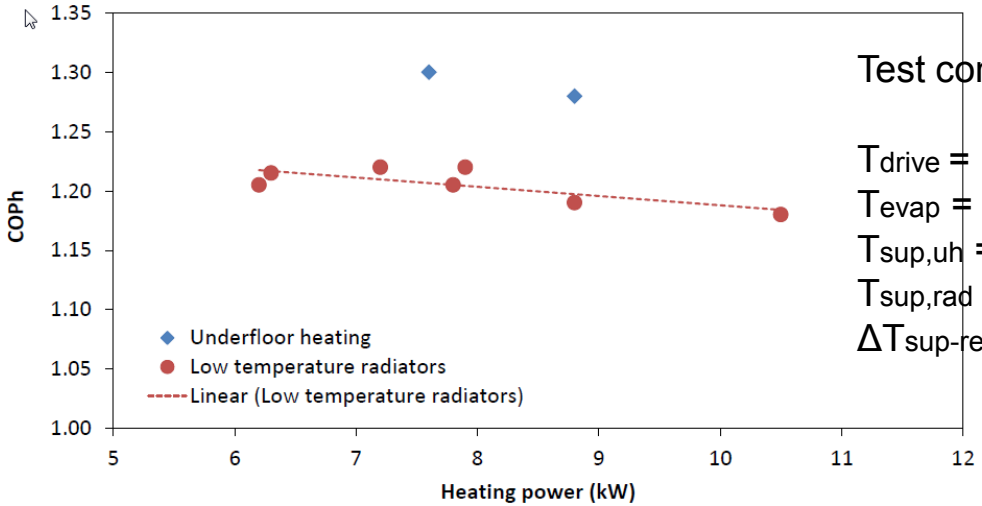
Sorption Energy: Technology and status

- Two-bed adsorption heat pump with heat recovery between beds
- Working pair: active carbon / ammonia
- Predicted performance: Overall COP at 7 kW thermal output – 1.2
- Challenges: complexity, production process, price

Source: University of Warwick





Test conditions:

T_{drive} = 150°C
T_{evap} = 0-7°C
$T_{sup,uh}$ = 36°C
$T_{sup,rad}$ = 50°C
$\Delta T_{sup-ret}$ = 10 K

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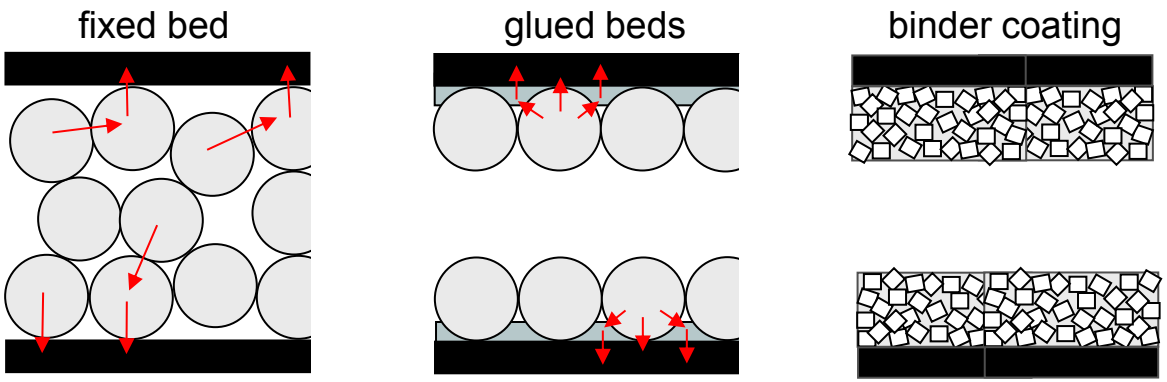
ADOSO Project: Innovation

