BIN METHOD FOR THE RATING OF SOLAR COOLING

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AGENDA

- Background electrical chillers and motivation
- Results of the project „proposal for a DIN-standard solar cooling“
- Bin-Method procedure for solar cooling

Background

- EU Directive Nr. 206/2012 for compression chillers uses the bin method
  - Definition of a frequency distribution for hours per temperature (reference weather)

j	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Tj	°C	17	18	19	**20**	21	22	23	24	**25**	26	27	28	29	**30**	31	32	33	34	**35**	36	37	38	39	40
hj	h	205	227	225	225	216	215	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0

  - Definition of reference cooling load profile

$$P_c(Tj) = \text{part load} = \text{design load} \times \text{part load ratio} = \mathrm{P}_{\text{designC}} \times \frac{Tj - 16}{T_{designC} - 16}$$

  - Measurement of the electric chiller performance at 4 bins

Background

- Result: Energy label

A+++	SCOP ≥ 5,10	SEER ≥ 8,50
A++	4,60 ≤ SCOP < 5,10	6,10 ≤ SEER < 8,50
A+	4,00 ≤ SCOP < 4,60	5,60 ≤ SEER < 6,10
A	3,40 ≤ SCOP < 4,00	5,10 ≤ SEER < 5,60
B	3,10 ≤ SCOP < 3,40	4,60 ≤ SEER < 5,10
C	2,80 ≤ SCOP < 3,10	4,10 ≤ SEER < 4,60
D	2,50 ≤ SCOP < 2,80	3,60 ≤ SEER < 4,10
E	2,20 ≤ SCOP < 2,50	3,10 ≤ SEER < 3,60
F	1,90 ≤ SCOP < 2,20	2,60 ≤ SEER < 3,10
G	SCOP < 1,90	SEER < 2,60

Motivation

Options for solar Cooling:

- create a new solar cooling energy label

Or:

- Stay close to the ecodesign-guildeline: „My solar cooling system operates like an A+++ cooling system“
  → stay as close as possible to the EU directive
  → use of the bin Method

Questions:

- Can the reference climate data easily be extended with radiation data?
- How will the calculation method look like?

DIN-Project „Development of a standard for solar cooling“

- Workshop in June 2012 in Frankfurt
- Compilation of the results
- Road map for a Standard for solar cooling

Proposal for a DIN Standard

Solar cooling – vacabulary, safety, measurement procedure, performance evaluation

- Part 1: Vocabulary
- Part 2: General requirements
- Part 3: Safety requirements
- Part 4: Test requirements
- Part 5: Test procedure
- Part 6: Calcualtion of Seasonal Performance figures

Scope of appliance

- Solar cooling kits (collector, hot water storage, chiller)
- Integrated or separate heat rejection unit
- Open or closed cooling tower
- With or without DHW production
- With or without chilled water storage
- With or without space heating
- Distribution system: chilled water systems, systems for cooling ceilings, systems for fan coils, systems for air ducts
- Solar cooling kits with or without electrical backup
- Solar cooling kits with or without thermal backup

Proposed procedure for the bin-Method

1. Calculate collector gain potential from collector efficiency curve
2. Calculate rejected heat due to filled storage
3. Calculate heat losses from storage UA-value
4. Calculate produced cold from measured EER_{th} and compare to cold demand
   → $SEER_{th}$
   → solar fraction
5. Calculate required electricity from measured EER_{el}
   → $SEER_{el}$

