Industrial Heat Pumps – Standards and Energy Efficiency

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refrigerants delivered by mother nature

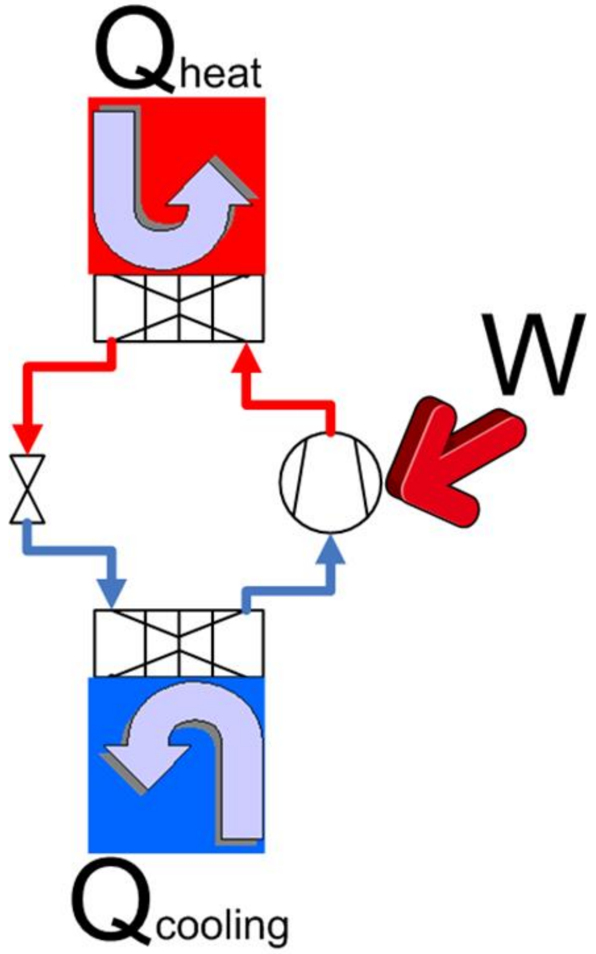
Some Initial Considerations

Definitions

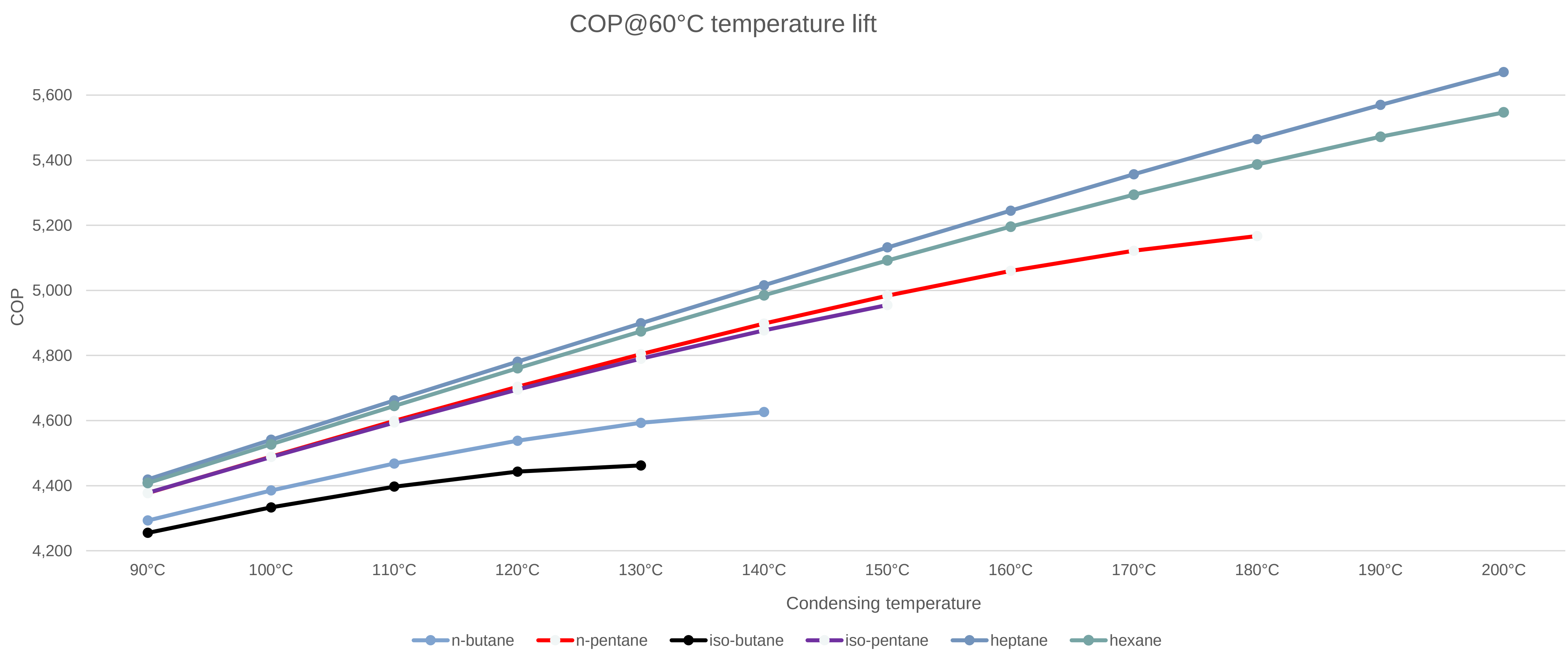
- A refrigeration system and a heat pump are basically identical; BUT
- In a heat pump the warm side has a value

