Lucerne University of
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Swiss Heat Pump Research Highlights II – Advanced Heat Pumps in Switzerland

Prof. Dr. Beat Wellig
Lucerne School of Engineering and Architecture
CC Thermal Energy Systems and Process Engineering
Horw, Switzerland

Workshop Heat Pump Development in Switzerland and IEA HPT Projects
Muttenz, November 9th, 2015

CC Thermal Energy Systems and Process Engineering

Our Competence Center:

Prof. Dr. Beat Wellig:
Thermal Energy Systems and Process Engineering

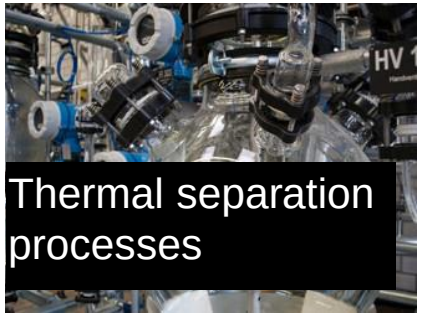
Prof. Dr. Jörg Worlitschek:
Thermal Energy Storage

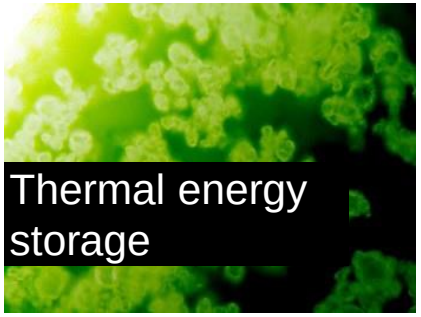
Prof. Dr. Mirko Kleingries:
Sorption Processes

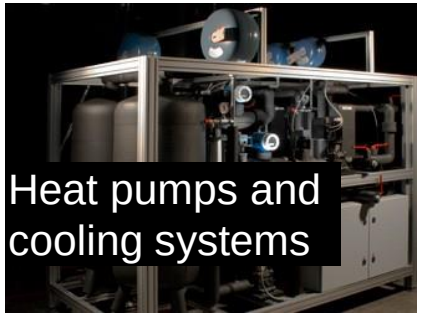
Prof. Dr. Thomas Nussbaumer:
Bioenergy and Sustainability

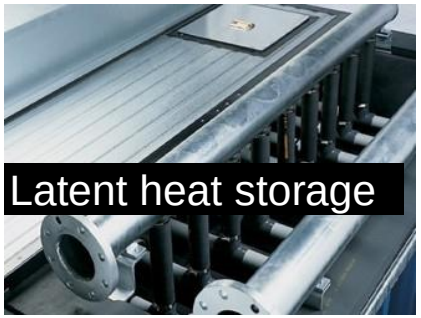
CC Thermal Energy Systems and Process Engineering

Some of our Research Activities:









CC Thermal Energy Systems and Process Engineering

Project examples in the field of HP technology:

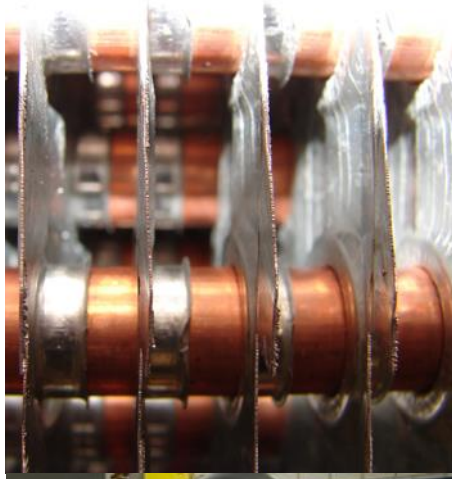
- WEXA – Exergy analysis for increasing the efficiency of air/water heat pumps
- LOREF – Air cooler optimization with reduction of the ice and frost formation
- CO2 geothermal heat probe
- Combined heat pump and chiller systems for the use in electric and hybrid vehicles

1 - **Efficient heat pumps with continuous capacity control**

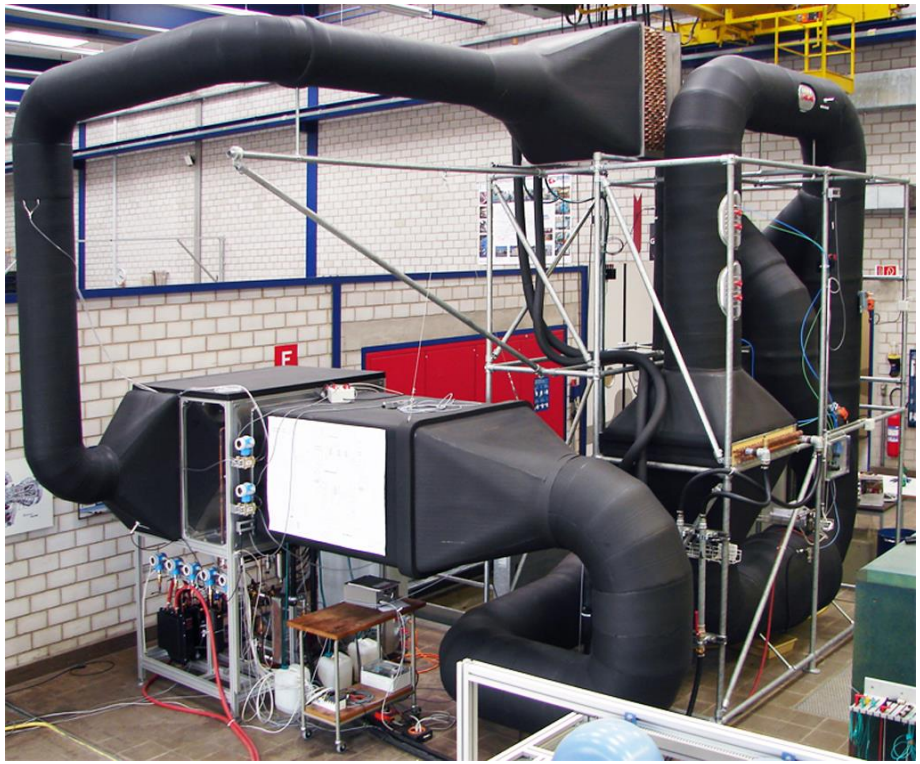
2 - **High efficient heat pumps with turbo compressor for low temperature lifts**

3 - **Household appliances with integrated heat pump technology**

- etc.

