A simple tool for the economic evaluation of thermal energy storages

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A simple tool for the economic evaluation of thermal energy storages

- Motivation
- Top-Down approach
- Bottom-Up approach
- Summary

Introduction

Motivation: Cost uncertainty!

Assumption:

Costs of energy supplied by the storage

≤

Costs of energy from the market

Introduction

Motivation: Cost uncertainty!

Assumption:

Annual payment for storage investment

$$\leq$$

Annual savings of reference energy costs

Methods

Top-Down approach:

Maximum acceptable storage capacity costs

How much may (thermal) energy storage cost?

Bottom-up approach:

Realised storage capacity costs

How much do existing storages cost?

Top-Down approach

Top-Down approach

Annuity factor ANF

$ANF \cdot investment\ costs$ = Annual payment for storage investment

Top-Down approach

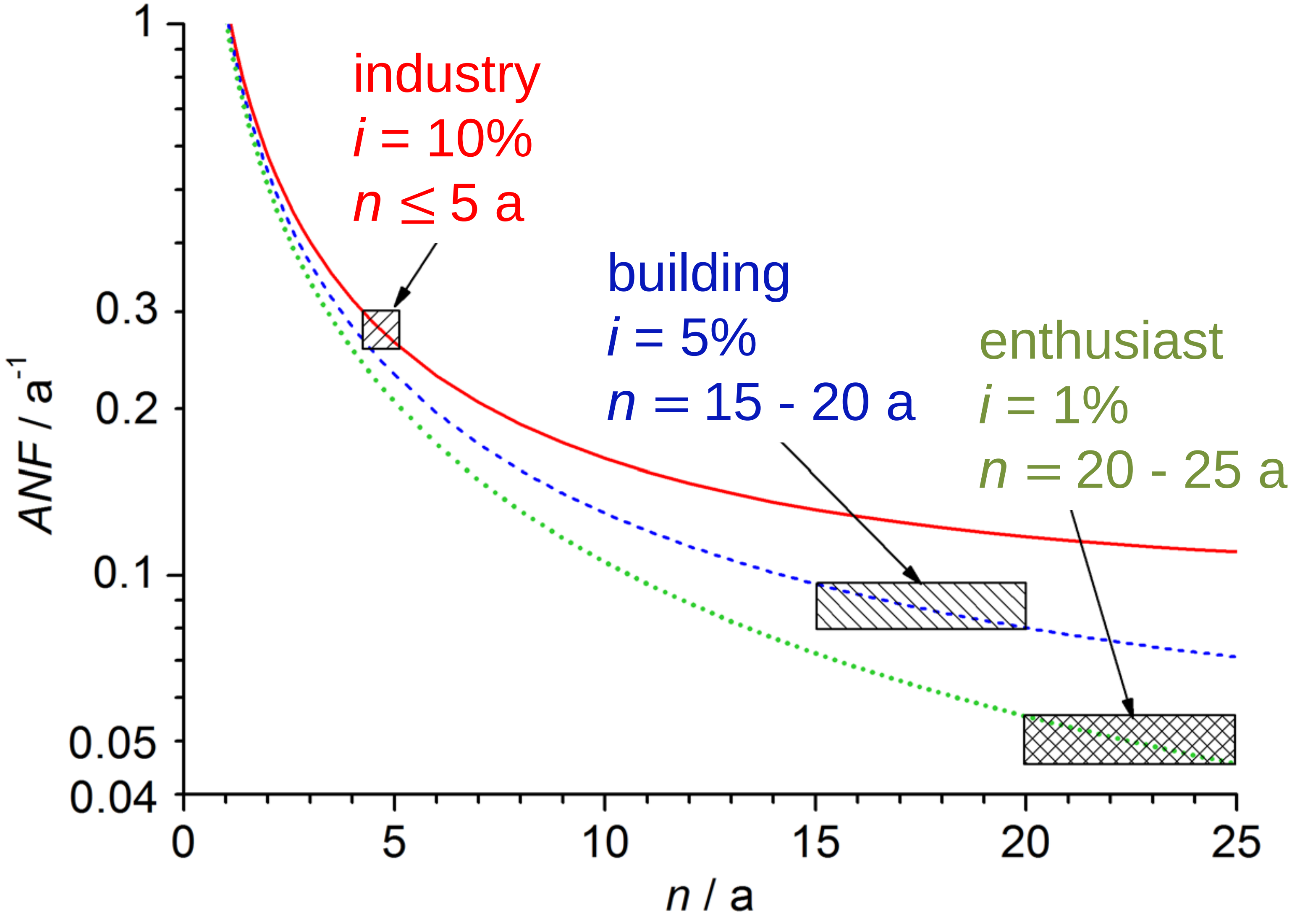
Annuity factor ANF

ANF · *investment costs* = Annual payment for storage investment

$$ANF = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$

i = interest rate

n = payback period



Top-Down approach