- $COPc = \frac{Qc}{W}$
- $COPh = \frac{Qh}{W}$
- $COPs = \frac{Qc+Qc}{W}$

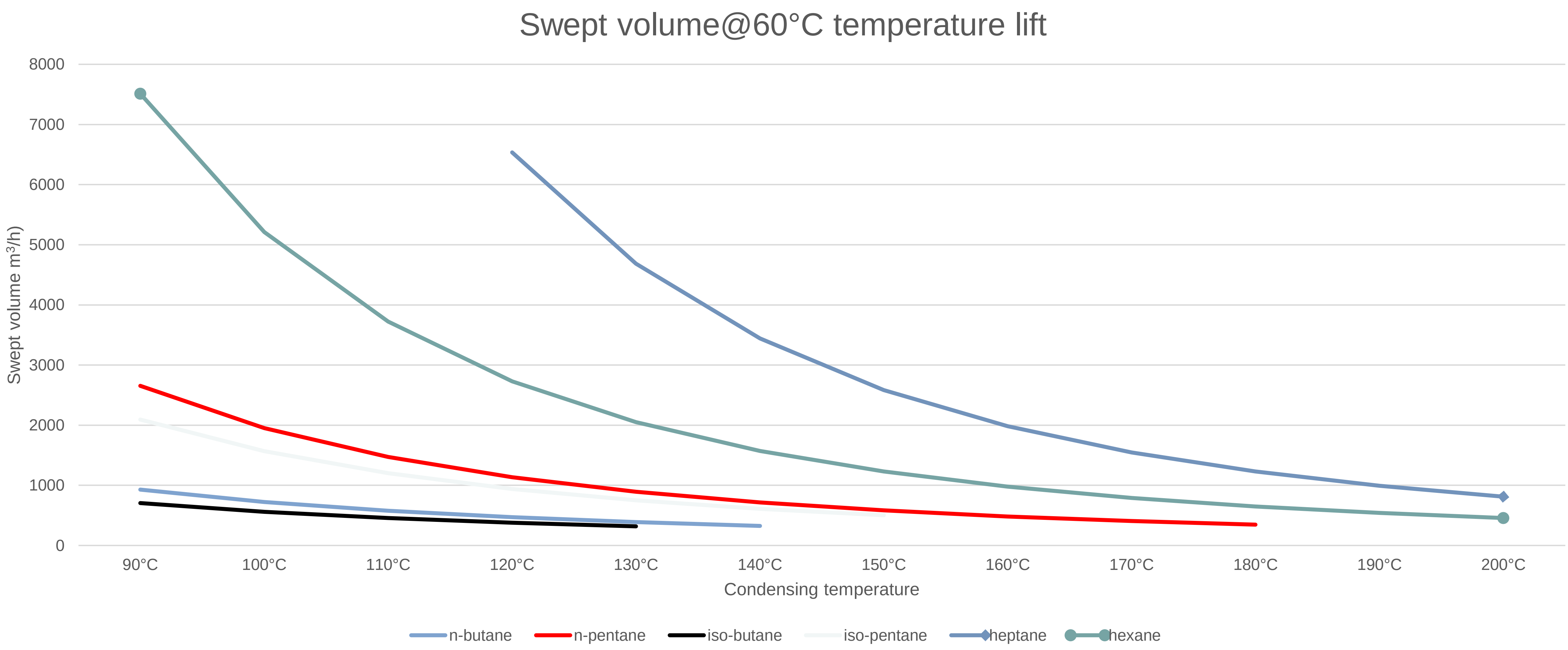
- EN 14825:2018 define high temperature as everything over 65°C/149°F
- District heating systems often work at temperatures between 70°C/158°F and 130°C/266°F
- If heat is recovered from a system connected to a cooling tower the savings on water and chemicals can be relatively high; a heat pump reduces these values which are not included in the COP



