HVACC 4.0
- A Green Field Approach -

Expert meeting
SHC Task 53

Abu Dhabi, 29.10.2017

Dr. Thomas Noll, Kipfenberg
TNT (Thomas Noll Technologies)

HVACC 4.0 =
Heating
Ventilation
Air Conditioning &
Chilling (fridges, freezers)
4.0: Smart Grids
Sector coupling

Similar to SHC task 44:
ST and Heat Pumps

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 53

Agenda

HVACC 4.0
Personal #1: Curriculum vitae

1954:	**Born 14.5.54 in Frankenthal/Pfalz (Germany)**
1987:	**PhD in Physics @ Univ. Kaiserslautern**
1988:	**Post-Doc (Univ. Kaiserslautern)**
1989-2017:	**Osram GmbH, thereof**
2011-2014:	**Leader Task 1 of „Enlight"-Projekt**
2014:	**Enlight Innovation Award**
2014-2017	**Passive phase of early retirement**
9/16-today:	**Patent application and founding easy-tnt**

EnLight INNOVATION AWARD 2014

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Thomas Noll Technologies

Dr. Dipl.-Phys. Thomas Noll
Mühlleite 2
85110 Kipfenberg

Tel. +49(0)8465 905-155
Mobil: +49(0)176 3537 4265
Mail: tnoll1954@gmail.com

Introduction #1
HVAC megatrends: Summary

Megatrends:

- (Extra) Low temperature District Grids (≥4G) for heating and cooling

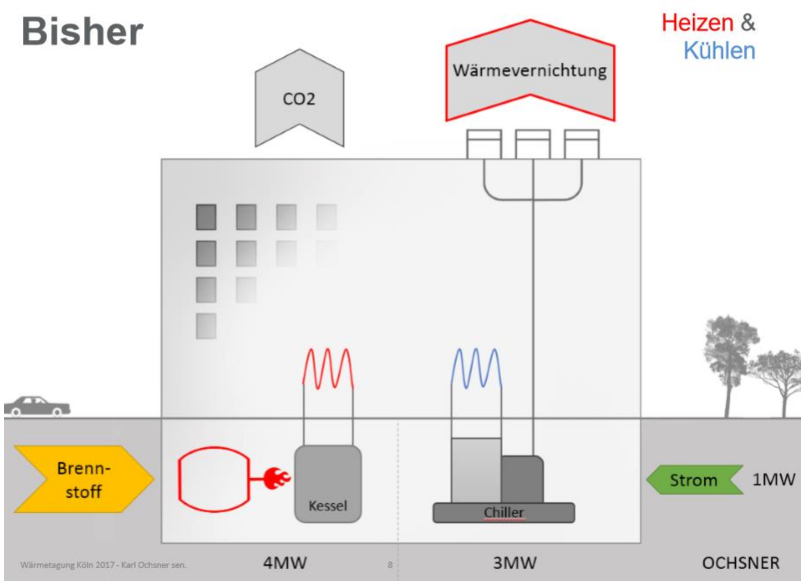
Managing the energy transition:

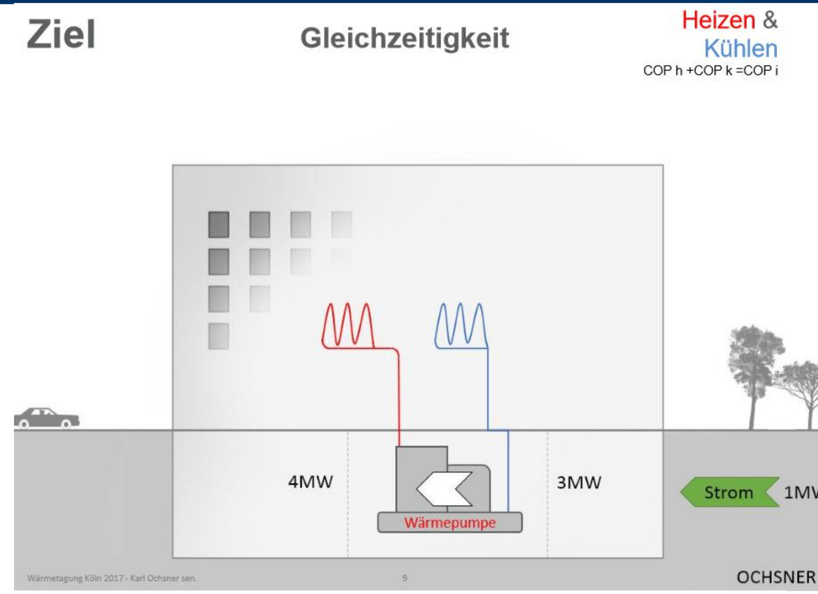
- Phase out firing Hydrocarbons by 2050
- Sector coupling: Electricity, Traffic & HVAC
- Smart electric grid coupled to thermal DG

Regulations for Heat Pumps:

		Effective
• Ban of F-gases with GWP	> 150: mobile chillers	2020
e.g. R404A, R422, R227ea,…	> 2500: service stop	2020
	> 150: Central > 40kW	2023
	> 750: mono split < 3kg	2025

HVAC megatrends (Ochsner, heat summit, Cologne, 20.11.17) "Simultaneous" heating & cooling (VRF)

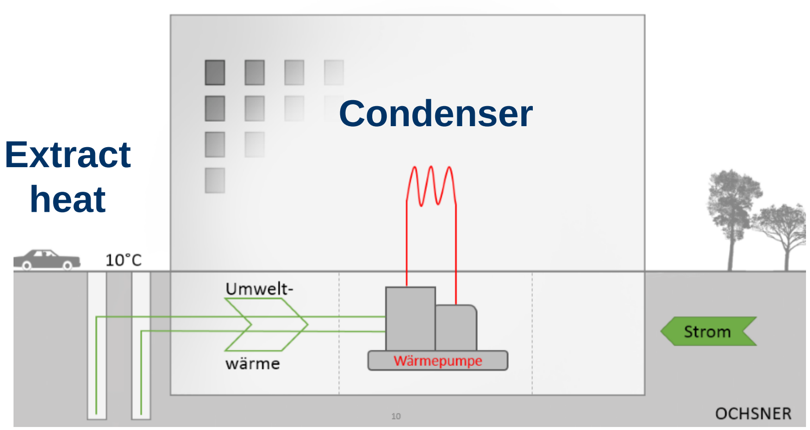


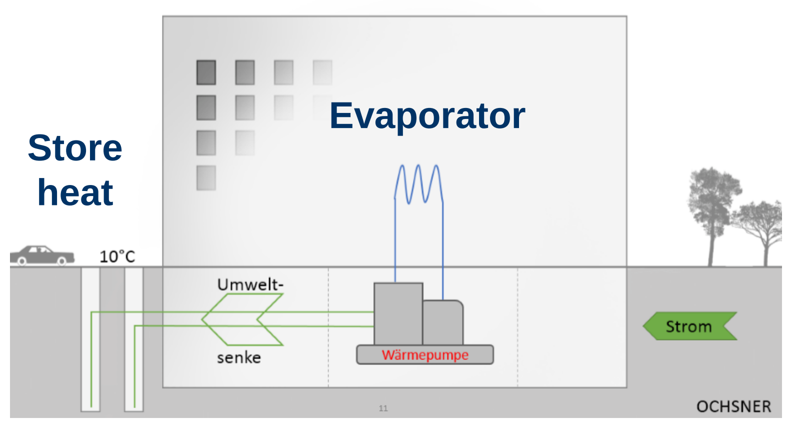


Ziel Winterbetrieb Heizen

Ziel Sommerbetrieb Kühlen

Source: [O17]