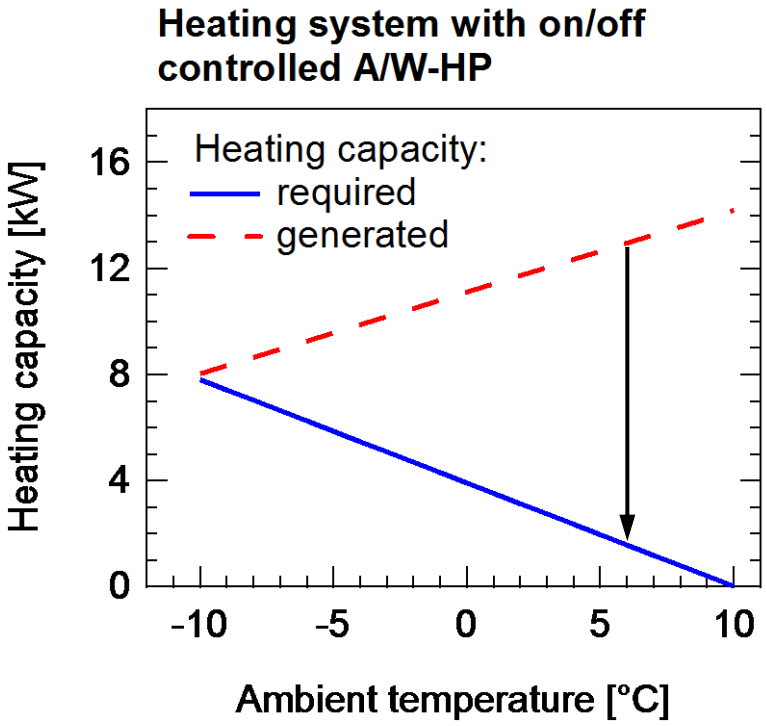


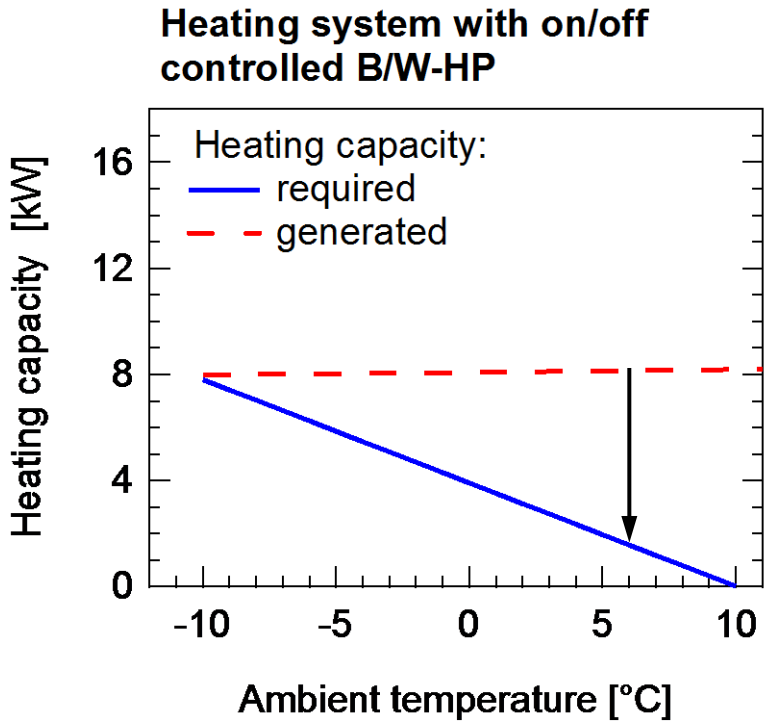
1 Efficient Heat Pumps with Capacity Control



1 Efficient HPs with continuous capacity control

Unfavourable operating characteristic of HPs on/off control:





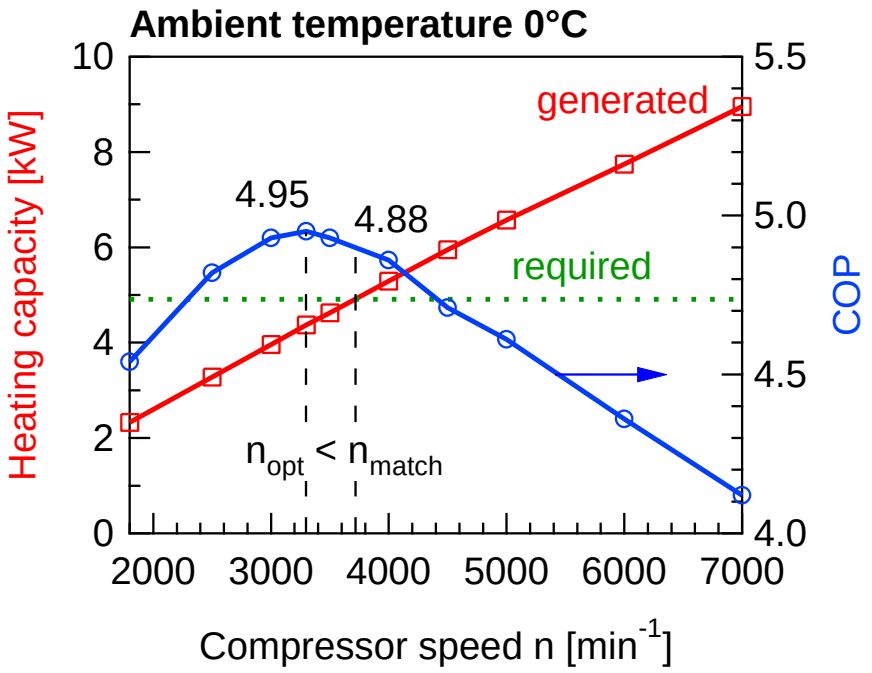
Cause: Inappropriate operation characteristic of the constant-speed compressor

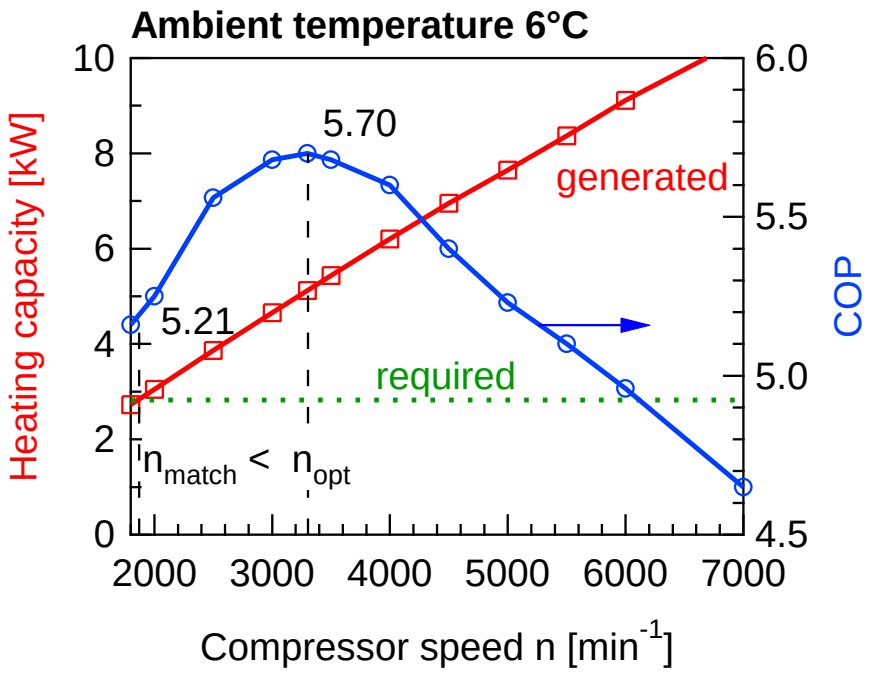
Goal: Adaption of the generated heating capacity to the heating capacity continuously required by the building

[2] Gasser *et al.*: WEXA: Exergie-Analyse zur Effizienzsteigerung von Luft/Wasser-Wärmepumpen, BFE, 2008.

1 Efficient HPs with continuous capacity control

Optimal control strategy of capacity controlled A/W-HPs:



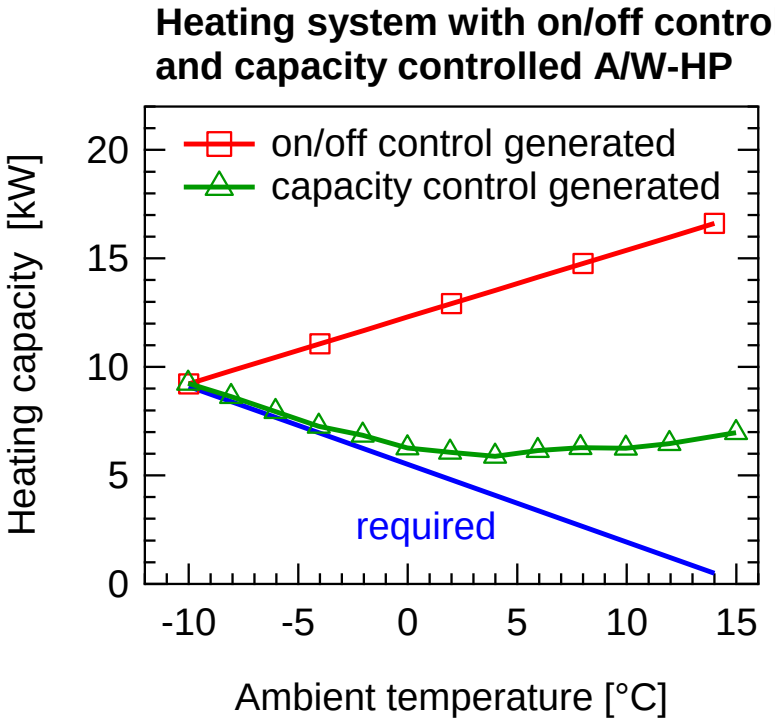


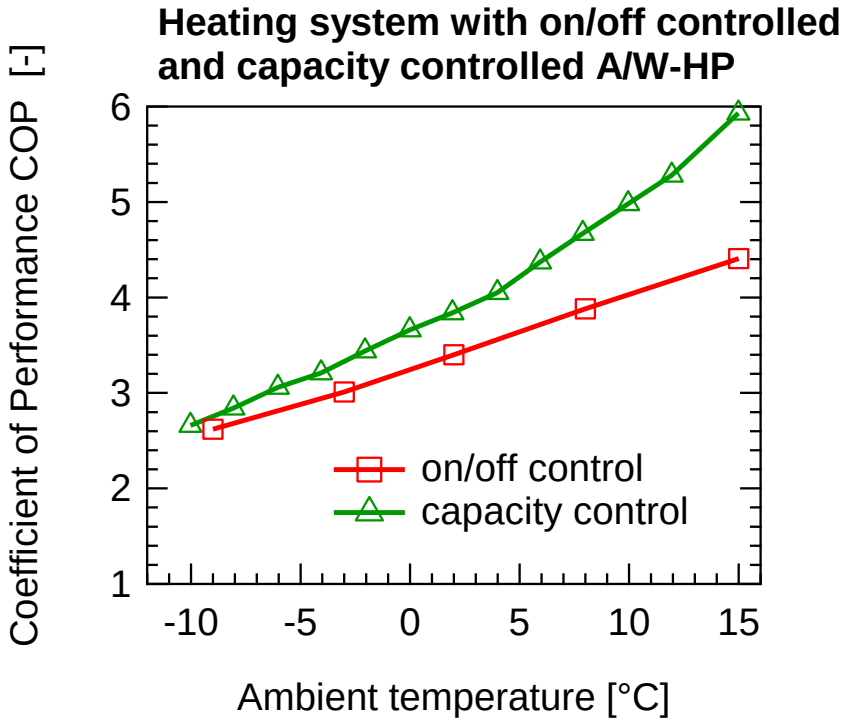
Adjusting the generated to the required heating capacity over the entire part load range of the compressor is not generally advisable!

Operating conditions: 0°C, 6°C ambient temperature, 85% rel. humidity and heating curve «Minergie», supply/return-temp. 30/25°C at -10°C, COP without consideration of the fan (measurements)

1 Efficient HPs with continuous capacity control

Efficiency of A/W-HPs with on/off and capacity control:



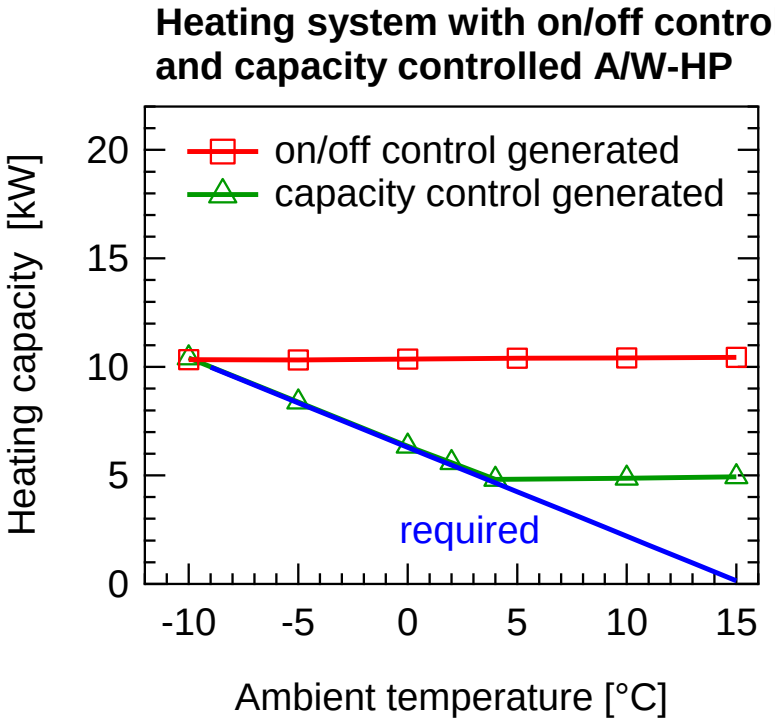


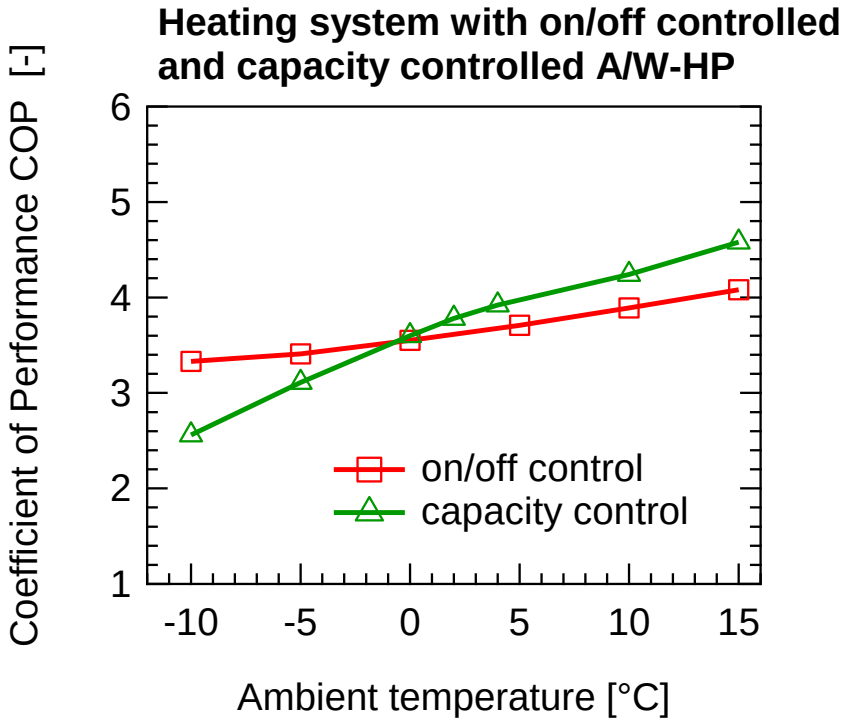
Due to the continuous capacity control the efficiency of A/W-HPs can considerably be increased!

Heating curve reconstructed old building supply/return-temp. 46/38°C at -10°C, Measurements HSLU

1 Efficient HPs with continuous capacity control

Efficiency of B/W-HPs with on/off and capacity control:





Due to the continuous capacity control the efficiency of B/W-HPs can also (slightly) be increased!

Heating curve reconstructed old building supply/return-temp. 46/38°C at -10°C, Measurements HSLU

1 Efficient HPs with continuous capacity control

Experimental proof - Seasonal performance factors SPF

(incl. fan/brine circulation pump, without heating water circulation pump, without domestic hot water generation, climatic region Zurich):

HP-system	Heat source Borehole temp. / heat probe depth	**Minergie-Standard** supply/return 30°C/25°C at -10°C		**Reconstructed old building** supply/return 46°C/38°C at -10°C	
		SPF on/off	**SPF** capacity control	**SPF** on/off	**SPF** capacity control
air to water	ambient air	**3.90**	**4.41**	**3.12**	**3.79**
brine to water	soil/heat probe 6°C/~100 m	**4.54**	**4.88**	**3.64**	**3.83**
	soil/heat probe 13°C/~320 m	**6.21**	**6.90**	**4.62**	**5.09**

- Clear increase in efficiency has been confirmed!
- Capacity control has a high potential for reconstructed old buildings.