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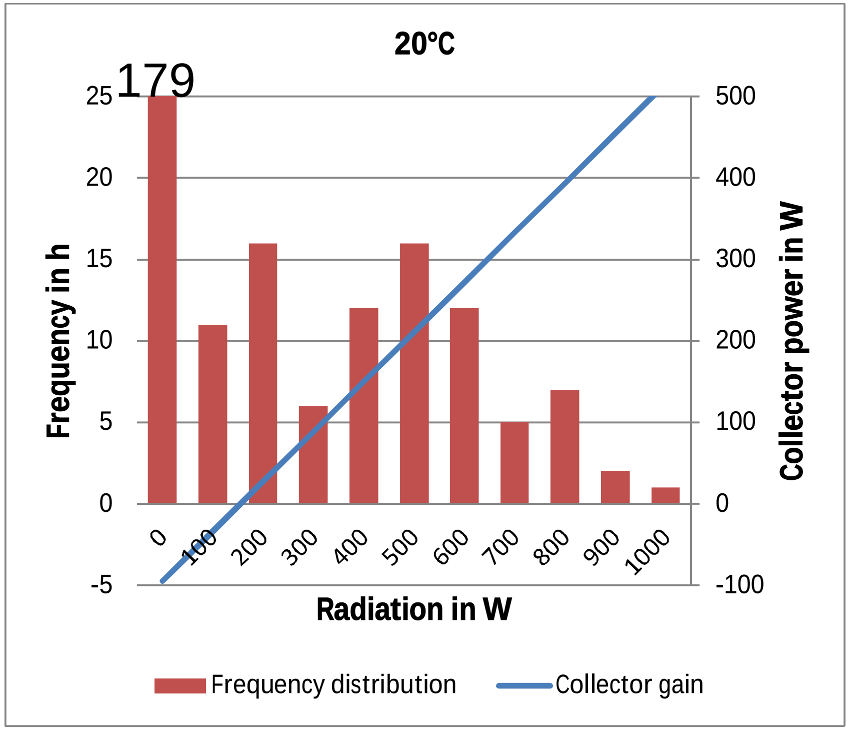
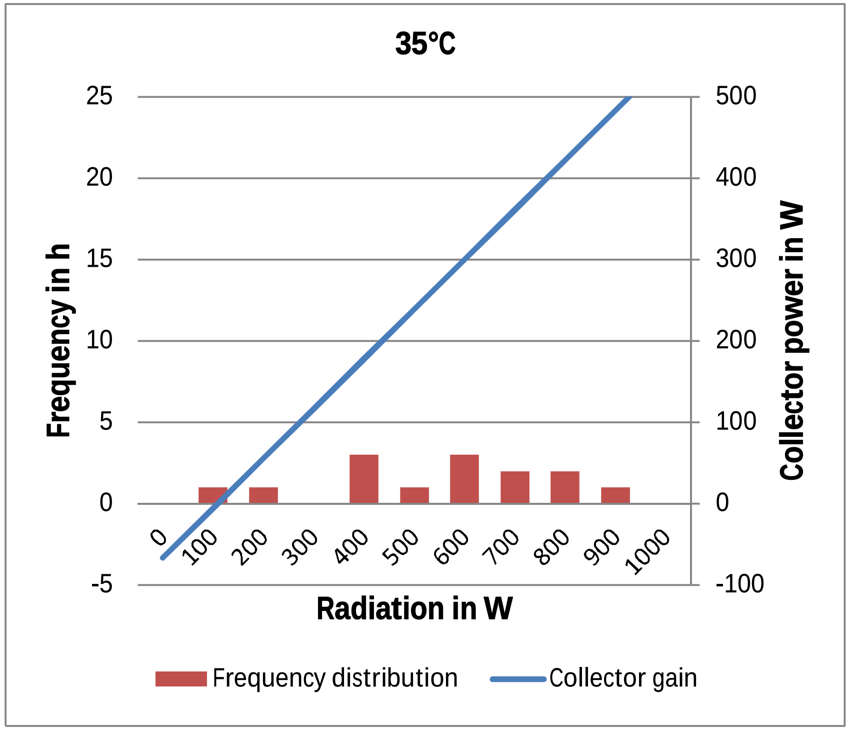
Requirement

- Definition of reference solar radiation and distribution





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Calculation of solar gain

- Collector efficiency curve

$$\eta = \eta_0 - \frac{a_1}{G} \times (T_{Col} - T) - \frac{a_2}{G} \times (T_{Col} - T)^2 = \eta_0 - \frac{P_2(T_{Col}, T)}{G}$$

- Collector gain potential

$$P_{col} = \begin{cases} G \times \eta_0 - P_2(T) & G > G_{mini} \\ 0 & else \end{cases}$$

- Solar gain for temperature T

$$Q_{col,T} = \int_{G_{mini}}^{G_{maxi}} f_T(G) \times P_{col} \, \mathrm{dG}$$

$$Q_{col,T} = \eta_0 \times \int_{G_{mini}}^{G_{maxi}} f_T \times G \, \mathrm{dG} + P_2(T) \times \int_{G_{mini}}^{G_{maxi}} f_T \, \mathrm{dG}$$