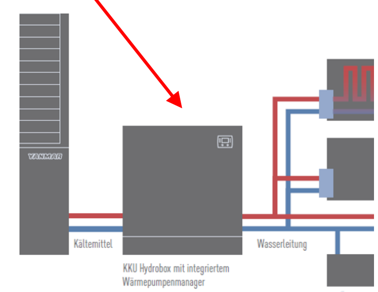


HVAC megatrends
VRF: Separating facts from fictions

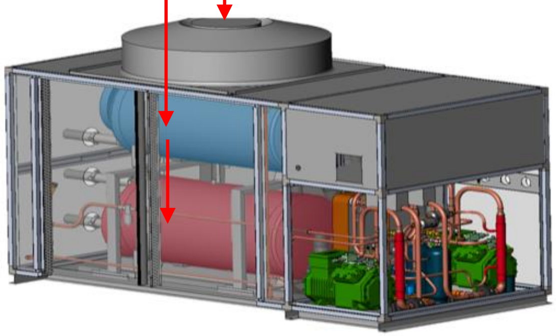
- Strongly promoted as „The future HVAC-technology“.
- Simultaneous H&C @ HP only in case of Classic VRF - with usually >> 3kg refrigerant - and use of special indoor units.
- No simultaneous H&C @ HP in case of water based systems, only “toggling source and sink” between “Hydrobox” and “outdoor device”.
- Simultaneous H&C @ consumers only in case of additional hot & cold BS serving circuits for space heaters & coolers.
- Mainly air based systems -> high T_w and low T_c.
- Not suitable for DHW.
- No storing of excess heat/chillness in BS, but in contrast to HVACC 4.0 release to environment.