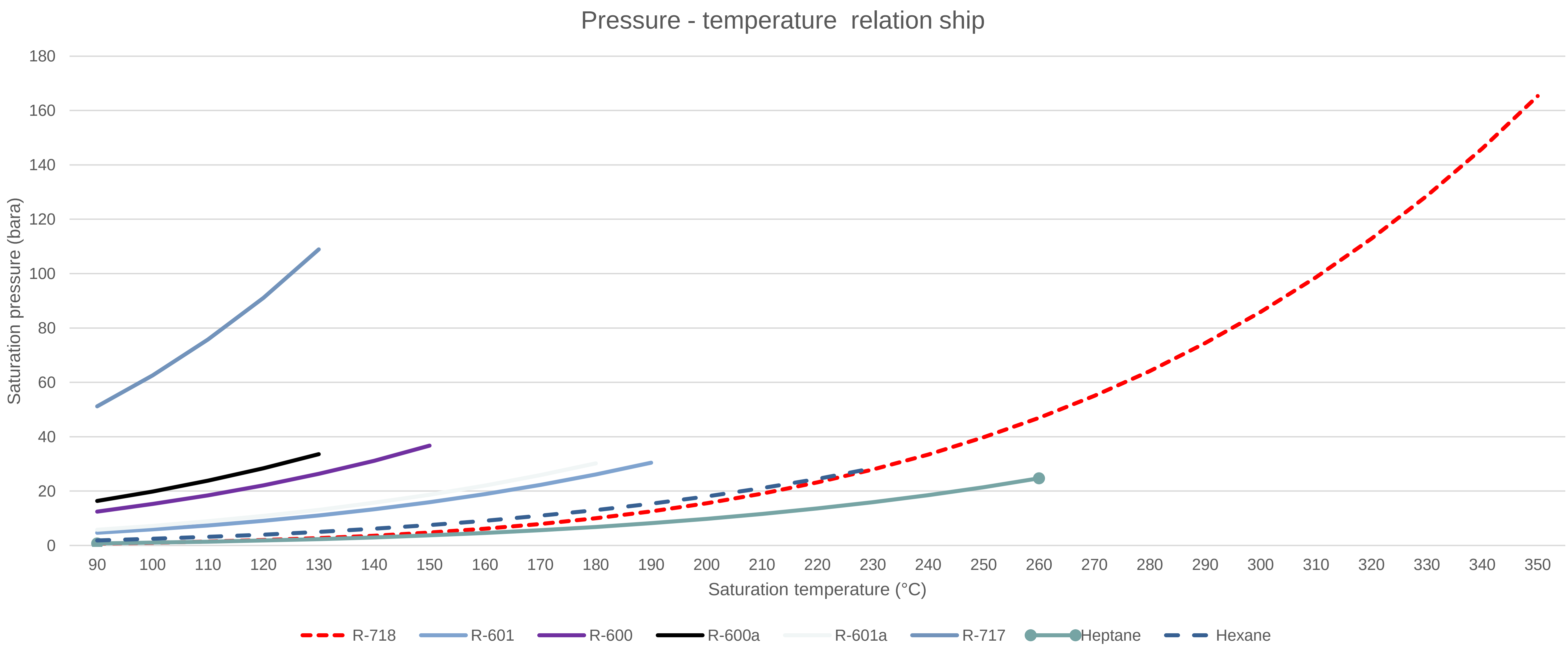
Theoretical COP for various natural gases