1 Efficient HPs with continuous capacity control

Field measurements A/W-HP with continuous capacity control:

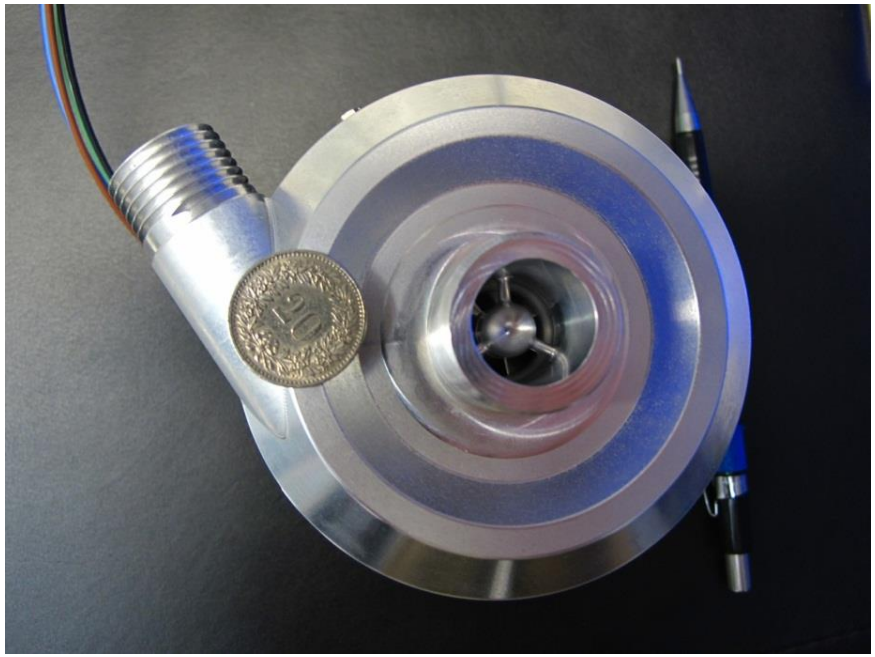
- Measurements in the lab of the HSLU
- Installation in single family house of Beat Wellig, Suhr
- Field measurements has been running since December 2011

SPF_{H+D} = 4.1-4.3 (heating and defrosting)

$SPF_{H+D+DHW}$ = 3.7-3.9 (incl. domestic hot water)

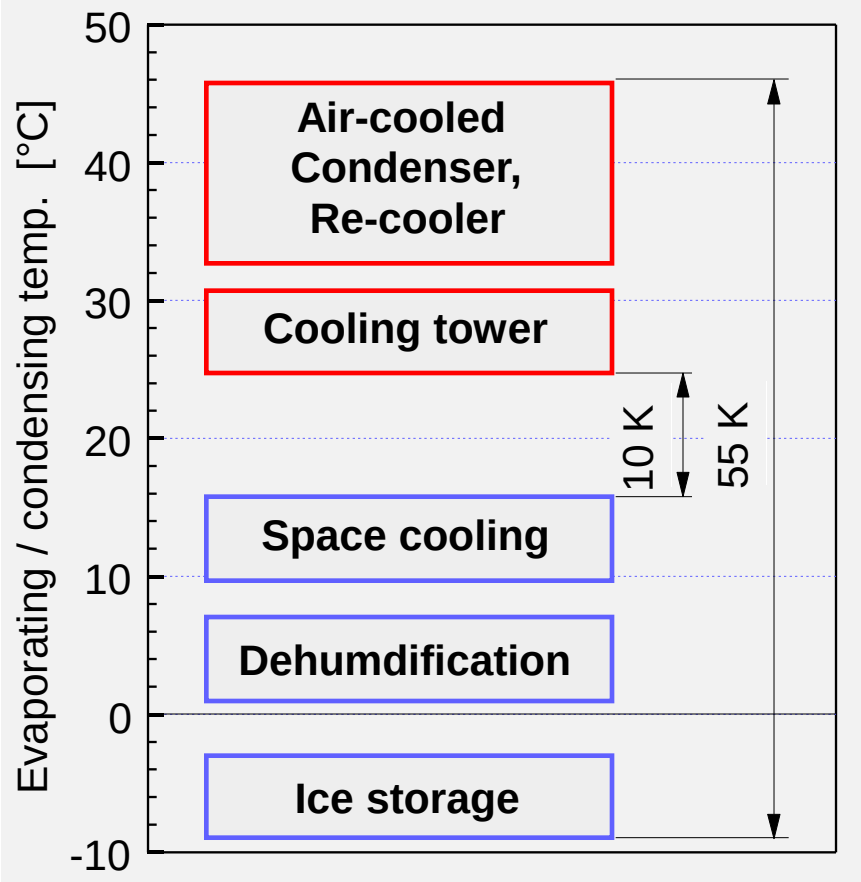
Bild: Beat Brechbühl

2 Low Temperature Lift Heat Pumps



2 Low temperature lift HP with turbo compressor

Potential of low temperature lift HVAC applications:

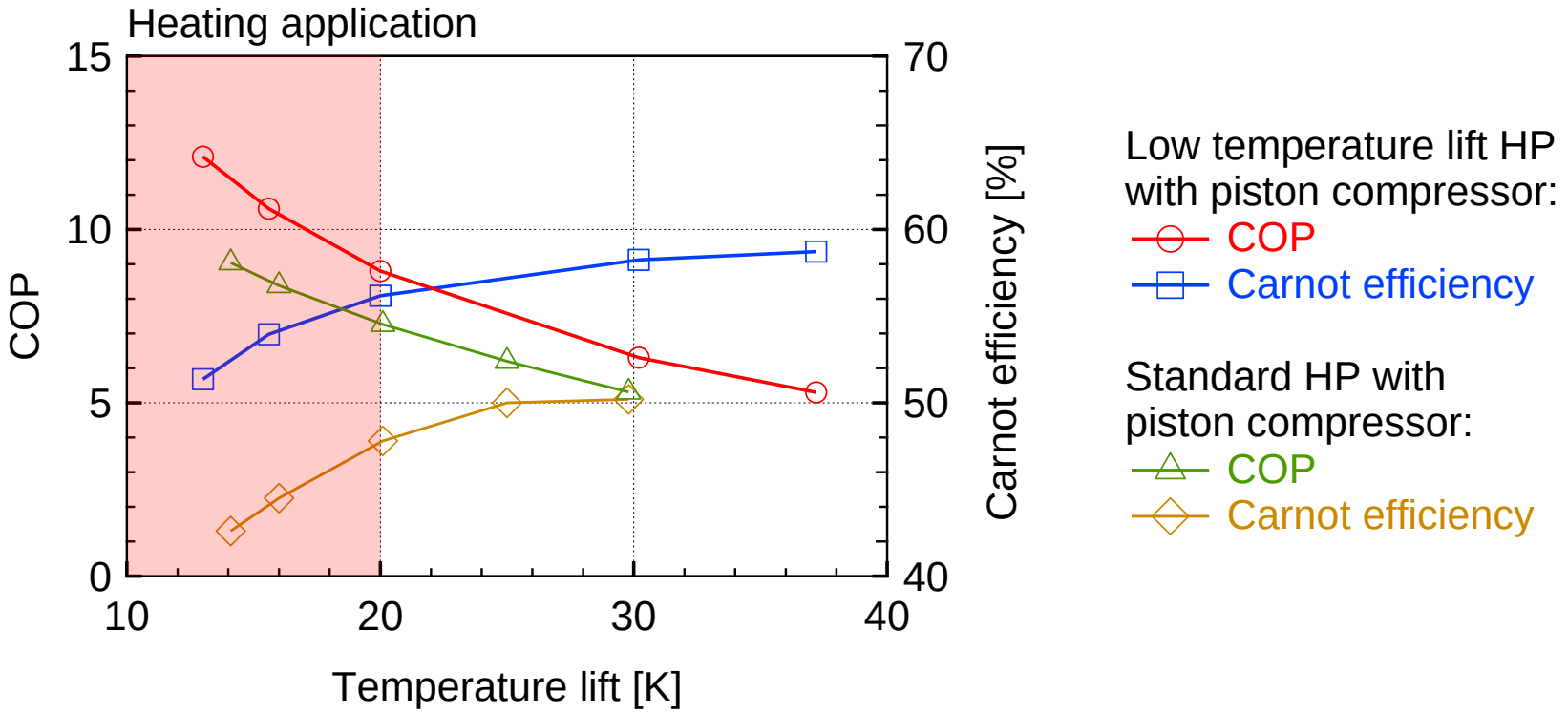


- Temperature lift depends decisively on the conditions of the heat source and sink!
  - Efficient cooling applications: 8–15 K
  - Efficient heating applications: 20–35 K
- Standard HPs and chillers are designed for lifts of 30-60 K

Potential for high efficient low temperature lift heating and cooling applications is not exploited!

2 Low temperature lift HP with turbo compressor

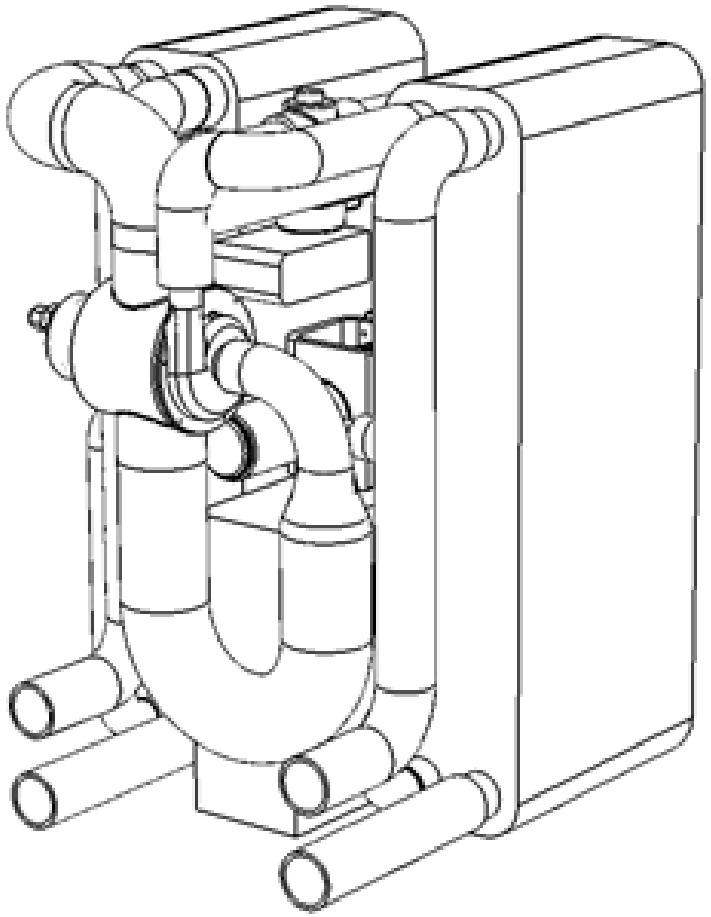
Operating behavior of standard HPs and chillers:



The carnot efficiency of standard HPs and chillers strongly decreases at low temperature lifts

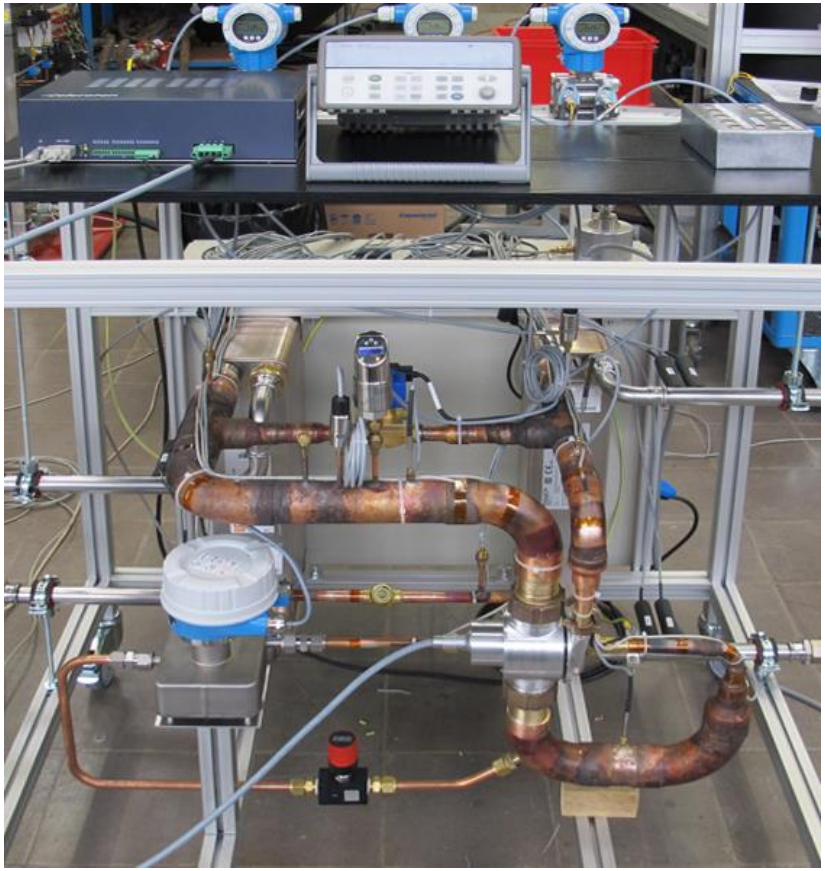
Goal: Development of HPs and chillers with oil free turbo compressors specially designed for low temperature lift applications

2 Low temperature lift HP with turbo compressor



- **Expansion valve**
  - Low superheating
  - ➢ Electronic expansion valve
- **Compressor**
  - Small internal pressure ratio
  - ➢ Oil free turbo compressor
- **Heat exchanger**
  - ΔT as low as possible
  - ➢ «thermally long» brazed plate heat exchangers
- **Refrigerant**
  - Oil free system
  - ➢ Butane (R600)

2 Low temperature lift HP with turbo compressor



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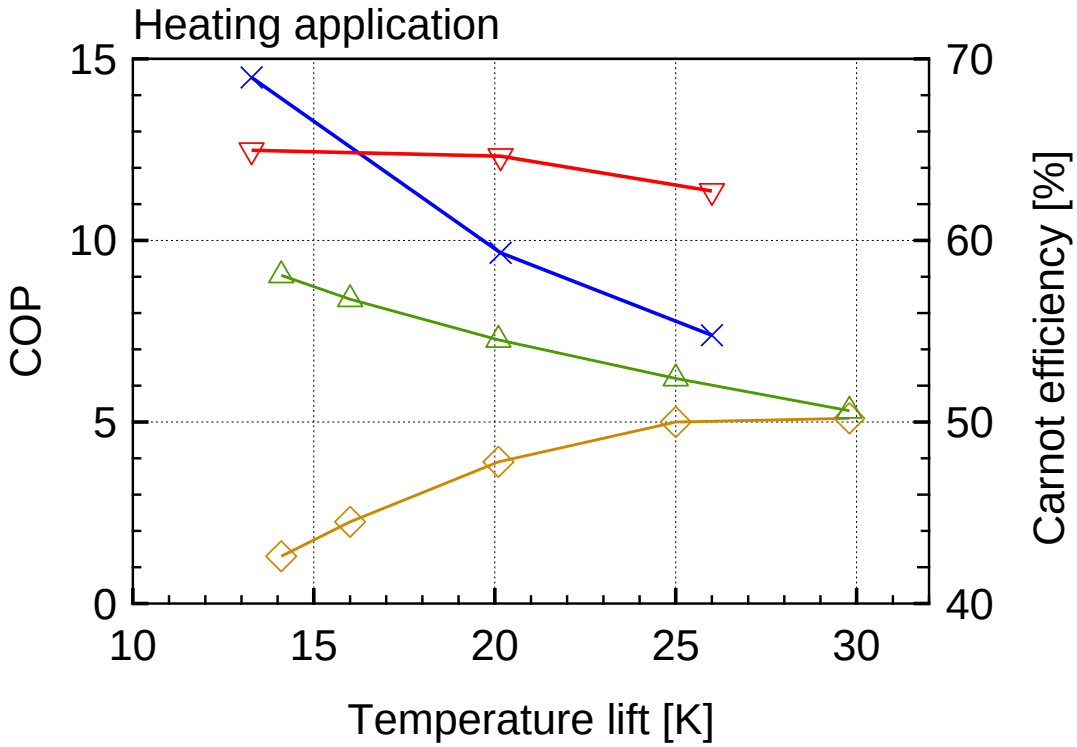
2 Low temperature lift HP with turbo compressor