VRF System Market worth 22.79 Billion USD by 2023

Source: Bauherrenwissen



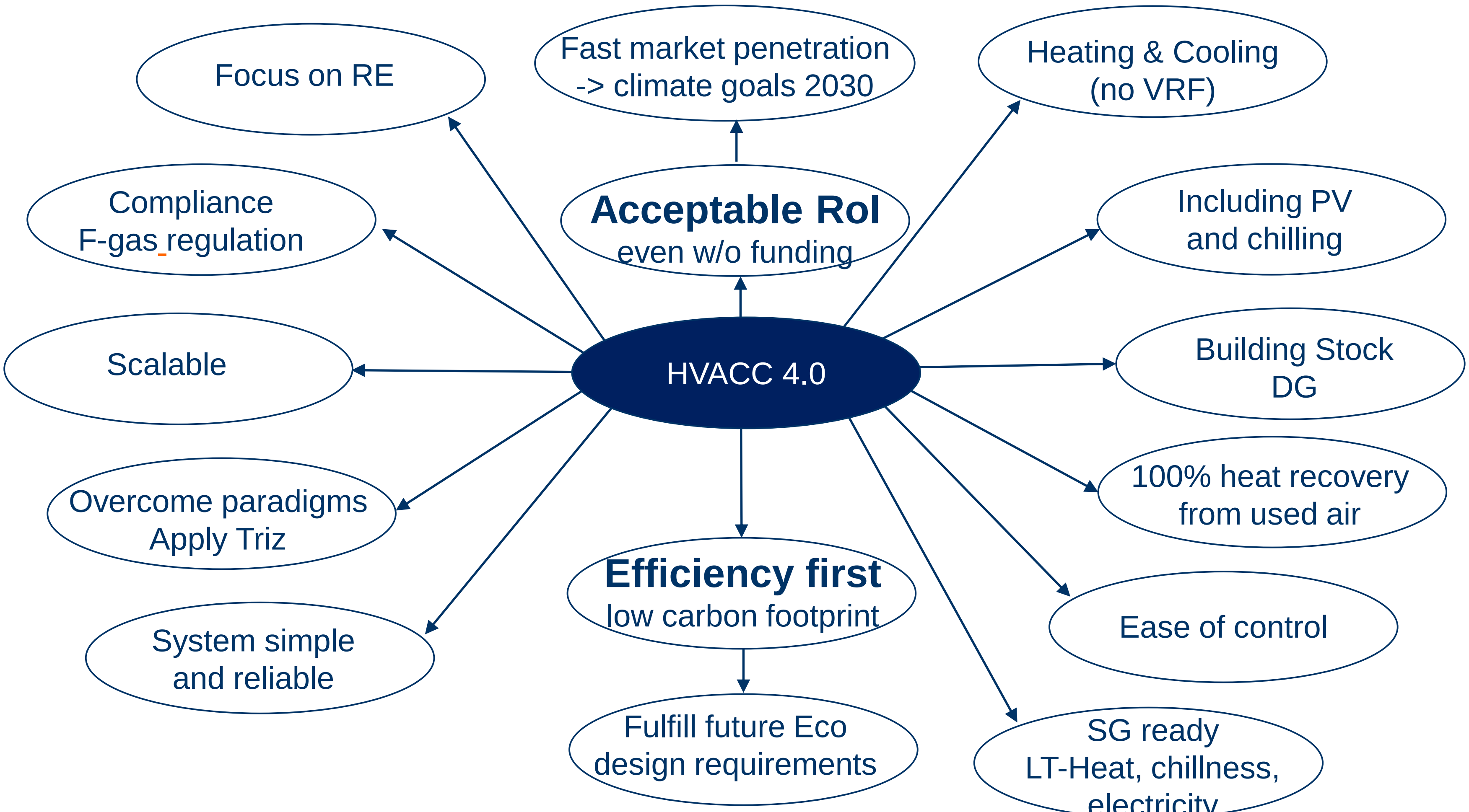
Source: Yanmar



Source: van der Hoff/TripleAqua

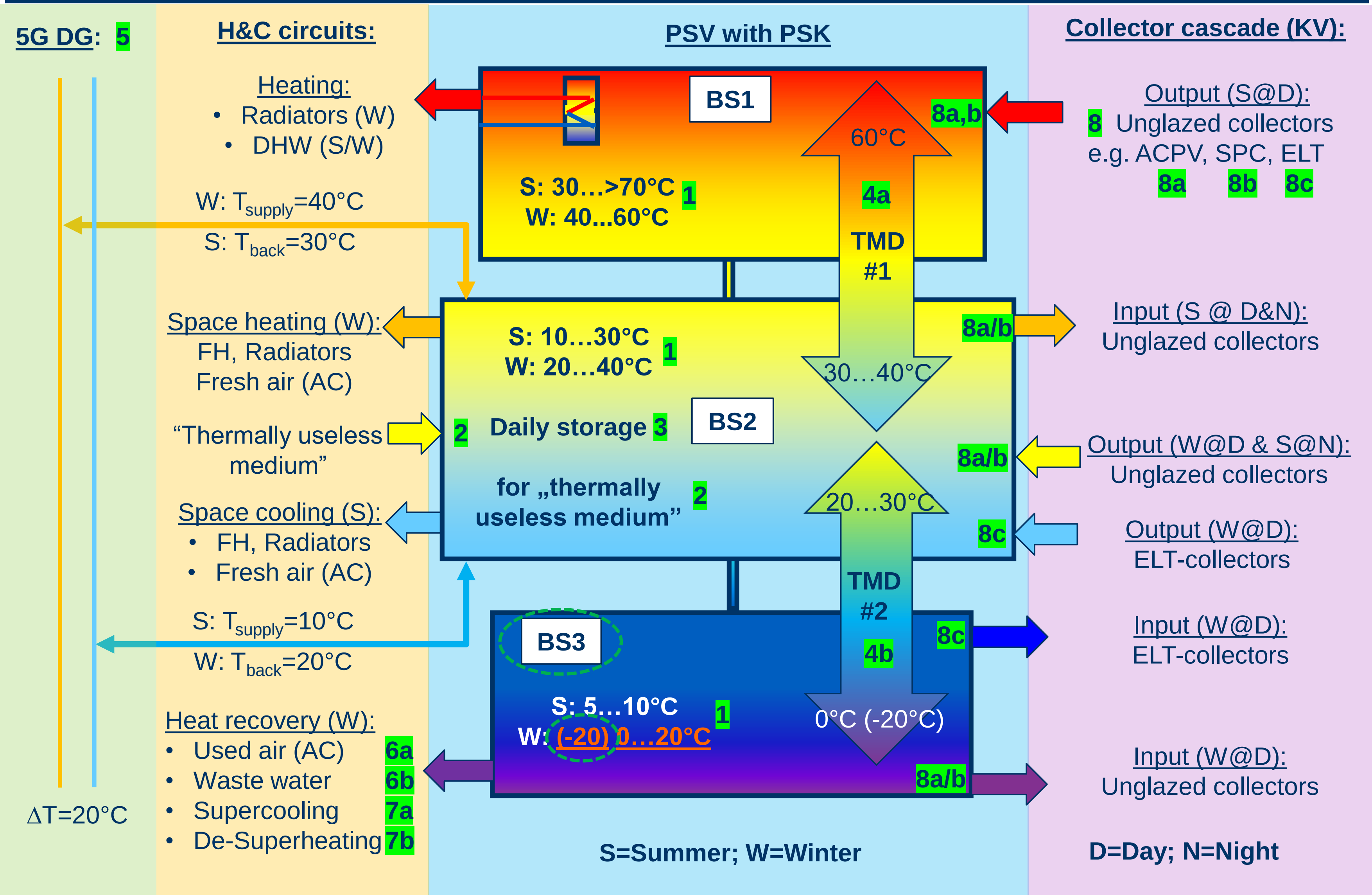
Introduction #2
Requirements on future proof HVAC systems

Legal & Design goals | Cost & efficiency | (Technical) Capabilities



HVACC 4.0
Thermal management and functional blocks

n New or unusual



HVACC 4.0
Thermal management: Description and what is new

The "heart" of HVACC 4.0 is the buffer storage cascade PSK, consisting of preferably three hydraulically coupled storages BS1, BS2 and BS3 with predefined temperature profiles, which are seasonally different (1). They range from about 70°C on top of BS1 in summer and may fall below -20°C in BS3 in winter by the action of TMD#2 (4b). BS2 is designed as a daily storage (3) for chillness, which is needed for operation of water and air based chillers and optionally for active PV cooling. The size of BS2 for AC should be ≅3500 l for a 100m² building @ 100kW/a*m². BS2 could be e.g. a modified oil tank in the building stock, if refurbishment of the heater system is necessary.

The PSV is basically identical with the PSK, but includes additional, preferably PSK-integrated components like HEX for energy exchange with collectors of the KV and condensers & evaporators of TMD#1/2 (not shown). The two TMDs (4) work like heat pumps with the difference, that in a first step there is no dissipation of waste heat or chillness to ambient like in case of water based VRF. And they are only active if the KV is not able to maintain the desired T-profiles in the PSK. In difference to SotA, the T-lifts are low (<30°C), resulting in high COP and EER. For each °C the KV or the DG (5) lifts T(BS2) above 5°C in winter (=T_{Brine}) or lowers T(BS2) below 40°C in summer (=T_w @ $T_{outside}$=30°C), the efficiency is 3% ahead of a brine-water HP or an air based chiller [AEA07].

The PSK acts as heat and chillness source for serving the H&C circuits for space heating and cooling. Radiators are supplied with hot medium from top of BS1 and floor heaters with medium from top of BS2. The backflow of thermally useless medium (2) ends in the middle part of BS2.

BS3 is the source for HEX like e.g. for heat recovery from used air in winter (6a) and waste water (6b), boosting efficiency above 100% if T(BS1) is below $T_{outside}$, which is much ahead of SotA (<80%). Other examples are HEX for heat recovery from superheated compressed refrigerant via DSH (7b) and from condensed refrigerant via SCD (7a), refer to slide 10.

The PSK may be coupled to a 4G DG, which is operated between 50…60°C for heating. Alternatively, a new heating & cooling 5G DG (5), refer to slide 13, could be designed with two pipes operated @ a ΔT of 20°C by exchanging medium from the top resp. bottom of BS2 with the DG. This may be done in summer @ 30/10°C and in winter @ 20/40° as consumer, producer or prosumer of energy.

The KV consists of different types of preferably unglazed ST collectors (8) like Actively Cooled Photo Voltaic collectors ACPV (8a), cheap Swimming Pool Collectors SPC (8b), or new collectors designed for Extra Low Temperatures ELT (8c), which are not explained here.

ACPV collectors (8a) are basically modified PVT-collectors with an additional evaporator on the back side, allowing 8 different operation modes, refer to the table below. The most important ones are evaporation of excess refrigerant in winter and regenerative cooling of BS2 over night.

Unglazed collectors (5) are preferred over glazed ones due to their ability to boost the collector efficiency >100% if T_{input} < $T_{outside}$. In summer and during night, BS2 is chilled down to 10…25°C, depending on the climate zone. Like in SHC task 53, this is done mostly regeneratively. The cooling power is boosted by the NRC-Effect @ a cooling power 50…100W/m² allowing EER values up to 60 [POK15].