Maximum acceptable storage capacity costs SCC_{acc}

Assumption:

Annual payment for storage investment

= Annual savings of reference energy costs

Top-Down approach

Maximum acceptable storage capacity costs SCC_{acc}

Annual payment for storage investment

= Annual savings of reference energy costs

$$\boxed{SCC_{\mathrm{acc}} \cdot ANF = REC \cdot N_{\mathrm{cycle}}}$$

$$\boxed{SCC_{\mathrm{acc}} = \frac{REC \cdot N_{\mathrm{cycle}}}{ANF}}$$

REC = reference energy costs
(heat / cold suppy)

N_{cycle} = storage cycles / year

ANF = annuity factor

Top-Down approach

Maximum acceptable storage capacity costs SCC_{acc}

$$\boxed{SCC_{acc} = \frac{REC \cdot N_{cycle}}{ANF}}$$

REC = reference energy costs
(heat / cold suppy)

N_{cycle} = storage cycles / year

ANF = annuity factor

User class	***REC / €·kWh$_{en}^{-1}$***		***ANF / a^{-1}***	
	min.	max.	min.	max.
Industry	0.02	0.04	0.25	0.30
Building	0.06	0.10	0.07	0.10
Enthusiast	0.12	0.16	0.04	0.06

SCC_{acc} (upper limit)

Top-Down approach

Maximum acceptable storage capacity costs SCC_{acc}

$$SCC_{\mathrm{acc}} = \frac{REC \cdot N_{\mathrm{cycle}}}{ANF}$$

REC = reference energy costs (heat / cold suppy)