Calculation of solar gain 2

- $$Q_{col,T} = \overbrace{\eta_0}^{\text{Collector}} \times \underbrace{\int_{G_{mini}}^{G_{maxi}} f_T \times G \, \mathrm{dG}}_{\text{Climate (hours per bin)}} - \overbrace{P_2(T)}^{\text{Collector}} \times \underbrace{\int_{G_{mini}}^{G_{maxi}} f_T \, \mathrm{dG}}_{\text{Climate (solar radiation per bin)}}$$
- Separation of climate key figures and collector parameters possible
- Influence of G_{mini} causes an error in the range of 1%

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Bin-Method for solar cooling

- One additional column (solar radiation) is necessary and sufficient to describe the reference climate conditions
- Multiply losses P_2 with hours and eta_0 with energy
- Uncertainty is within 1%
- For flat plate and vacuum tube collectors

Bin	Temperature	Hours	Energy
#	°C	h	kWh
1	16	117	9,5
2	17	170	12,7
3	18	199	17,2
4	19	262	29,4
5	20	267	37,4
6	21	303	51,2
7	22	316	54,7
8	23	354	71,2
9	24	361	84,7
10	25	345	84,4
11	26	321	110,2
12	27	271	97,9
13	28	237	92,8
14	29	169	70,3
15	30	158	75,1
16	31	115	56,4
17	32	85	44,5
18	33	49	26,4
19	34	30	17,0
20	35	14	7,7
21	36	2	1,1
22	37	3	2,0

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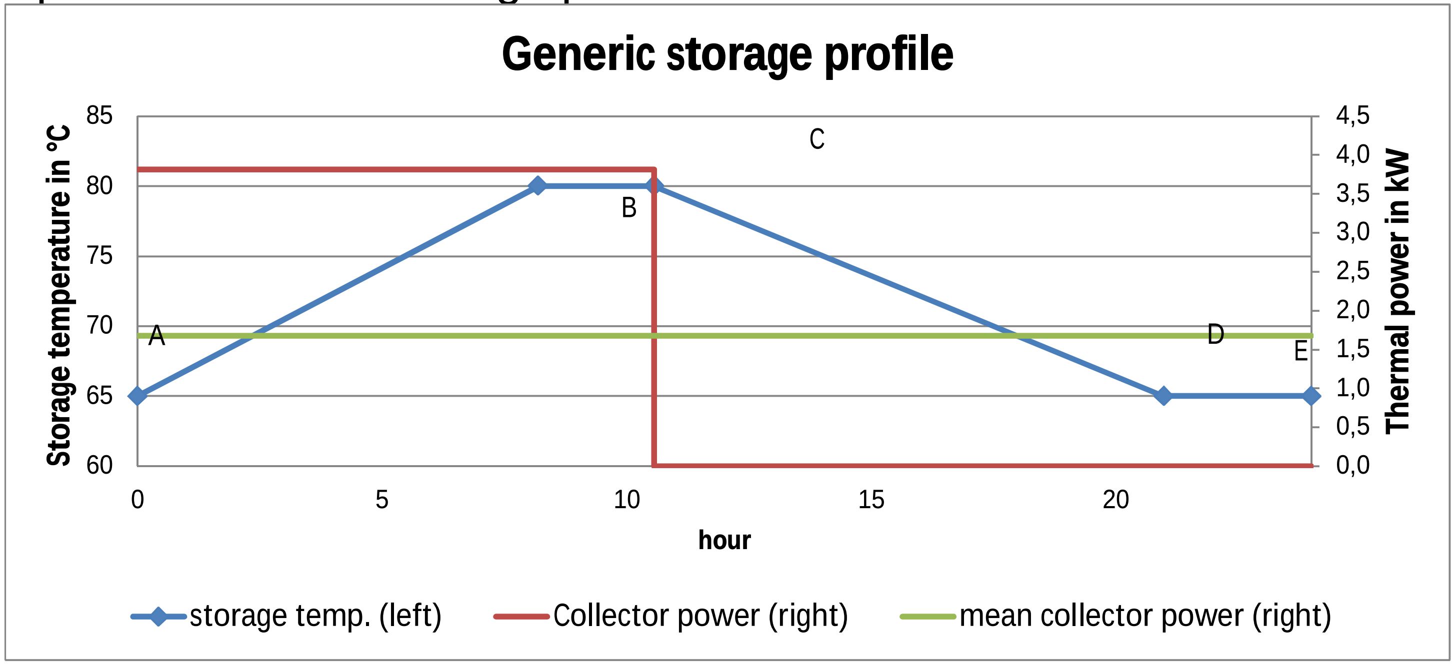
Correlation of collector and storage