#	Task	BS	8 hybrid operation modes (ext. to SotA PVT)	Day/Night	Season
1	H	3	Evap. of excess refr. (M3) (in cold regions)	D+N	Wi
2	C	2/3	RE cooling utilizing air cooling + NRC effect	N	Su
3	H	2	Boosting COP by rising T_{cold} > T_{Brine}	D	Wi
4	H	1	WW-production (T>50°C)	D	Su+Wi
5	PV	2/3	Maximize PV output by active cooling (M2)	D	Su
6	H	./.	Preheat outside air for AC	D	W
7	C	2/3	Active cooling by evaporation of refrigerant	N	Su
8	PV	1/2	Max. PV output by evaporation of refrigerant	D	Su

HVACC 4.0
Chiller process: Log p(h)

Cycle:	T in °C
4‘,1‘: Evap#1 (no overheating needed):	10
1‘2‘: Comp#1 (15°C Superheating)	55
2‘2‘‘: De-Superheating (via DSH-Device) **7b**	41
2‘‘3‘: Cond#1 (SC 30°C via SCD) **7a**	10
2‘‘2‘‘‘: Comp#2 (15°C Superheating)	85
2‘‘‘3‘‘: Cond#2 (SC 60°C via SCD) **7a**	10

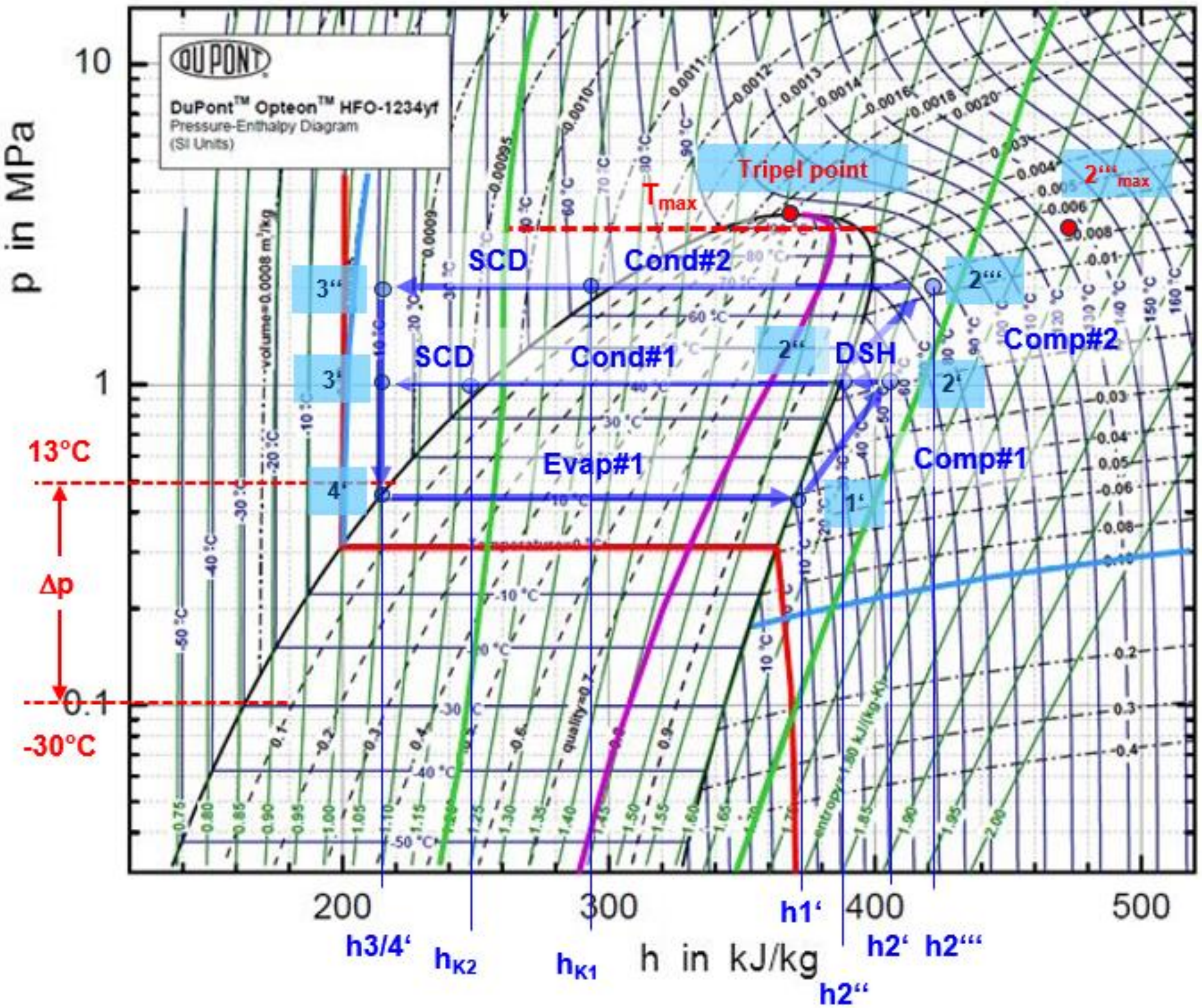
Formulas:

$$COP = \frac{Q_h}{P_V} = \frac{h2' - h3'}{h2' - h1'} = \eta_{WP} * \frac{T_W}{T_W - T_k}$$

$$EER = \frac{Q_c}{P_V} = \frac{h1' - h4'}{h2' - h1'} = \eta_{KM} * \frac{T_W}{T_W - T_k}$$

Efficiency improvement potential:

	COP/EER für R1234yf (Fig. 3a)				
	Enthalpie [kJ/kg]		Tw/Tk	°C	
	h1'	371	Tk (PS3)	10	
	h2'	406	Tw(PS2)	40	
(A)	h2''	387	Tw(PS1)	70	
	h2'''	424	Freiwerdende Enthalpien [kJ/kg]		
	h3', h3'', h4'	214	2'->2'': EHS/HGK -> PS1		19
	h_{K1}	293	SCS Kond. 1 (hK1-h3'')		79
	h_{K2}	248	SCS Kond. 2 (hK2-h3')		34
(B)	T-Hub	Definition Enthalpie		Definition Tw/Tk	
	°C	EER	COP	EER	COP
	10↔70	2,96	3,96	2,96	3,96
	10↔40	4,49	5,49	4,49	5,49
(C)	η für T-Hub	η ber.	COP/EER	SdT	Potenzial
	ηWP 10…70	69%	134%	45%	54%
	ηWP 10…40	53%		45%	17%
	ηKM 10…70	52%	122%	33%	59%
	ηKM 10…40	43%		33%	32%