Swept volume required for a 500kW heat pump



Pressure – temperature relationship for selected refrigerants



Where will the high temperature heat pumps be used?

- The industrial world is very diversified and so are the solutions used
- One barrier for a quick roll out of high temperature heat pumps is the fear of affecting taste, color, texture or flavor of the food or drink
- Other industries are less sensitive on the product but more on the reliability of new technologies
- All major manufacturers are ready to produce high temperature heat pumps but there is no market pull

Branche	Beispiele für thermische Produktionsprozesse
Lebensmittel	• Erwärmen (20-60°C), • Pasteurisierung/Sterilisierung (70-120°C) • Kochen (100-240°C) • Destillieren (40-100°C) • Trocknen (40-250°C) • Eindampfen (40-170°C) • Waschen (30-60°C) • Aufkonzentrieren (60-70°C) • Backen (160-260°C) • Reinigung (30-70°C) • Raumheizung (20°C)
Metall	• Galvanik (20-100°C) • Waschen/Beizen (30-60°C) • Trocknen (60-90°C) • Reinigung (30-70°C) • Raumheizung (20°C)
Papier	• Erwärmen (40-80°C) • Kochen (160°C) • Trocknen (110-240°C) • Reinigung (30-70°C) • Raumheizung (20°C)
Textil	• Färben (40-130°C) • Waschen/Putzen (40-100°C) • Bleichen (60-100°C) • Reinigung (30-70°C) • Raumheizung (20°C)
Chemie	• Erwärmen (~60°C) • Kochen (95-105°C) • Destillieren (110-300°C) • Thermoumformen (130-160°C) • Aufkonzentrierung, Eindicken (125-130°C) • Reinigung (30-70°C) • Raumheizung (20°C)
Holz	• Trocknen (50-80°C) • Verleimen (120-180°C) • Lackieren (50-80°C)