- Option 1: tables from simulation
- Option 2: Generic storage profile



- Output: mean temp. → heat losses full storage → rejected heat

Proposed procedure for the bin-Method

1. Calculate collector gain potential from collector efficiency curve
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Input data

Input Data															
Climate		hot	Athen	35			**Legend**								
							canufacturer								
		hot	Athen	35	°C		From other norms								
		mean	Strasbourg	31	°C		measurement								
		cold	Helsinki	27	°C		selection field								
		Deutschl	Wuerzburg	31	°C										
Collector							**Storage**								
		8	m²				size				1000	L			
eta_o		0,67					heat capacity				4200	J/(kg K)			
k_1		0,8	W/m²K				heat loses				5,06	W/K			
k_2		0,005	W/(m²K)²				basement temp				25	°C			
cor. Direction		1													
cor. IAM		0,8													
Temp		75,5	°C				**Domestic hot water**								
Heat exch.		1					applied				yes	yes	no		
Cold system							priority				equal	DHW	Cold	equal	
cooling power		1	kW				water load				5	L/h			
Nom. HW-in-Temp.		80	°C				inlet temp				15	°C			
Nom. HW-out Temp.		65	°C				outlet temp				50	°C			
							heat load	P_{TW}			0,204	kW			
Climate															
Design. Temp		35													

Excel table

Bin	Temperature	hours	radiation (direct)	radiation (diffus)	specific collector gain	collector gain potential	collector efficiency	collector power	collector gain	cold demand	cooling energy	heat demand		COP_th	COP_el	estimated heat load	storage acceptance	storage efficiency
		h	$s_{direkt,i}$	$s_{diffus,i}$		$P_{KolPot,i}$	$\eta_{Kollektor,i}$	$P_{Kol,i}$	$Q_{Kol,i}$	$P_{K,Bedarf}$		$P_{W,Bedarf}$		$\varepsilon_{th,i}$	$\varepsilon_{el,i}$	P_L		
	°C	---	W/m²	W/m²	kWh/m²a	kW	---	kW	kWh	kW	kWh	kW		JAZ_{th}	JAZ_{el}	kW		
		4148			785,9				2951		1931			0,358	4,609			62%
1	15	0	0									0,20	0	0,55	7		1,000	0,000
2	16	0	0	0	0,0	0,00	0,0000	0,00	0	0,00	0	0,20	1	0,55	7		1,000	0,000
3	17	117	46	32	5,4	0,50	-0,1457	0,00	0	0,05	6	0,30	2	0,55	7		1,000	0,000
4	18	170	56	36	9,5	0,59	-0,0130	0,00	0	0,11	18	0,40	3	0,55	7		1,000	0,000
5	19	199	69	49	13,7	0,75	0,1515	0,09	18	0,16	31	0,49	4	0,55	7		1,000	0,000
6	20	262	84	59	22,0	0,92	0,2518	0,18	48	0,21	55	0,59	5	0,55	7,00	0,18	1,000	0,000
7	21	267	107	64	28,6	1,10	0,3288	0,29	77	0,26	70	0,69	1	0,54	6,8		1,000	0,123
8	22	303	112	64	33,9	1,13	0,3459	0,31	95	0,32	96	0,80	2	0,53	6,6		1,000	0,246
9	23	316	136	68	43,1	1,31	0,3970	0,42	131	0,37	116	0,91	3	0,52	6,4		1,000	0,369
10	24	354	158	82	56,0	1,53	0,4429	0,54	193	0,42	149	1,03	4	0,51	6,2		1,000	0,492
11	25	361	161	91	58,0	1,61	0,4585	0,59	213	0,47	171	1,15	5	0,50	6,00	0,59	1,000	0,615
12	26	347	228	117	79,0	2,21	0,5196	0,92	318	0,53	183	1,30	1	0,48	5,6		0,981	0,654
13	27	321	231	132	74,1	2,32	0,5308	0,99	317	0,58	186	1,46	2	0,46	5,2		0,962	0,693
14	28	271	250	146	67,7	2,53	0,5453	1,10	299	0,63	171	1,64	3	0,44	4,8		0,943	0,732
15	29	237	280	141	66,4	2,70	0,5560	1,20	284	0,68	162	1,83	4	0,42	4,4		0,924	0,771
16	30	169	317	158	53,6	3,04	0,5716	1,39	235	0,74	125	2,05	5	0,40	4,00	1,39	0,904	0,810
17	31	158	346	150	54,6	3,17	0,5782	1,47	232	0,79	125	2,40	1	0,36	3,8		0,898	0,815
18	32	115	385	148	44,2	3,41	0,5870	1,60	184	0,84	97	2,84	2	0,32	3,6		0,892	0,821
19	33	86	401	142	34,5	3,48	0,5908	1,64	141	0,89	77	3,40	3	0,28	3,4		0,886	0,826
20	34	49	436	140	21,3	3,68	0,5973	1,76	86	0,95	46	4,15	4	0,24	3,2		0,880	0,832
21	35	30	417	134	12,5	3,52	0,5962	1,68	50	1,00	30	5,20	5	0,20	3,00	1,68	0,874	0,837
22	36	14	479	94	6,7	3,66	0,6011	1,76	25	1,05	15	6,78	1	0,16	2,4		0,874	0,837
23	37	2	547	97	1,1	4,12	0,6106	2,01	4	1,11	2	9,41	2	0,12	1,8		0,874	0,837
24	38	0	0	0	0,0	0,00	0,0000	0,00	0	1,16	0	14,68	3	0,08	1,2		0,874	0,837
25	39	0	0	0	0,0	0,00	0,0000	0,00	0	1,21	0	30,47	4	0,04	0,6		0,874	0,837
26	40	0	0	0	0,0	0,00	0,0000	0,00	0	1,26	0	#DIV/0!	5	0,00	0,00		0,874	0,837