HVACC 4.0
Chiller process: Description

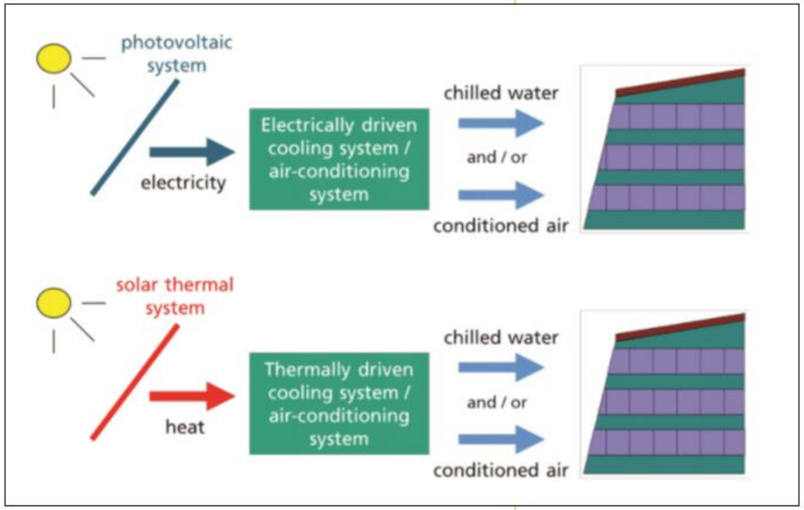
The process can be best described by looking at the log p(h) diagram as shown for e.g. R1234yf with a GWP of 4. Once the process is defined via the points 1'…4', the enthalpies h1'…h4' can be taken as readings from the x-axis. COP, EER and the efficiency η_{HP} of the heat pump and η_{CM} of the chiller can be calculated straightforward using the formulas shown. The following specific features are worth mentioning:

1. There is a 2-stage compression process 1'→2' and 2''→2'''.
2. Compressor #1 enables a T-lift of ≅30°C from e.g. 10°C, which is the upper temperature in BS3, to 40°C, which is the upper temperature in BS2 in winter. This T-level is needed for operation of e.g. floor or wall heaters.
3. Compressor #2 enables a T-lift of ≅30°C from 40°C, which is the upper temperature in BS2, to 70°C, which is the upper temperature in BS1. This T-level is needed for DHW production and operation of radiator heaters.
4. Between the 1st and 2nd compression De-Superheating (DSH) takes place (7a) by means of a HEX, which is supplied with medium of 40…45°C from BS1. This "sequential cooling" allows to store „high value heat" of 19 kJ/kg in BS1 instead of BS2 and reduces the work of TMD#1 in winter.
5. If condensation takes place @ 40°C in BS2, subcooling (7b) is from 40→10°C with a heat release of 34 kJ/kg. If condensation takes place @ 70°C in BS1, subcooling is from 70→10°C with a heat release of 79 kJ/kg. Compared to SotA, where subcooling is typically <5°C, the PSV concept allows <u>strong subcooling</u> close to 0°C - or even lower if the medium in BS3 is with antifreeze - due to the availability of cold medium in BS3.
6. The thermal energy is exchanged in a liquid-liquid HEX, which is preferably integrated in BS3. While the released heat is stored in BS3, cooling the refrigerant increases the cooling power and lowers the risk of flash gas formation, which should not happen in the tubing of liquid refrigerant. In addition, heating of BS3 helps to avoid freezing of the medium by the action the evaporator of TMD#2.
7. As a consequence, flash gas formation, which would be up to 50% w/o subcooling, can be totally avoided. This is the reason for the much higher EER, where the difference h1'-h4' is in the nominator of the EER formula.
8. Strong subcooling (7b) is essential for refrigerants like HFOs and natural refrigerants like R433A, where the liquid-vapor curve has in the relevant pressure range often "flat shape", especially if conden-sation takes place @ high temperatures close to the triple point.
9. In contrast to SotA, where there is generally a pressure drop of ≅0,5 bar in the evaporator necessary as driving force for refrigerant flow [SBT0x], in case of HVACC 4.0 evaporation takes place preferably in an "evaporator spiral" located inside BS2 or BS3 and with a much higher cross section as e.g. in plate HEs. The evaporation process is therefore mostly isobar.
10. In contrast to SotA, where an overheating of typically 5°C is needed to avoid a compressor damage due to liquid refrigerant [Vi11], in case of HVACC 4.0 at the point of evaporation the compressor is „far away" and will heat up anyway in the tubing.
11. As can be seen in the table, the efficiency of the heat pump η_{HP} is increased between 17%…54% if compared with an anyway efficient brine-water HP with η_{HP}=45% [Zo09]. In case of anyway efficient water based chillers with η_{CM}=33%, η_{CM} is increased between 32%…59%. The efficiency improvement potential is higher for the higher T-lift due to the additional savings from DSH (7b) and the higher supercooling (7a). In absolute values, the efficiency η_{HP} of the heat pump is 69%, and η_{CM} of the chiller is 52%. Both would be world record for cost optimized domestic applications.
12. Further optimizations of the COP and EER should be possible, if the refrigerant is a zeotropic mixture of HFOs or a HFO with other HFC like R452 and R454, so that the T-glide of the refrigerant is adapted to the T-glide the condenser [ZBE17]., which is also preferably located inside BS1 or BS2.

HVACC 4.0
Difference to SHC task 53

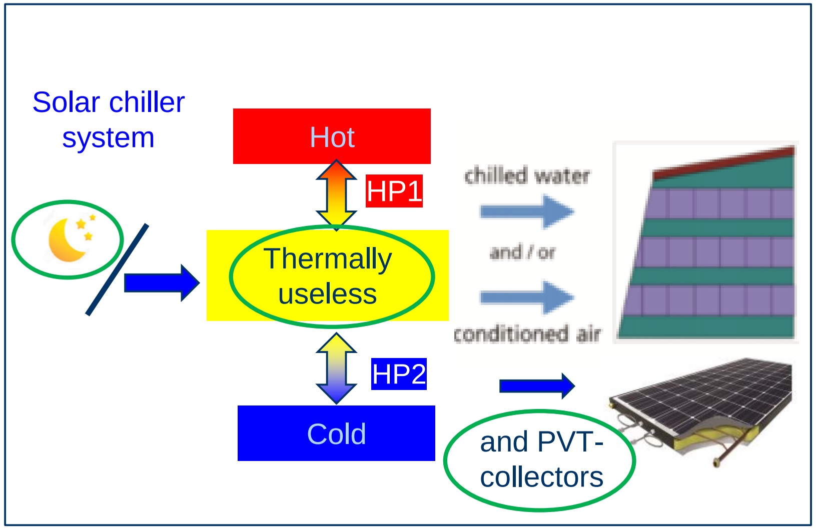
Differences

In SHC task 53 for solar cooling basically two possibilities are investigated:



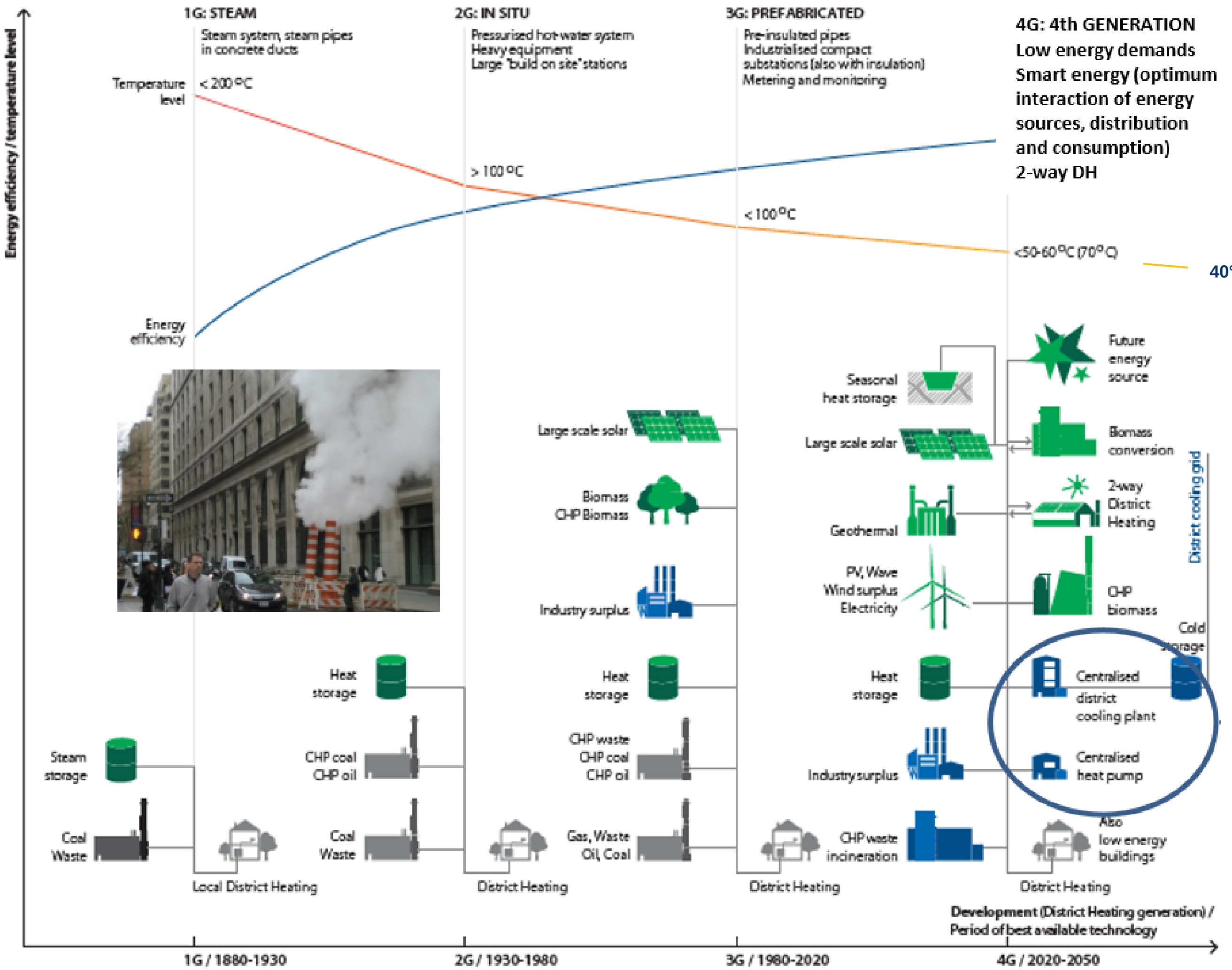
Source: [Mu14]

In HVAC 4.0 solar cooling is shifted to the night.
In addition Heating and Chilling (fridges,…) is addressed.



1. **EER up to 60 if produced over night with unglazed collectors instead 3,5 if produced during day using a PV driven water based chiller**
2. **Affordable, unglazed collectors + NRC effect (50…100 W/m² free of cost)**
3. **The price to pay is the more complex PSK and the size of BS2 (daily storage)**
   But: Additional active PV cooling is possible

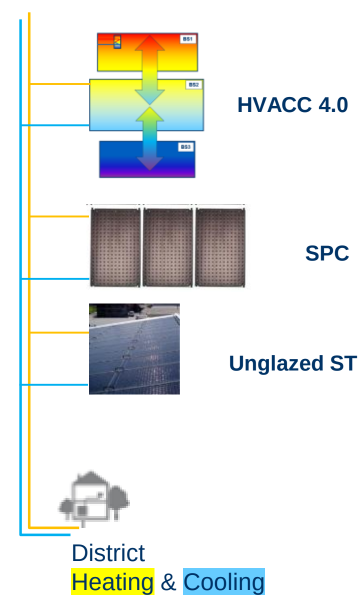
HVACC 4.0
Difference to DG 4G



40°C

5G: 5th generation extra low temperature DG for heating & cooling of buildings utilizing HVACC 4.0

Summer: T_{supply}=10°C -> Cooling
Winter: T_{supply}=40°C -> Heating
$\Delta T_{in/out}$=20°C



Source: [P17]

HVACC 4.0: Results #1
Efficiency improvement potential

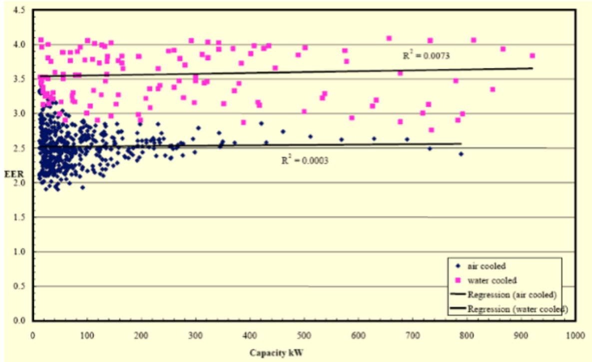
Benchmark heat pump and chiller: SotA vs. HVACC 4.0

Techn.	Mode	Type	Heat source	Twarm °C	Tcold °C	ΔT °C	η %	COP/ EER	Eff.-Potential abs.	Eff.-Potential per °C	Remark
SotA	HP	WW	Tsole	65	5	60	45%	2,5			Tcold=Tsole is fix @ 5°C
HVACC 4.0	HP	WW	TBS2	65	12,5	52,5	69%	4,5	76%	10,1%	Tcold↑ due to BS2+collectors
SotA	Chiller	AW	Toutside	30	7,5	22,5	33%	4,4			Tcold ≅ 7,5°C, Twarm=Ta
HVACC 4.0	Chiller	WW	TBS2	20	12,5	7,5	43%	16,8	282%	18,8%	Tcold↑ due LWR, Twarm↓ due BS2
SotA	HP	AW	Toutside	65	-10	75	35%	1,6			Tcold um 10°C unter Ta=0°C
HVACC 4.0	HP	WW	TBS2	65	10	55	69%	4,3	170%	8,5%	Tcold bei Ta=0°C 10°C
SotA	Chiller	WW	Triver	20	7,5	12,5	33%	7,7			Tcold ≅ 7,5°C, Twarm=Triver
HVACC 4.0	Chiller	WW	TBS2	20	12,5	7,5	43%	16,8	120%	23,9%	Tcold due LWR↑, Twarm id.