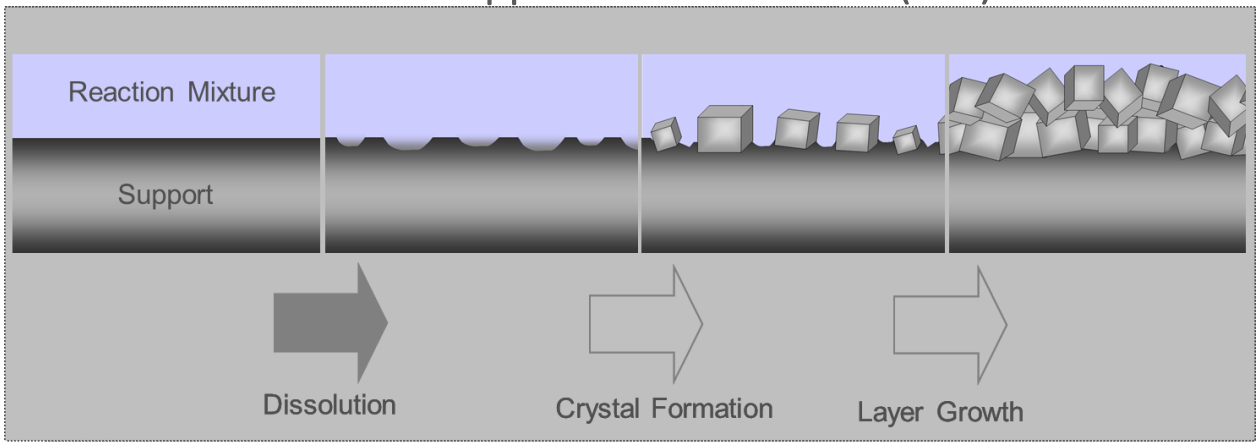
SorTech

STIEBEL ELTRON

Conventional sorption beds / HXs



Partial Support Transformation (PST)



Source: SorTech

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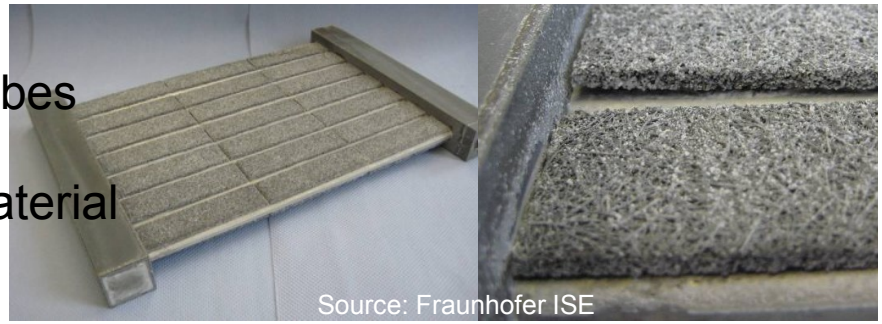
ADOSO Project: Novel adsorber heat exchangers

SorTech

STIEBEL ELTRON

First prototype

- Fibre mats moulded on extruded flat tubes
- PST coating: problems with thermal material expansion
- Huge and massive collector



Novel fibre adsorber heat exchangers

- Flat tubes, hydraulic collector and fibre mats are vacuum brazed to form the heat exchanger
- The heat exchanger is PST coated including calcination and He-leakage testing