Experimental proof:

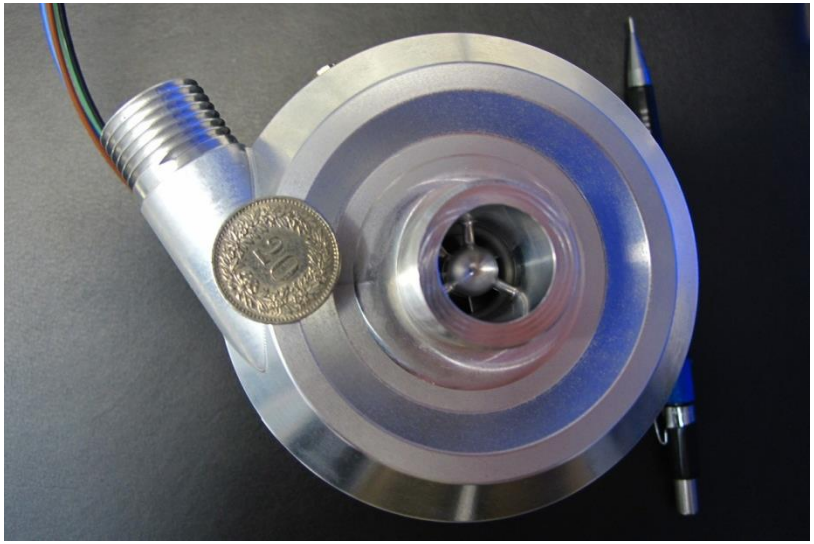


Low temperature lift HP with turbo compressor:
- COP
- Carnot efficiency

Standard HP with piston compressor:
- COP
- Carnot efficiency

Carnot efficiency of the low temperature lift HP with turbo compressor remains constant over 60% even at low lifts!

2 Low temperature lift HP with turbo compressor



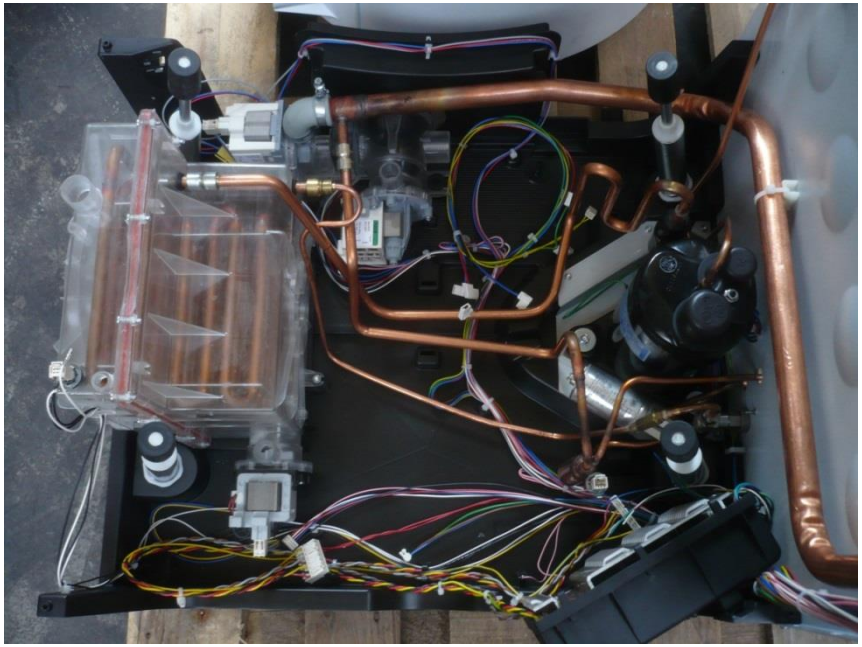
- Eficiency of the developed HP for low temperature lift applications:

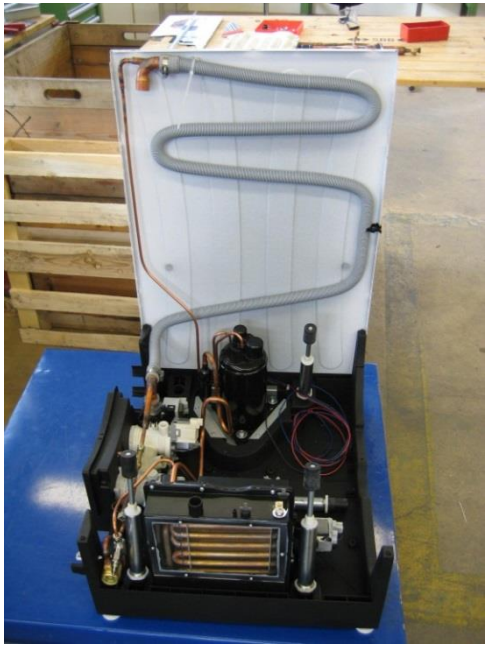
  - Heating at 20 K lift:
    $COP_{Heating} > 9$

  - Cooling at 10 K lift:
    $COP_{Cooling} > 15$

- **Distinctive reductions in primary energy consumption possible!**

3 Household Appliances with Heat Pump Technology

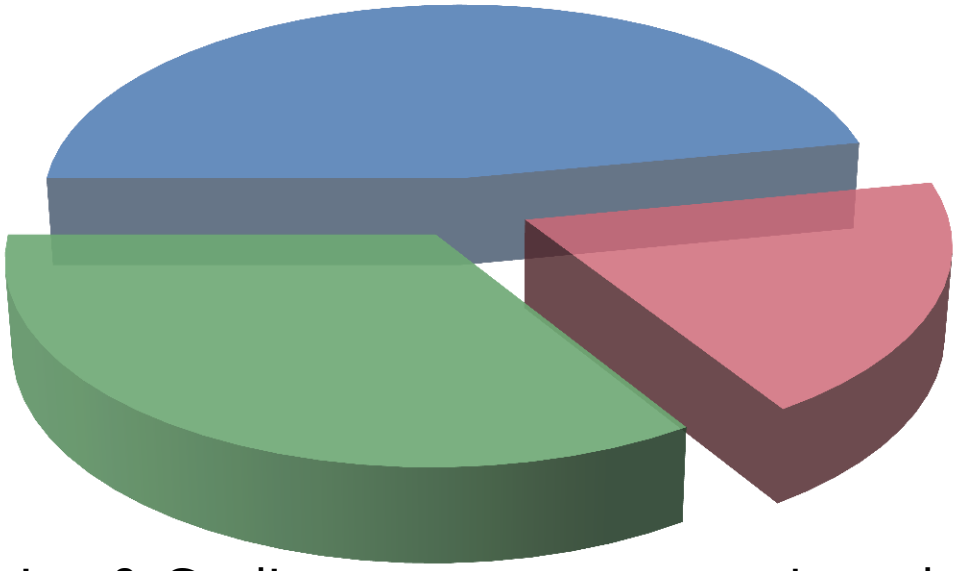




3 Household appliances with HP technology

Energy consumption of household appliances in Switzerland in 2012:

Cooking & Dishwashing
2.67 TWh / 47%



Freezing & Cooling
1.92 TWh / 34%

Laundry & Drying
1.08 TWh / 19%

Energy saving potential:

- Laundry dryer: up to 70%
- Washing machine: ~50%
- Dishwasher: ~50%

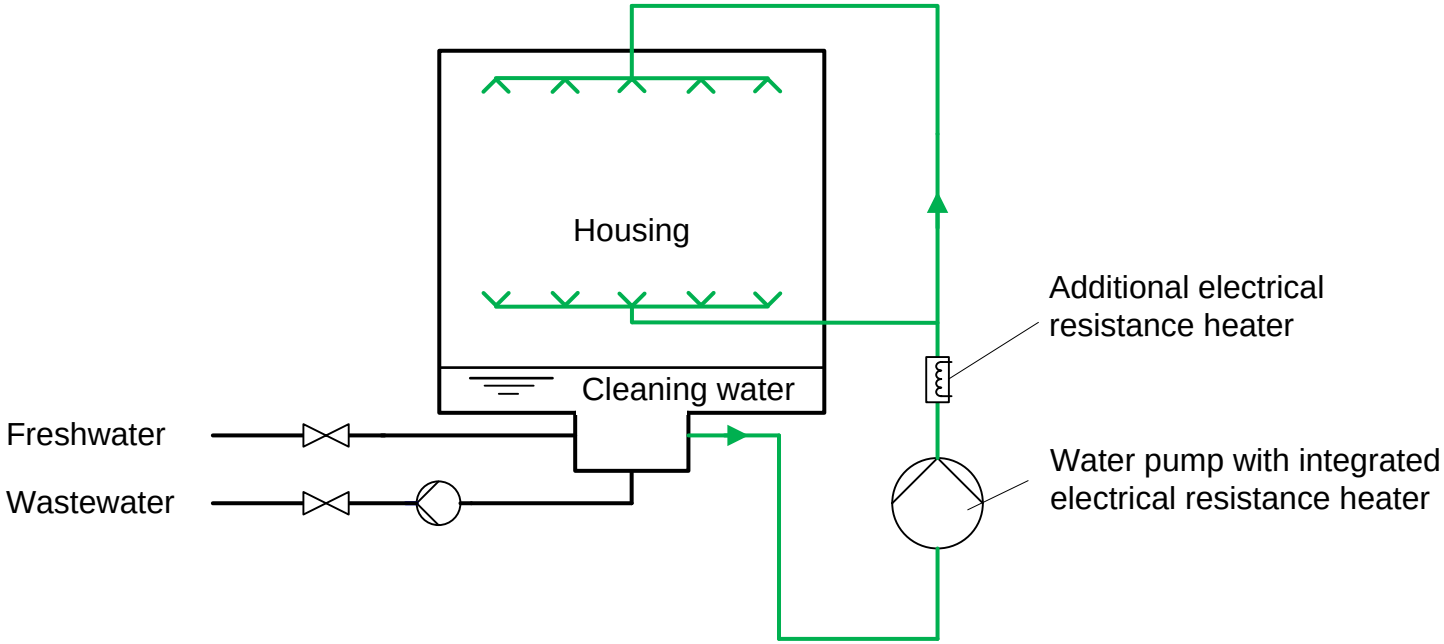
...by integration of a heat pump!

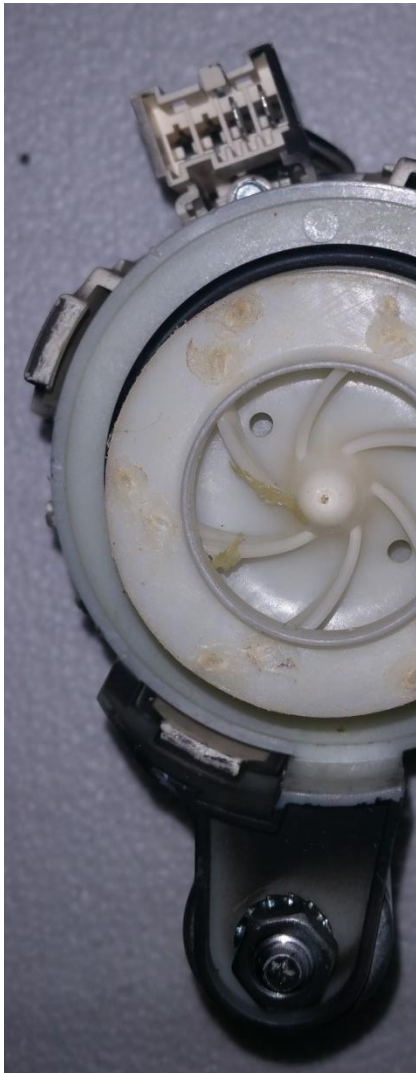
Total energy consumption 2012: 5.67 TWh

Source: A. Kemmler *et al*. – Analyse des schweizerischen Energieverbrauchs 2000 – 2012 nach Verwendungszwecken

3 Household appliances with HP technology

Dishwasher with electrical resistance heater:

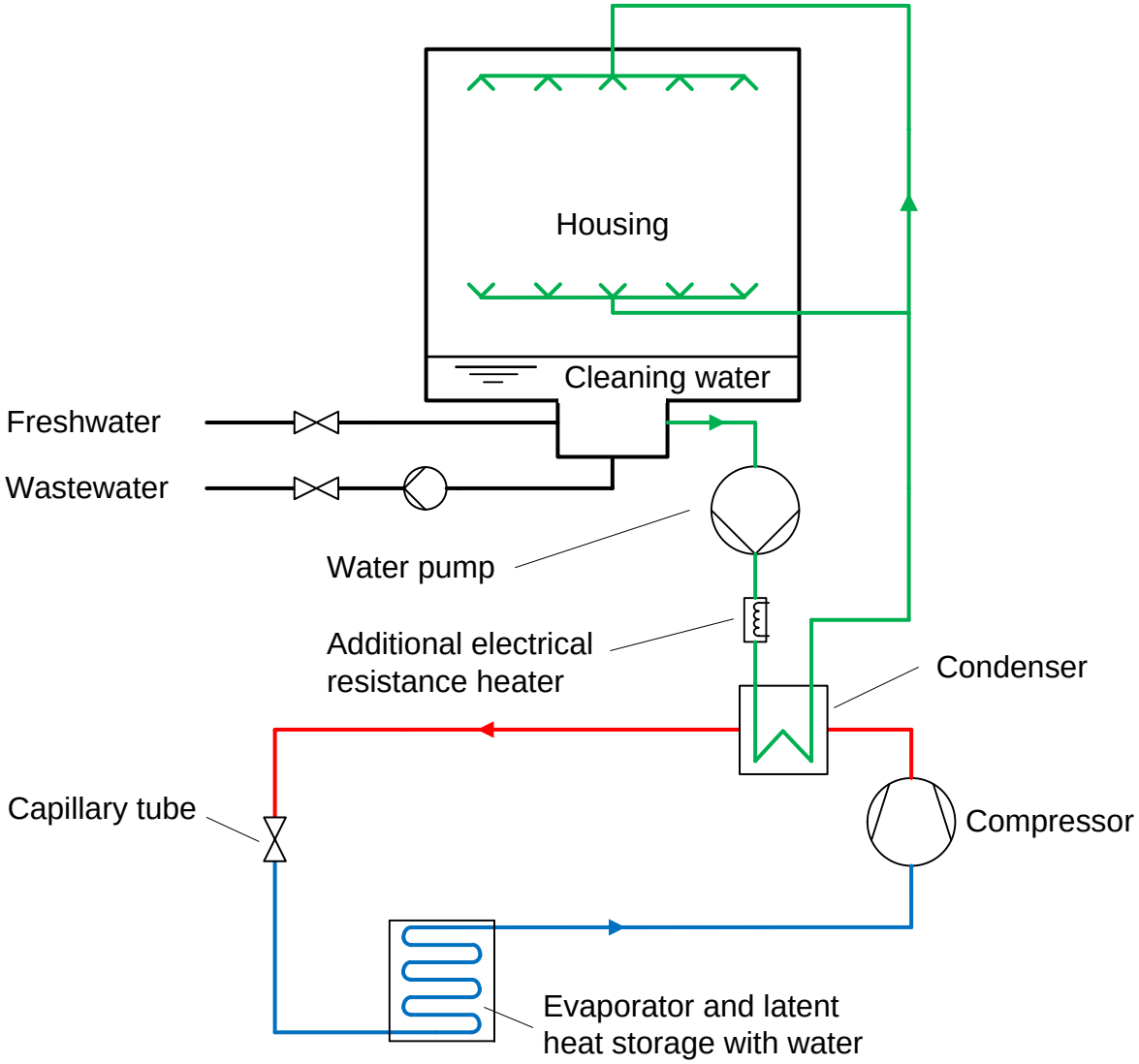




CTI-Projects V-ZUG AG and Lucerne School of Engineering and Architecture

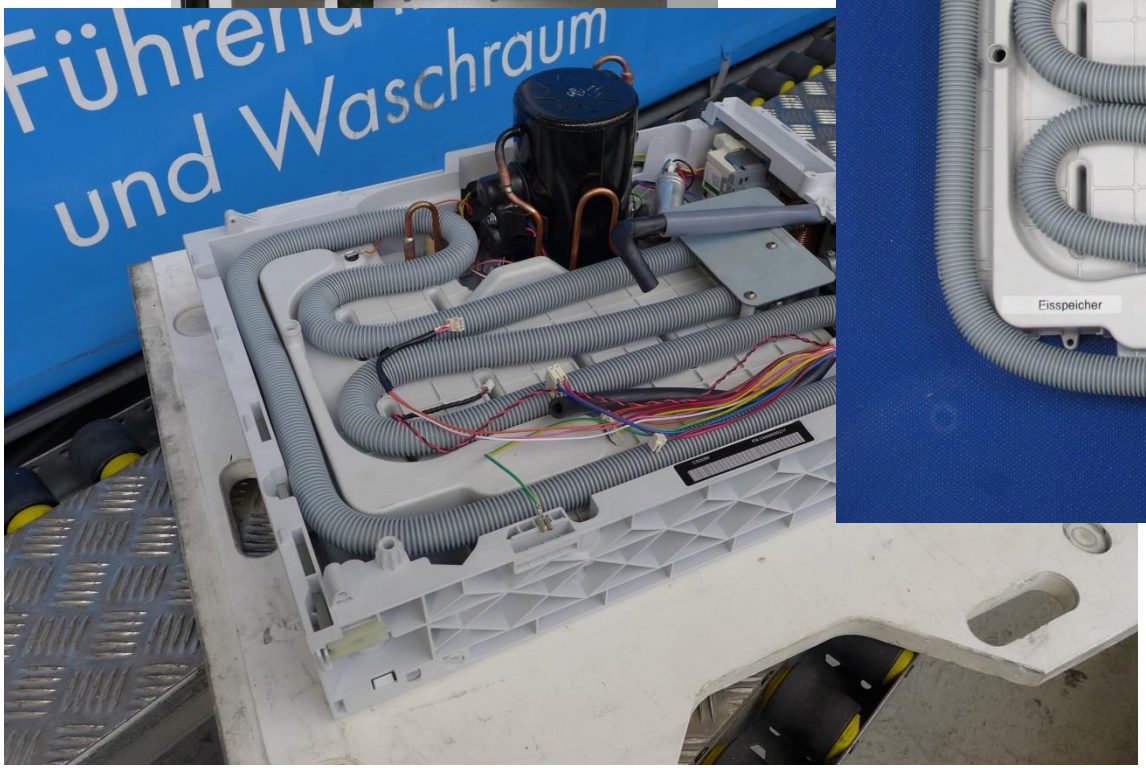
3 Household appliances with HP technology

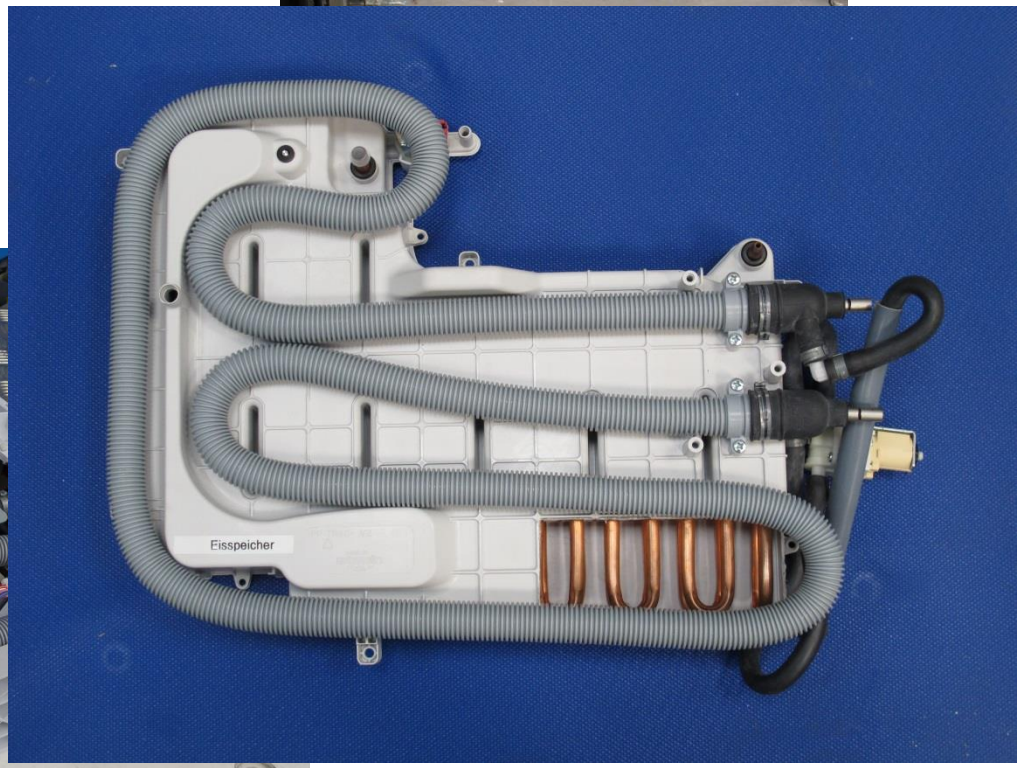
Dishwasher with integrated heat pump:



3 Household appliances with HP technology

Some impressions:





«World Champion in Energy Saving»: **A+++ minus 40%**

3 Household appliances with HP technology

Comparison of the average efficiency:

Year of construction	Laundry dryer [kWh/kg dry laundry]	Washing Machine [kWh/kg dry laundry]	Dishwasher Cycle [kWh]	Dishwasher Total Year [kWh]
2004	0.60	0.170	1.05	294
	HP ~-50% ↓			
2012	0.31	0.125	0.83	232
		HP ~-50% ↓	**HP** ↓	**~-40%**
New	0.18	0.065	0.49	137

Possible energy reduction for dishwashing, laundry and drying in Switzerland compared to 2012 : **~45%**

Thank you for your attention!

The project team thanks the Swiss Federal Office of Energy (SFOE) and the Commission for Technology and Innovation (CTI) for financial support and all industrial partners for their valuable inputs and assistance with the latest products and technologies.