Efficiency improvement potentials:

- **Baseline = COP sole-water heat pump: ≅76%**
- **Baseline = EER air based chiller ≅282%**
- **Baseline = COP air based HP: ≅170%**
- **Baseline = EER water-water chiller: ≅120%**

➢ **Fulfillment of stringent requirements of next gen. chillers [EC12]**



Source: [UBA07]

The efficiency improvement potential is a direct result of

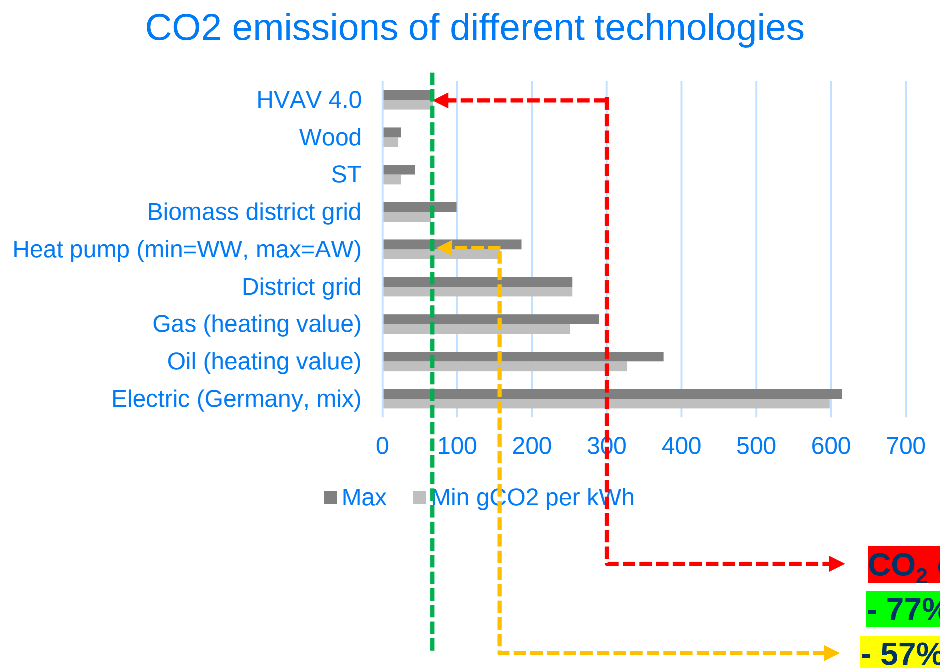
- **The lower T-lift $\Delta T = T_W - T_C$ due to the buffer storage architecture :+3% per °C**
- **The improvement of η_{HP} resp. η_{CM} due to the special cooling process with R1234yf**

$$COP = \frac{Q_h}{P_V} = \frac{h2' - h3'}{h2' - h1'} = \eta_{WP} * \frac{T_W}{T_W - T_k}$$

$$EER = \frac{Q_c}{P_V} = \frac{h1' - h4'}{h2' - h1'} = \eta_{KM} * \frac{T_W}{T_W - T_k}$$

$$COP_{ges} = \%COP_{heat} + \%COP_{chill}$$

HVACC 4.0. Results #2
Carbon footprint of different technologies



<u>Data source:</u> Öko-Institut
<u>Excel:</u> Misc#18

<u>Achievable with HVACC 4.0: 68g CO_2/kWh</u>
-> same level as biomass in district grids
-> close to glazed ST-collector

CO_2 emissions for oil/gas: 300g CO_2/kWh (mean)
- 77% for baseline combustion
- 57% for baseline WW-HP: 157g CO_2/kWh

<u>Energy saving potential in Germany by switch from combustion to HVACC 4.0 (Baseline = WSVO95):</u>

- **77% energy saving compared to combustion of oil/gas @ 300 g CO_2/kg**
- **57% energy saving compared to water-water heat pump @ COP≅4,0 for T-Hub 10°C → 70°C (= worst case)**
- **Saving ≅100 Mio t oil-equivalent resp. ≅350 kg CO_2/person**
- **Fulfillment of climate goals 2030 by change over to HVAVV 4.0 for 55% of building stock**
- **Additionally needed electricity for HP operation i.e. via 15.000 windmills of 6 MW class @ 40% full load**

Summary #1: Business model
"What will be the mainstream in future?"

Technical, economical and ecological:

1. **Efficiency first: This is not negotiable (if RoI ok)**
2. **COP_{total} = $\%COP_{heat}$ + $\%COP_{cool}$ due to simultaneous heating & cooling (no VRF)**
3. **Cost: No boreholes, ice or seasonal storages or PCM, cheap unglazed collectors**

Political:

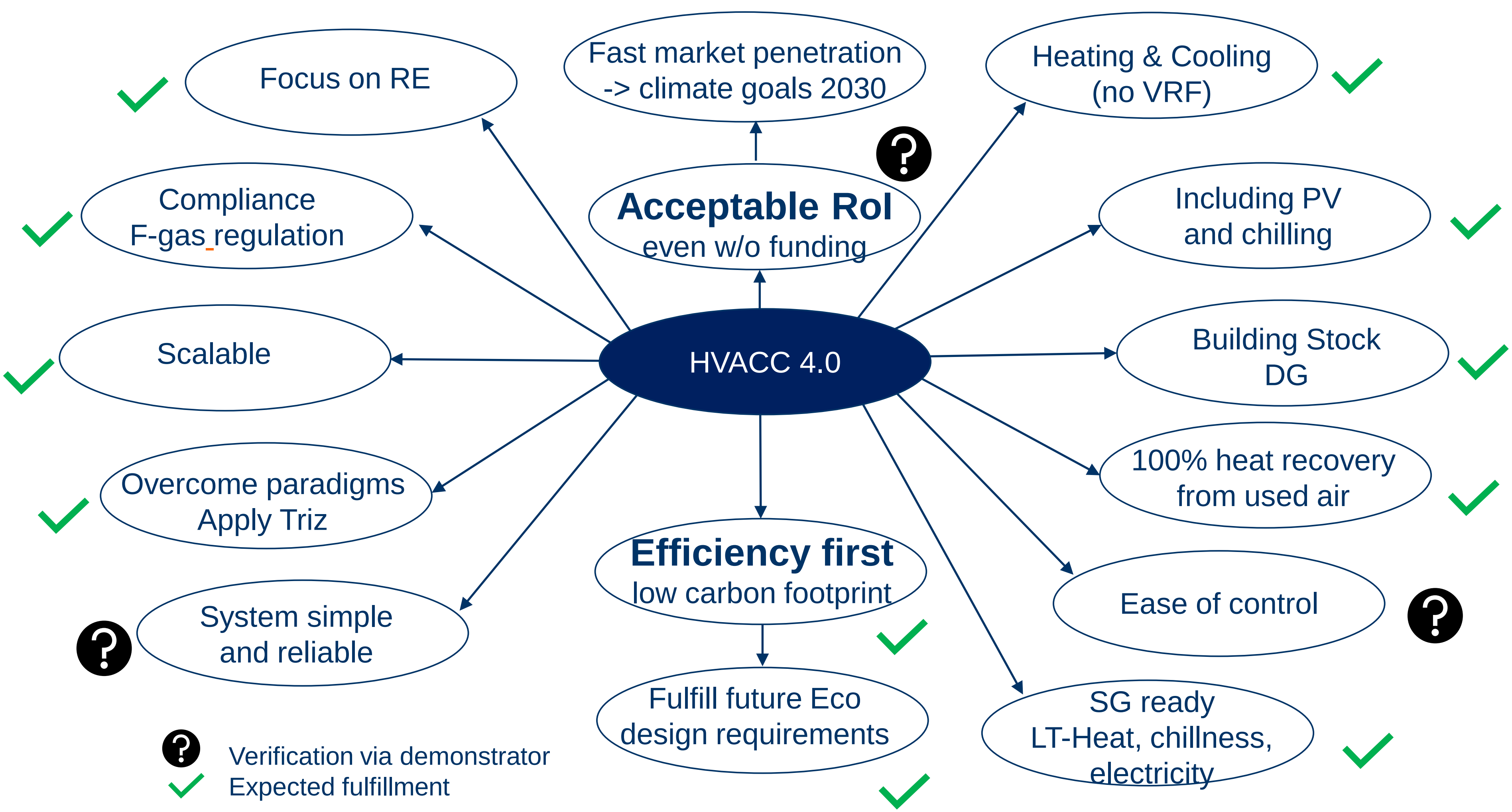
1. **F-gas regulation**
   -> ban of F-gases GWP>750; use of HFO or zeotropic mixtures with 1 digit GWP
2. **More stringent requ. on Ecolabel and BAT-Approach (Best Available Technology)**
   -> phase out air based systems with lower T_{cold} , fan & defrosting
3. **Funding: Stop discrimination of unglazed ST collectors**