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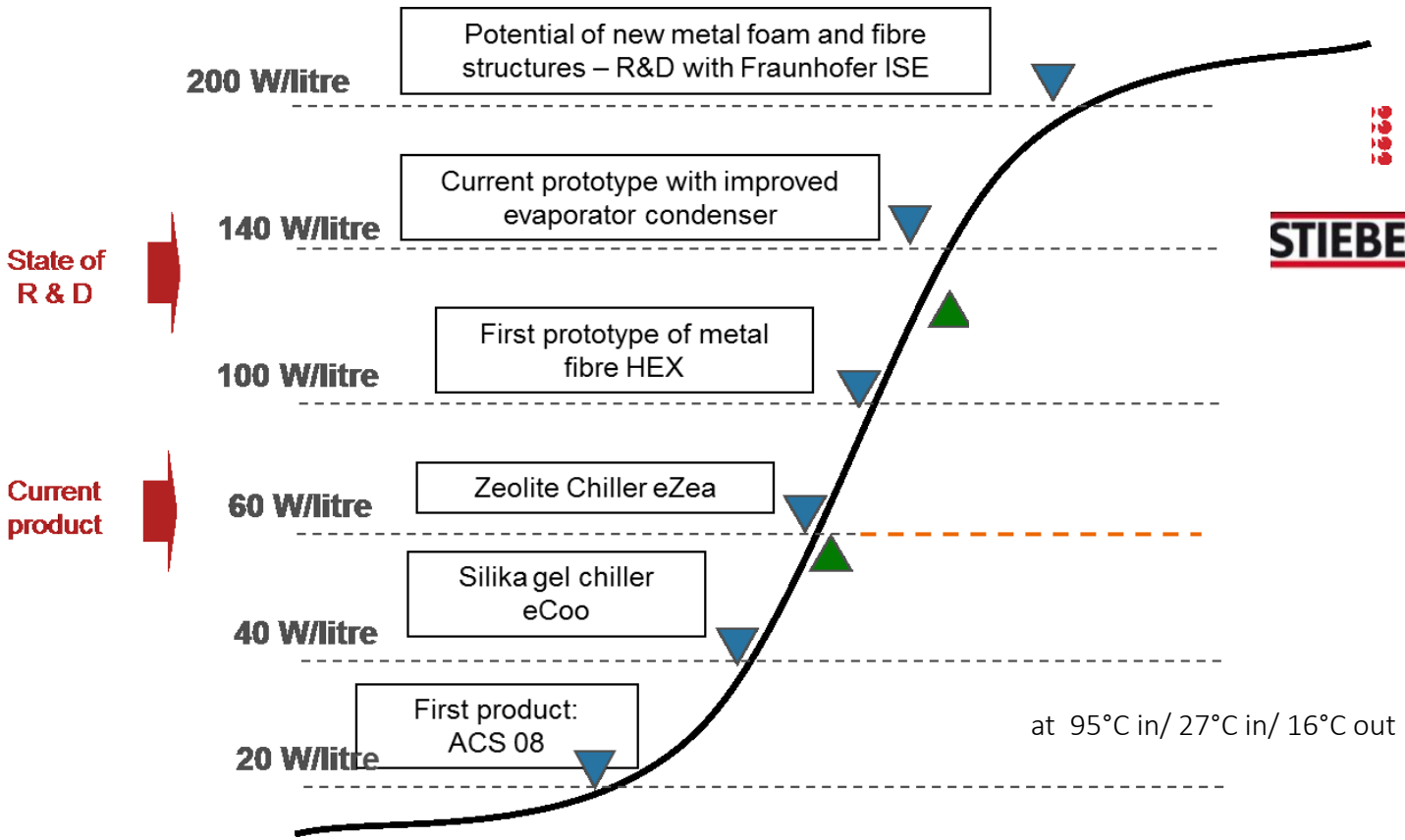
ADOSO Project: Novel adsorber heat exchangers



SorTech

STIEBEL ELTRON

Performance

- At driving temperatures of 90 to 95 °C cooling capacities of 6 to 7 kW have been measured.
- Based on the volume of the adsorption modules a capacity of 90 to 100 W/l has been achieved in first prototype
- Reducing size of spacer and evaporator the volume was reduced by about 25 % leading to 120 to 140 W/l.

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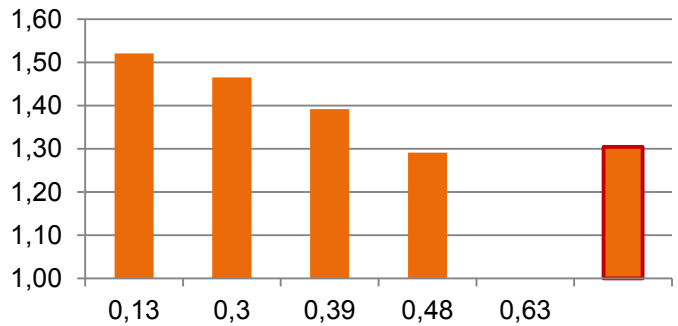
ADOSO Project: Novel adsorber heat exchangers

SorTech

STIEBEL ELTRON

- The prototypes are based on a simple design consisting of:
- 2 Adsorption modules each including 1 adsorber, 1 evaporator/ condenser and 1 spacer in between
- Identical aluminium fibre heat exchangers are used for adsorber and evaporator/condenser
- Hydraulic and control unit



P/Pn	Power	dQ	COP
0,13	2,0 kW	16,4 kW	1,52
0,3	4,5 kW	13,8 kW	1,47
0,39	5,9 kW	11,3 kW	1,39
0,48	7,2 kW	9,5 kW	1,29
0,63	9,5 kW		1,00
		SPF	**1,33**