N_{cycle} = storage cycles / year

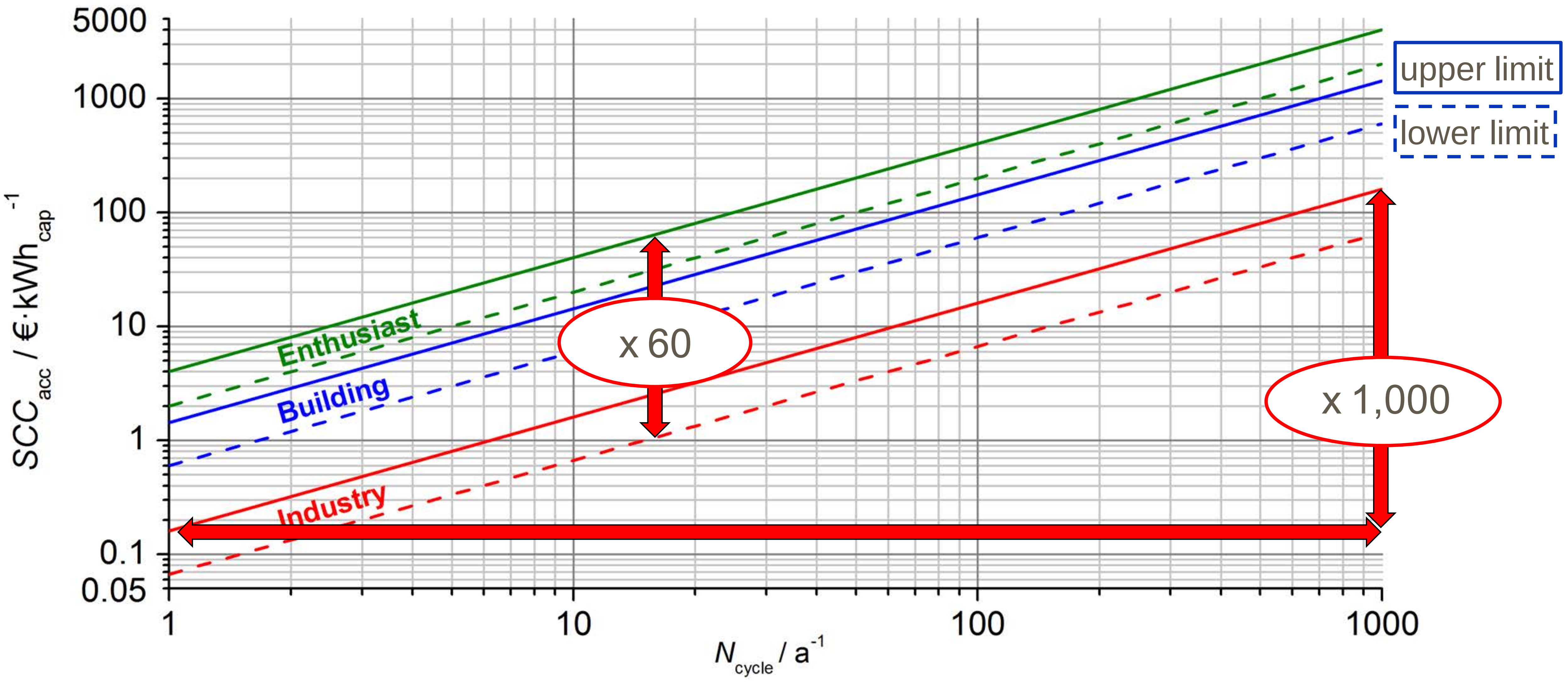
ANF = annuity factor

User class	***REC* / €·kWh$_{\mathrm{en}}^{-1}$**		***ANF* / a^{-1}**	
	min.	max.	min.	max.
Industry	0.02	0.04	0.25	0.30
Building	0.06	0.10	0.07	0.10
Enthusiast	0.12	0.16	0.04	0.06

SCC_{acc} (lower limit)

Top-Down approach

Maximum acceptable storage capacity costs *SCC*$_{acc}$



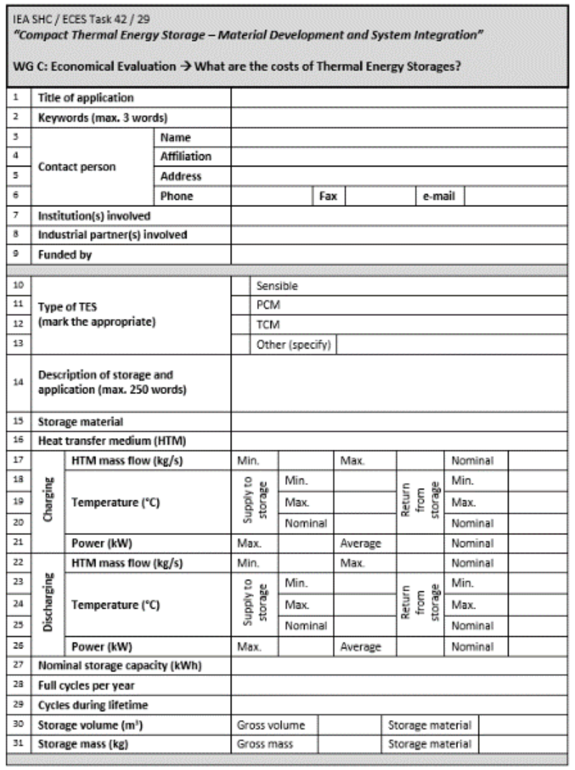
→ Short-term storages allow much higher *SCC*$_{acc}$ than long-term storages!