Bin			Domestic hot water													
	Heat load	Heat produced	DHW Power	DHW Energy	Solar fraction	solar fraction in hours	Heat for cooling	Cooling power	coling energy	Used cooling power	used cooling energy	Solar fraction	Solar fraction	electric power	electric energy	uncoverd hours
	$P_{Wärmeertrag,i}$	$Q_{Wärme,i}$	$P_{TW,i}$	$Q_{TW,i}$	$f_{TW,i}$		$P_{W,KB,i}$	$P_{K,produziert,i}$	$Q_{K,produziert,i}$	$P_{K,genutzt,i}$		f				
	kW	kWh	kW	kWh			kW	kW	kWh	kW	kWh	%	h	kW	kWh	h
		1832,86		224,1	26%	1097,8			656		656	**26%**	1098		142,37	
1					26%							**34%**				
2	0,00		0,000	0,000			0,000	0,000	0,0	0,00	0,00					
3	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	117,0
4	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	170,0
5	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	199,0
6	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	262,0
7	0,04	9,5	0,010	2,798	5%	13,7	0,025	0,014	3,6	0,01	3,61	5%	13,7	0,002	0,53	253,3
8	0,08	23,3	0,020	5,940	10%	29,1	0,057	0,030	9,2	0,03	9,19	10%	29,1	0,005	1,39	273,9
9	0,15	48,5	0,034	10,840	17%	53,1	0,119	0,062	19,6	0,06	19,56	17%	53,1	0,010	3,06	262,9
10	0,27	94,8	0,053	18,792	26%	92,0	0,215	0,109	38,8	0,11	38,75	26%	92,0	0,018	6,25	262,0
11	0,36	131,0	0,064	23,232	32%	113,8	0,299	0,149	53,9	0,15	53,90	32%	113,8	0,025	8,98	247,2
12	0,59	204,3	0,092	32,075	45%	157,1	0,496	0,238	82,7	0,24	82,69	45%	157,1	0,043	14,77	189,9
13	0,66	211,2	0,092	29,477	45%	144,4	0,566	0,260	83,6	0,26	83,59	45%	144,4	0,050	16,07	176,6
14	0,76	206,5	0,095	25,711	46%	125,9	0,667	0,293	79,5	0,29	79,54	46%	125,9	0,061	16,57	145,1
15	0,85	202,4	0,095	22,539	47%	110,4	0,759	0,319	75,5	0,32	75,53	47%	110,4	0,072	17,17	126,6
16	1,02	172,2	0,102	17,179	50%	84,1	0,917	0,367	62,0	0,37	62,00	50%	84,1	0,092	15,50	84,9
17	1,07	169,8	0,092	14,460	45%	70,8	0,983	0,354	55,9	0,35	55,92	45%	70,8	0,093	14,71	87,2
18	1,17	135,0	0,084	9,717	41%	47,6	1,089	0,348	40,1	0,35	40,08	41%	47,6	0,097	11,13	67,4
19	1,20	103,6	0,072	6,219	35%	30,5	1,132	0,317	27,3	0,32	27,25	35%	30,5	0,093	8,02	55,5
20	1,29	63,1	0,063	3,104	31%	15,2	1,225	0,294	14,4	0,29	14,40	31%	15,2	0,092	4,50	33,8
21	1,23	36,9	0,048	1,447	24%	7,1	1,181	0,236	7,1	0,24	7,09	24%	7,1	0,079	2,36	22,9
22	1,29	18,0	0,039	0,543	19%	2,7	1,250	0,200	2,8	0,20	2,80	19%	2,7	0,083	1,17	11,3
23	1,47	2,9	0,032	0,064	16%	0,3	1,441	0,173	0,3	0,17	0,35	16%	0,3	0,096	0,19	1,7
24	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	0,0
25	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	0,0
26	0,00	0,0	0,000	0,000	0%	0,0	0,000	0,000	0,0	0,00	0,00	0%	0,0	0,000	0,00	0,0