Comparison of adsorption modules

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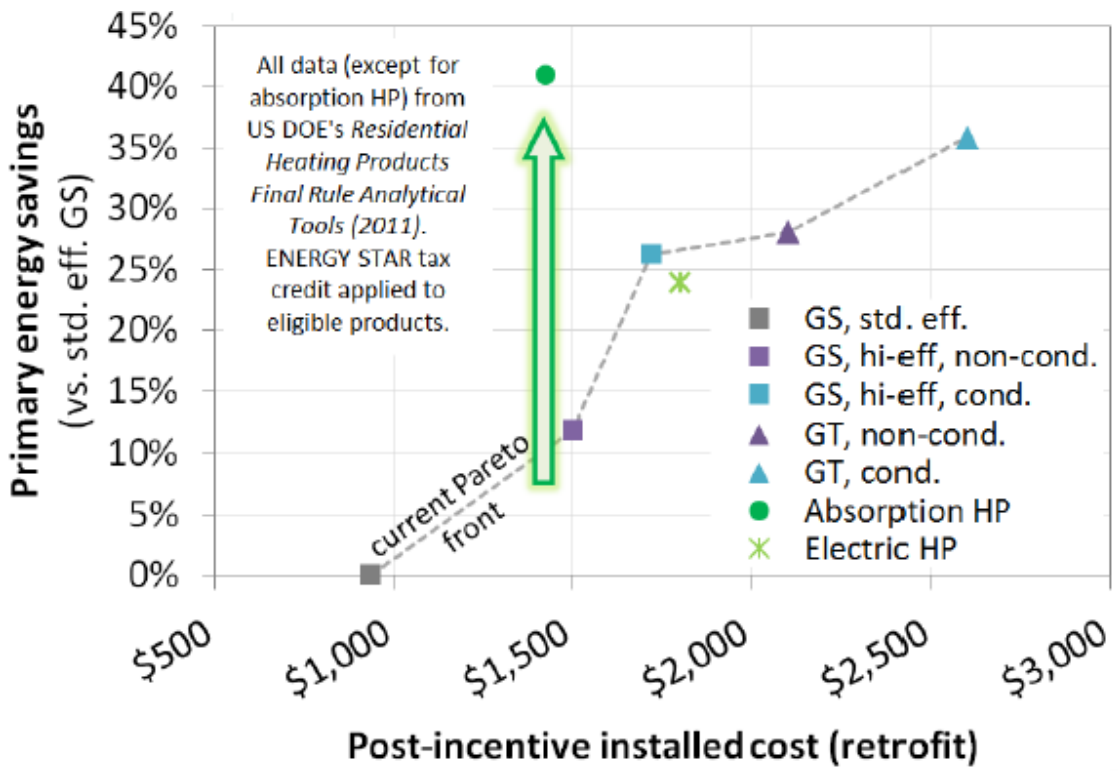
Activities in the US

Due to specific market situation in the US, the focus of current activities in the field of FSHPs seem to be on the DHW application



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Activities in the US

Company	Technology	Capacity	Application
A.O. Smith/ORNL/ SMTI	NH_3/H_2O		Commercial
SMTI	NH_3/H_2O	3 kW	Residential, DHW
GE/ORNL/Uni FL	H_2O/IL	3,4 kW	Residential, DHW
ORNL	NH_3/carbon		Residential, DHW
SMTI	NH_3/H_2O	40 kW (25-100%)	Residential, SH