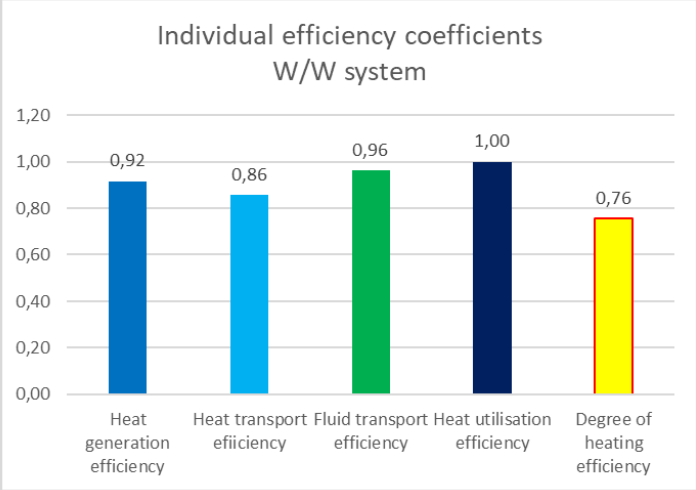
Creating a overview and standard

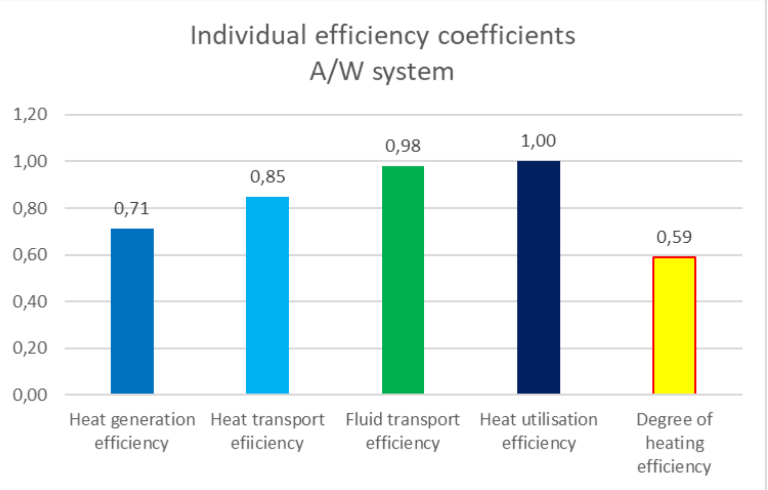
- The aim was first to find a way to represent the published data that appears from announcement
- The data available very often does not make much sense alone
- Only by asking for more data you can build the case
- Finding new projects for case studies is more difficult than first anticipated.
- Industries are not that keen to show data about their success to competitors

Project sector	District heating
Project Process	Ambient air collectors
Temperature source:	-10
Temporal course	Continiously
Temperature sink:	67
Maximum temperature	72
Expected Condensing temp.	72
Temperature lift	82
Temporal course	Continiously
system with thermal storage	No
expected operating hours	6000
mode of operation	parallel
Drive power	Electricity
Drivers	Wind generator
Compressor type:	Reciprocating
part load control:	Stepwise and stepless
Refrigerant:	R717
GWP:	0
Annual production	8.000
Heating capacity:	1.283
Absorbed power	395,0
Cooling capacity:	888,0
Usefull cooling:	no
Service lige	20
CO2 reduction	1150
equivaltent to	70
COP (el.) :	3,25

Standards for heat pumps

- TEWI is a way but …..
- VDMA 24248
- The standard includes a proposal for a standardised calculation of efficiencies