Win Win Win:

1. **Customers: Homeowners, building operators: RoI, contracting, …**
2. **Environment: Fulfillment of climate goals, stop firing HC**
3. **Grid: Sector Coupling, Electricity ↓, Smart Grid, 5G DGs for H&C**

Summary #2: Requ. on future proof HVAC systems Does HVACC 4.0 meet the requirements?

Legal & Design goals | Cost & efficiency | (Technical) Capabilities



HVACC 4.0
Personal #2: LinkedIn Profile

Thomas Noll, PhD

Entrepreneur & Founder of €A$¥ - TNT - HVACC 4.0 -

easy-tnt • Technische Universität Kaiserslautern

Kipfenberg, Bayern, Deutschland • 403

Thinking in systems and consequent application of Triz-methodology offer opportunities to overcome paradigms, which is a prerequisite for boosting COP and EER of today's heat pumps & chillers towards double-digit values. A "Green Field Approach" opens the door for reduction of carbon footprint from today 300 mg CO2 to about 70 mg CO2 per kWh. The solution is HVACC 4.0, patent pending.

Missions & Visions:
- To realize a highly efficient water based chiller process for simultaneous heating & cooling w/o need for exploitation of a heat source like drillings.
- Use of future proof refrigerants with GWP<10 w/o conflict with F-gas act.
- To keep the system cost down by avoiding seasonal/ice storages and PCM.
- To fulfill Paris protocol for building sector and make the energy transition to happen.
- To invite first movers for collaboration @ free license.

Efficiency fist is not negotiable!

Web site www.easy-tnt.de under construction

Thank you for your attention

HVACC 4.0
Annex #1: Shortcuts

HVACC modules:

1. PSV: Puffer-Speicher-Vorrichtung (=Buffer Storage Device, including integrated components like HEX, condenser, evaporator, …)
2. PSK: Puffer-Speicher-Kaskade (=Buffer Storage Cascade, consisting of up to three hydraulically coupled BS)
3. H&C: Heating & Cooling (e.g. via FH/RH and warm/cold medium from PSK or via AC and warm/cold air supplied from BS-sourced HEX)
4. CRS: Central Refrigerant Supply (for consumers of KM as part of KMV) (not described here)
5. KMV: Kälte-Mittel-Verbraucher (=consumers of liquid refrigerant like HPs, chillers, fridges, VRF indoor units,…) (not described here)
6. KV: Kollektor-Vorrichtung (Collector Device) for regenerative charging of PSK with heat or chillness
7. BM: Building Module (for system control and operation, not described here)

System components and other:

AC: Air Conditioning (e.g. via air-liquid or liquid-liquid HEX sourced with warm/cold medium from PSK)
ACPV: Actively Cooled PV-Collector (modified PVT-Collector with additional evaporator for refrigerant)
BS_i: Buffer-Storage #i (with defined T-profile $T_i=[T_{ia},T_{ib}]$, $T_{ia}>T_{ib}$, i=1,2,3)
COP/EER: Coefficient of Performance (heat pumps) resp. Energy Efficiency Ratio (chillers and freezers)
DG: District Grid (e.g. 4G for heat 50…60°C or 5G for heat & chillness 10…40°C in combination with HVACC 4.0
DHW: Domestic Hot Water (e.g. produced via BS1-integrated HEX)
DSH: De-Super-Heating (cooling of superheated compressed refrigerant close to condensation temperature)
FH/RH: Floor Heaters resp. Radiator Heaters (for space heating & space cooling)
HEX: Heat Exchanger (either integrated in BS or external like e.g. plate or micro channel heat exchangers)
HFO/HFC: Refrigerants of the groups Hydro-Fluoro-Olefine resp. Hydro-Fluoro-Carbon
HP/CM: Heat Pump (AW=Air-Water, BW=Brine-Water, AA=Air-Air) resp. Cooling Machine like Chillers (either air or water based)
GWP: Global Warming Potential (use regulated in F-Gas regulation)
KM: Kälte-Mittel (=Refrigerant used in HP or CM)
LWR: Leit-Wert-Regler (=device for pressure regulation during evaporation process)
NRC: Nocturial Radiation Cooling (for cooling e.g. BS2 over night)
PV/PVT: Photo Voltaic resp. Photo Voltaic & Thermal
RE: REnewable energies like ST, PV,…
SotA: State of the Art (e.g. HVAC vs. HVACC 4.0)
SCD: Super Cooling Device (for strong subcooling of condensed KM)
SG: Smart Grid (electric, DG for heat and chillness)
SPC: Swimming-Pool-Collector (as e.g. low cost unglazed ST collector for cooling BS2 over night)
ST: Solar Thermal collector for HT (High Temperature), LT (Low Temperature) and ELT (Extra Low Temperature) applications
T_w/T_c: T_{warm} resp.T_{cold} in condenser resp. evaporator of HP/CM
TMD: Temperature-Modification Device (=pair of condenser and evaporator, which may be integrated in BS)
VAF/VRF: Variable Air Flow resp. Variable Refrigerant Flow
WW: Waste Water (heat recovery via HEX sourced with cold medium from BS3)

HVACC 4.0
Annex #2: Literature

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