Source: Kyle Glusenkamp, ORNL

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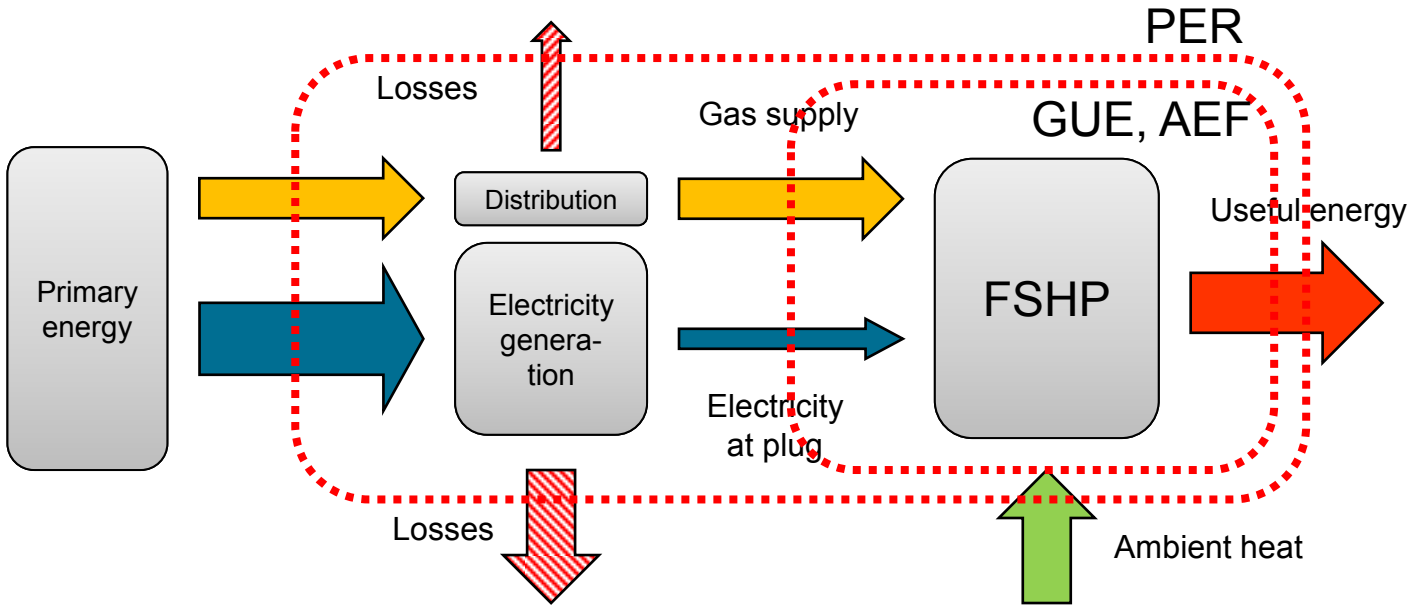
Performance evaluation of FSHP: Efficiency figures



Primary energy ratio:

$$\text{PER} = \frac{\text{Useful energy}}{\text{Primary energy consumption}}$$

PEF_i

Fuel efficiency: $$\text{GUE} = \frac{\text{Useful energy}}{\text{Gas consumption}}$$

El. Efficiency: $$\text{AEF} = \frac{\text{Useful energy}}{\text{El. consumption}}$$

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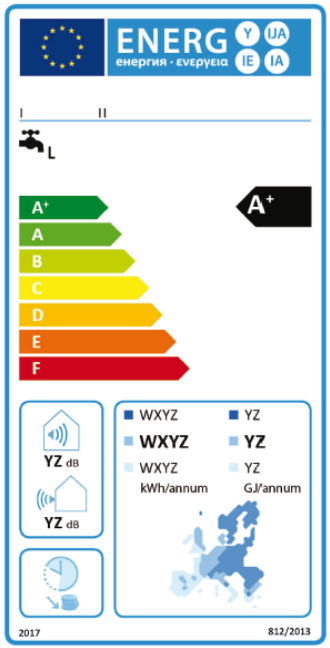
Performance evaluation: Energy Labelling

- Lot 1: In the commission communication regarding transitional methods for the measurement and calculation of energy efficiency for heating applications, prEN 12309:2013 is referenced
- The value of SPER is to be set equal to $SPER_h$
- Lot 2: In the commission communication regarding transitional methods for the measurement and calculation of energy efficiency for DHW applications, EN 13203-2 is referenced for the test rig preparation. Operating conditions are given in the delegated regulations 812 and 814 / 2013 and are the same as for EHP
- Testing of a FSHP and evaluation of the method according to the regulation is planned within Annex 43



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Performance evaluation: standards and regulations

- Two main normative documents for FSHP:
  - EN 12309, parts 1 to 7: Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW
  - VDI 4650-2: Simplified method for the calculation of the annual heating energy ratio and the annual gas utilisation efficiency of sorption heat pumps: Gas heat pumps for space heating and domestic hot water

	Heating	Cooling	DHW	Hybrid	Solar
EN 12309	x	x	-	x	(x)
VDI 4650-2	x	-	x	x	x

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EN 12309: Seasonal efficiency of GSHPs for heating applications

- The standard was developed under a mandate by the EC and should be harmonised with the relevant EU guidelines and regulations
- Testing procedures, operating conditions and calculation methods for seasonal efficiencies correspond largely to EN 14511 and EN 14825 for electrically driven heat pumps -> good basis for technology comparisons!