VDMA 24248	Standard formula and values			only chang
Thermal capacities			**Standard**	**Actual**
Heating Power	Q_W	kW	1970,4	1282,7
Refrigerating Power	Q_0	kW	1500	888,0
Temperatures and temperature differences				
Heat transfer medium input of evaporator	t_K	°C	18	2,8
Heat transfer medium input minus heat transfer medium output	$\Delta T_{K\text{-ein-aus}}$	K	12	5
Heat transfer medium output of evaporator	$t_{K\text{-aus}}$	°C	6	-2,2
Heat transfer medium output minus evaporation temperature	$Dt_{K\text{-o}}$	K	2	3
Evaporator temperature	$t0=t_{K\text{-aus}}-\Delta t_{k\text{-}0}$	°C	4	-5,2
Hot water temperature (effective temperature)	t_W	°C	70	68,1
Hot water output minus hot water input	$\Delta T_{w\text{-aus-ein}}$	K	30	31,8
Hot water input on condenser	$t_{w\text{-ein}}$	°C	40	36,3
Condensation temperature minus hot water output temperature	$\Delta t_{c\text{-W}}$	K	2	5
Condensing temperature	$tc=t_W+\Delta t_{c\text{-w}}$	°C	72	73,1
Drive power of compressor and oil cooling (screw compressor)				
COP compressor, cold production	COP_{oc}	-	3,19	2,25
Mechanical drive power, compressor	P_{oc}	kW	470	395
Electrical drive power, compressor	$P_{oc\text{-el}}$	kW	480	407
Oil input temperature on compressor	$t_{öl\text{-ein}}$	°C	70	
Oil output temperature on compressor	$t_{öl\text{-aus}}$	°C	100	
Oil cooler heat	$Q_{öl}$	kW	250	
Oil cooler heat utilisable or not	YES=0; NO=1	-	0	1
Degree of efficiency of electric motor	η_{el_motor}	-	0,98	0,97
Heat transfer medium transport, heat source (cold water)				
Specific heat capacity, water	c_{wasser}	kJ/kgK	4,19	4,19
Cold water mass flow rate	m_{wasser}	kg/s	29,9	42,4
Density, water	ρ_{wasser}	kg/m3	1000	1000
Cold water volume flow rate	V_{wasser}	m3/s	0,030	0,042
Pressure loss of cold water, evaporator	$\Delta P_{K\_Verdamfer}$	bar	1,5	1,5
Degree of efficiency of cold-water pump	$\eta_{el\_Wasserpumpe}$	-	0,7	0,7
Drive power of cold-water pump	$P_{FT\text{-K}}$	kW	6,3	8,9
Heat transfer medium transport, heat sink (hot water)				
Condensing heat	Q_c	kW	1970,4	1282,7
Specific heat capacity, hot water	$c_{Heisswasser}$	kJ/kgK	4,19	4,19
Hot water mass flow rate	$m_{Heisswasser}$	kg/s	15,7	9,6
Density, hot water	$\rho_{Heisswasser}$	kg/m3	1000	1000
Hot water volume flow rate	$V_{heisswasser}$	m3/s	0,016	0,010
Pressure loss of hot water, condenser	$\Delta P_{K\_verflüssiger}$	bar	1,5	1,5
Degree of efficiency of hot water pump	$\eta_{el\_heisswasser\ pumpe}$	-	0,7	0,7
Drive power of hot-water pump	$P_{FT\text{-W}}$	kW	3,3	2,0
Drive power of hot-water pump, corrected	$P_{FT\text{-W-korr}}$	kW	3,3	0,0
Total electric power requirements	$P_{ges}=P_{oc\text{-el}}+\Sigma P_{FT}\text{-K}+\Sigma P_{FT\text{-W}}$	kW	490	416
Utilisable heating power	$Q_{WN}=Q_0+P_{oc}+\Sigma P_{FT\text{-W}}-Q_{TR}$	kW	1962	1299
Individual efficiency coefficients				
Heat generation efficiency	$\eta_{KC\text{-WP}}=(Q_0+P_{oc})/P_{oc\text{-el}}/(T_c/(T_c-T_0))$	-	0,81	0,71
Heat transport efiiciency	$\eta_{WT\text{-WP}}=((T_c/(T_c-T_0))/(T_W/(T_W-T_K)))$	-	0,77	0,85
Fluid transport efficiency	$\eta_{FT}=P_{oc\text{-el}}/P_{ges}$	-	0,98	0,98
Heat utilisation efficiency	$\eta_{WN}=(Q_W)/(Q_0+P_{oc})$	-	1,00	1,00
Degree of heating efficiency	$\eta_{ges\text{-wp}}=\eta_{KC\text{-WP}}*\eta_{WT\text{-WP}}*\eta_{FT}*\eta_{WN}$	-	0,61	0,59
Transmission heat power dissipation	Q_{TR}	kW	28,02	4,44

Calculations can be done in many dimensions

- Cordin Arpagaus shows in his book how you can build up a model
- Papers show the lowest possible COP but which and integrated how?
- Many engineers have their version of "the true pictures" in an Excel sheet
- New technologies such as digital twins will help giving us a closer understanding

Electricity price	61,2	€/MWh
Gas price	26,2	€/MWh
Max amortisation time	5	years
η_{ref}	0,9	-
Operation hours	4500	Hours
$Inv_{heat\ pump}$	2500	k€
Inv_{ref}	1860	k€
Realistic COP	3,5	
Ratio (Eprice/Gprice)	2,34	
Energy cost saving	33,3	%
COP_{min}	2,11	