- Output: El. SCOP, Th. SCOP, solar fraction

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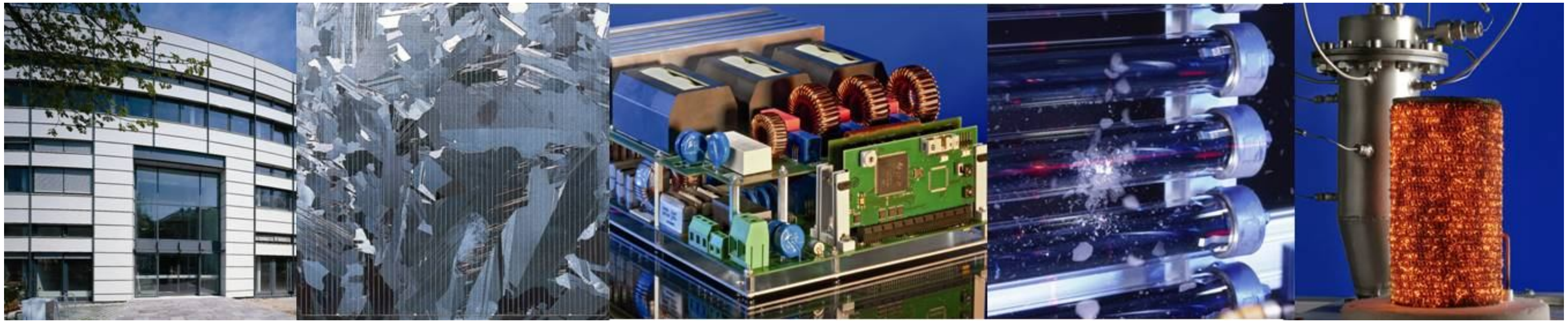
Strenght and weakness

- Strength:
  - Simple method
  - No simulation-license required
  - Transparent to the user
  - Very close to the compression chiller marked
  - Required parameters have a physical meaning
  - Only TDC-performance measurement at 4 points required (no system measurement required)
- Weakness:
  - Control issues not regarded (also true for CTSS)
  - On/off behaviour not yet regarded
  - Collector/storage behaviours must be analyzed
  - Additional radiation table for concentrating systems required

Thank you for your attention!



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Elements of a standard for solar cooling

Measurement place
- In-Situ
- laboratory
- outdoor

Measurement boundary
- Complete system
- Components with emulation
- Components separately

Component description
- Performance map
- Characteristic equation
- Characteristic figures

Performance figure calculation
- simulation tables

Key figures
- Solar fraction
- Primary energy
- Usefull energy

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