SGUE

$$SGUEh = \frac{\sum_{j=1}^{n} hj \times Ph(Tj)}{\sum_{j=1}^{n} hj \times \left(\frac{Ph(Tj)}{GUEh(Tj)} \right)}$$

$$GUE_h = \frac{Q_{Eh}}{Q_{gmh}}$$

SAEF

$$SAEF_h = \frac{Q_{refh}}{\frac{Q_{refh}}{SAEFh_{on}} + Q_{idle}}$$

$$AEF_h = \frac{Q_{Eh}}{P_{Eh}}$$

SPER

$$SPERh = \frac{1}{\frac{\Pr im_{\text{gas}}}{SGUEh} + \frac{\Pr im_{\text{elec}}}{SAEFh}}$$

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Robur K18: Lab test results

- Reproducibility of experiments was very good
- Cross-check between the laboratories successful (<1,5 %)
- Steady-state testing did not yield any difficulties
- Transient test with defrost cycles feasible but time-consumig
- Cycling tests with externally imposed duty cycle yielded difficulties when combined with defrost (on-off plus defrost, hard to meet the target power!)

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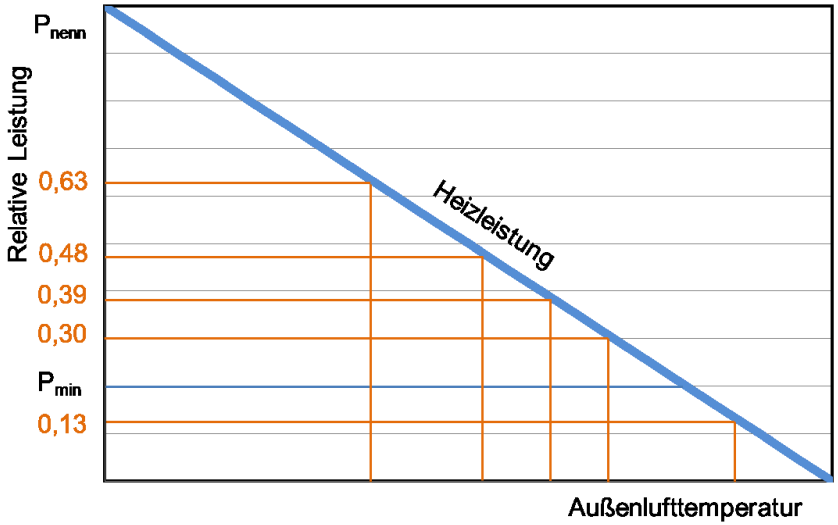
VDI 4650-2: Annual Heating Energy Ratio and Annual Gas Utilisation Efficiency for space heating and DHW

- The calculation procedure is based on DIN 4702-8 (modulating condensing boilers) with five equally weighted part-load efficiencies
- The performance figures give a gas utilisation efficiency and overall energy efficiency, however by equalising different energy sources
- Efficiency factors basis for German federal subsidy programme



Overall AHER and AGUE

$$\zeta_{WP} = \frac{1}{\frac{1-y}{\zeta_h} + \frac{y}{\zeta_w}} \qquad \eta_{N,WP} = \frac{1}{\frac{1-y}{\eta_{N,h}} + \frac{y}{\eta_{N,w}}}$$

y – fraction of DHW

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VDI 4650-2: Annual Heating Energy Ratio, Annual Gas Utilisation Efficiency for space heating