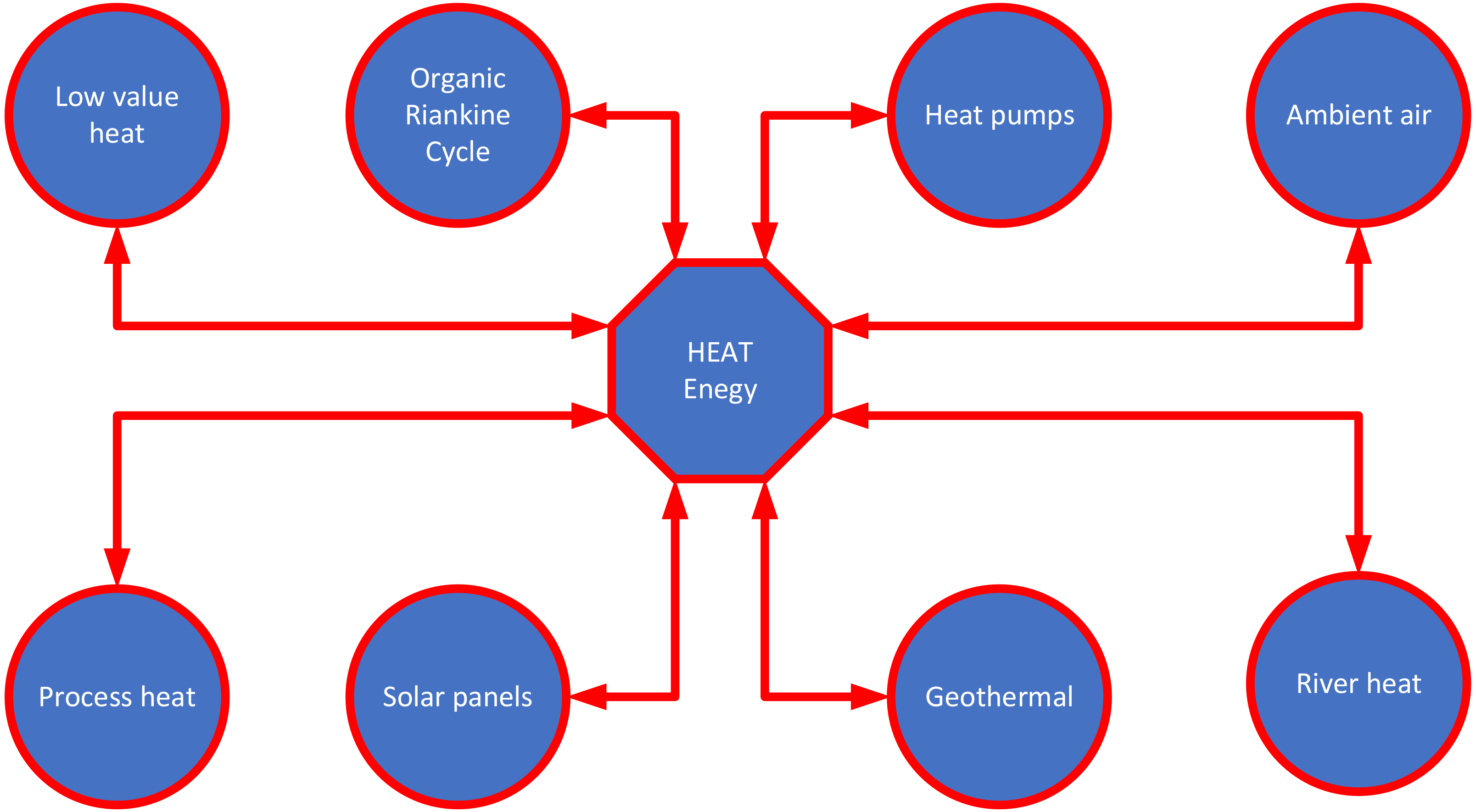
Source: Marktpotenzial für Hochtemperatur-Wärmepumpen in Europa
16. Symposium Energieinnovation, 12.-14.02.2020, Graz/Austria

Standards for heat pumps

- Standards limiting the charge of HC and NH_3 are mainly about systems in area with open access to the public
- In some countries there are special limiting rules for flammables especially NH_3
- Outdoor installation or installation in special machine room with limited access, competent persons only, is a totally different matter with less restrictions
- Will there be competent hands enough to meet the demand of new installations in the future if we are to meet the goals of decarbonising the heating systems before 2050?
- Standards are under revision, your participation will help driving the development in the right direction

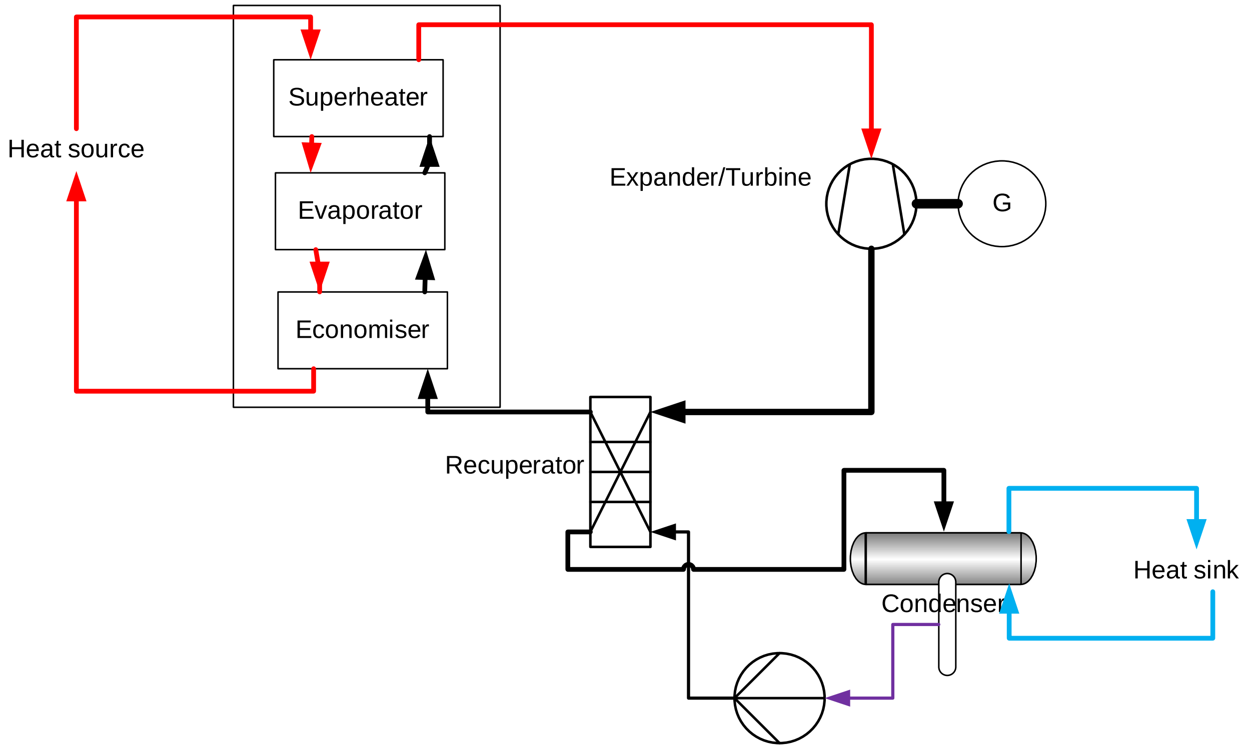
Sources and sinks

- Sector coupling and integration of heat pumps
- It is all about energy for heating either space or process
- Heat can also be recovered and produce energy
- Heat pumps is one of the cornerstones in the future energy system



Organic Rankine Cycle (ORC)

- Basically a heat pump with the fluid operating in the opposite direction
- Different natural refrigerants have been proposed for this process including CO_2, NH_3 and different HC types



Conclusions

- The market for higher and high temperature heat pumps is in demand, but orders lagging behind
- The different published data does not always give the full picture of the benefits of the products and their benefits
- Tools and standards are in place but not very often used e.g. VDMA 24248
- Does the end-user really want to take the step in to the future
- Especially in Europe there is a push to get out of fossil fuels, but the biggest users of fossil fuels are foot-dragging with their decision
- A worry is the lack of sufficient manpower to do the transition, but waiting is not an option

Thank you very much for your kind attention