AHER

$$\zeta_h = \frac{5}{\sum_{i=1}^{5} \frac{1}{\zeta_{h,i}}}$$

$$\zeta_{h,i} = \frac{P_{i,th}}{\quad}$$

$$\zeta_{h,S} = \frac{\zeta_h}{1-(1-z\cdot\zeta_h)\cdot X}$$

$$\zeta_w = \frac{P_w}{\quad}$$

AGUE

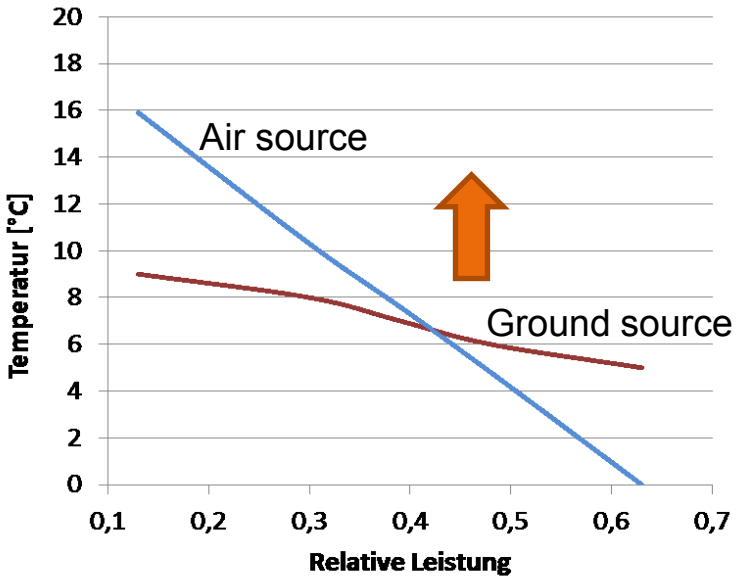
$$\eta_{N,h} = \frac{5}{\sum_{i=1}^{5} \frac{1}{\eta_{h,i}}}$$

$$\eta_{h,i} = \frac{P_{i,th}}{Q_i}$$

$$\eta_{N,h,S} = \frac{\eta_{N,h}}{1-X}$$

$$\eta_{N,w} = \frac{P_w}{Q_w}$$

As water can be used as refrigerant, heat source temperatures must be >0°C



X - fraction of direct solar heating
z - ratio of auxiliary electrical energy

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Conclusions

- It is predicted that FSHP will play an important role as a heating and DHW appliance in the future, especially in retrofit
- A number of appliances have been announced to enter the market soon
- Considerable R&D activities which target the main challenges regarding wider application of FSHP today and in the near future are on-going
- Standards for testing and rating of FSHP are partially available, however they should be tested on more appliances, revised regarding certain aspects and harmonised

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Next steps

- Initiation of a large scale monitoring project to improve the technology awareness level
- Diversification of products and applications
- Efficiency improvement on the component and system levels
- More development on materials, working pairs and productions processes
- Revision of current standards and development of new ones (e.g. DHW)

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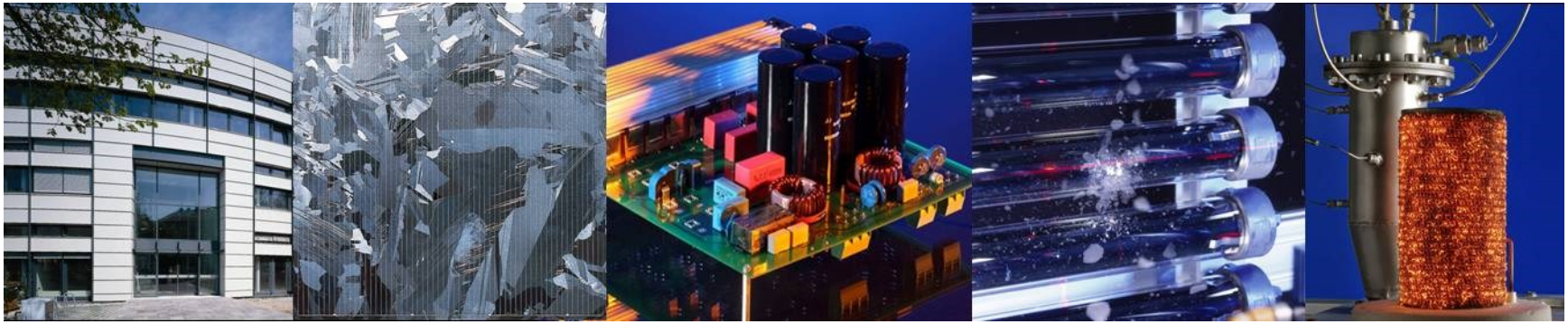
… thank you for your attention.



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