Bottom-Up approach

Bottom-Up approach

Realised storage capacity costs SCC_{real}

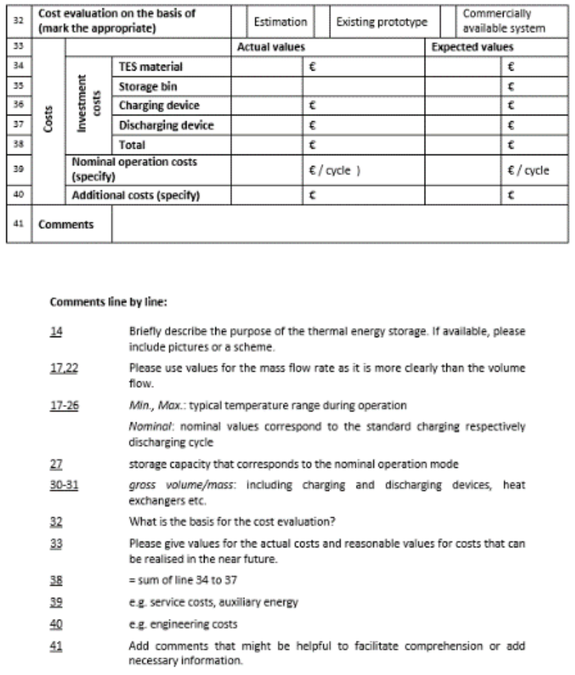
Questionary within
IEA SHC Task 42 / ECES Annex 29



IEA SHC / ECES Task 42 / 29
"Compact Thermal Energy Storage – Material Development and System Integration"

WG C: Economical Evaluation → What are the costs of Thermal Energy Storages?

1	**Title of application**							
2	**Keywords (max. 3 words)**							
3	**Contact person**	**Name**						
4		**Affiliation**						
5		**Address**						
6		**Phone**		**Fax**		**e-mail**		
7	**Institution(s) involved**							
8	**Industrial partner(s) involved**							
9	**Funded by**							
10	**Type of TES (mark the appropriate)**			Sensible				
11				PCM				
12				TCM				
13				Other (specify)				
14	**Description of storage and application (max. 250 words)**							
15	**Storage material**							
16	**Heat transfer medium (HTM)**							
17	**Charging**	**HTM mass flow (kg/s)**	Min.		Max.		Nominal	
18		**Temperature (°C)**	Supply to storage	Min.		Return from storage	Min.	
19				Max.			Max.	
20				Nominal			Nominal	
21		**Power (kW)**	Max.		Average		Nominal	
22	**Discharging**	**HTM mass flow (kg/s)**	Min.		Max.		Nominal	
23		**Temperature (°C)**	Supply to storage	Min.		Return from storage	Min.	
24				Max.			Max.	
25				Nominal			Nominal	
26		**Power (kW)**	Max.		Average		Nominal	
27	**Nominal storage capacity (kWh)**							
28	**Full cycles per year**							
29	**Cycles during lifetime**							
30	**Storage volume (m³)**		Gross volume		Storage material			
31	**Storage mass (kg)**		Gross mass		Storage material			



32	**Cost evaluation on the basis of (mark the appropriate)**				Estimation		Existing prototype	Commercially available system
33	**Costs**			**Actual values**		**Expected values**		
34		**Investment costs**	**TES material**		€		€	
35			**Storage bin**				€	
36			**Charging device**		€		€	
37			**Discharging device**		€		€	
38			**Total**		€		€	
39		**Nominal operation costs (specify)**			€ / cycle)		€ / cycle	
40		**Additional costs (specify)**			€		€	
41	**Comments**							

Comments line by line:

14	Briefly describe the purpose of the thermal energy storage. If available, please include pictures or a scheme.
17,22	Please use values for the mass flow rate as it is more clearly than the volume flow.
17-26	*Min., Max.*: typical temperature range during operation
	Nominal: nominal values correspond to the standard charging respectively discharging cycle
27	storage capacity that corresponds to the nominal operation mode
30-31	*gross volume/mass*: including charging and discharging devices, heat exchangers etc.
32	What is the basis for the cost evaluation?
33	Please give values for the actual costs and reasonable values for costs that can be realised in the near future.
38	= sum of line 34 to 37
39	e.g. service costs, auxiliary energy
40	e.g. engineering costs
41	Add comments that might be helpful to facilitate comprehension or add necessary information.

$$\boxed{SCC_{\text{real}} = \frac{INC}{SC}}$$

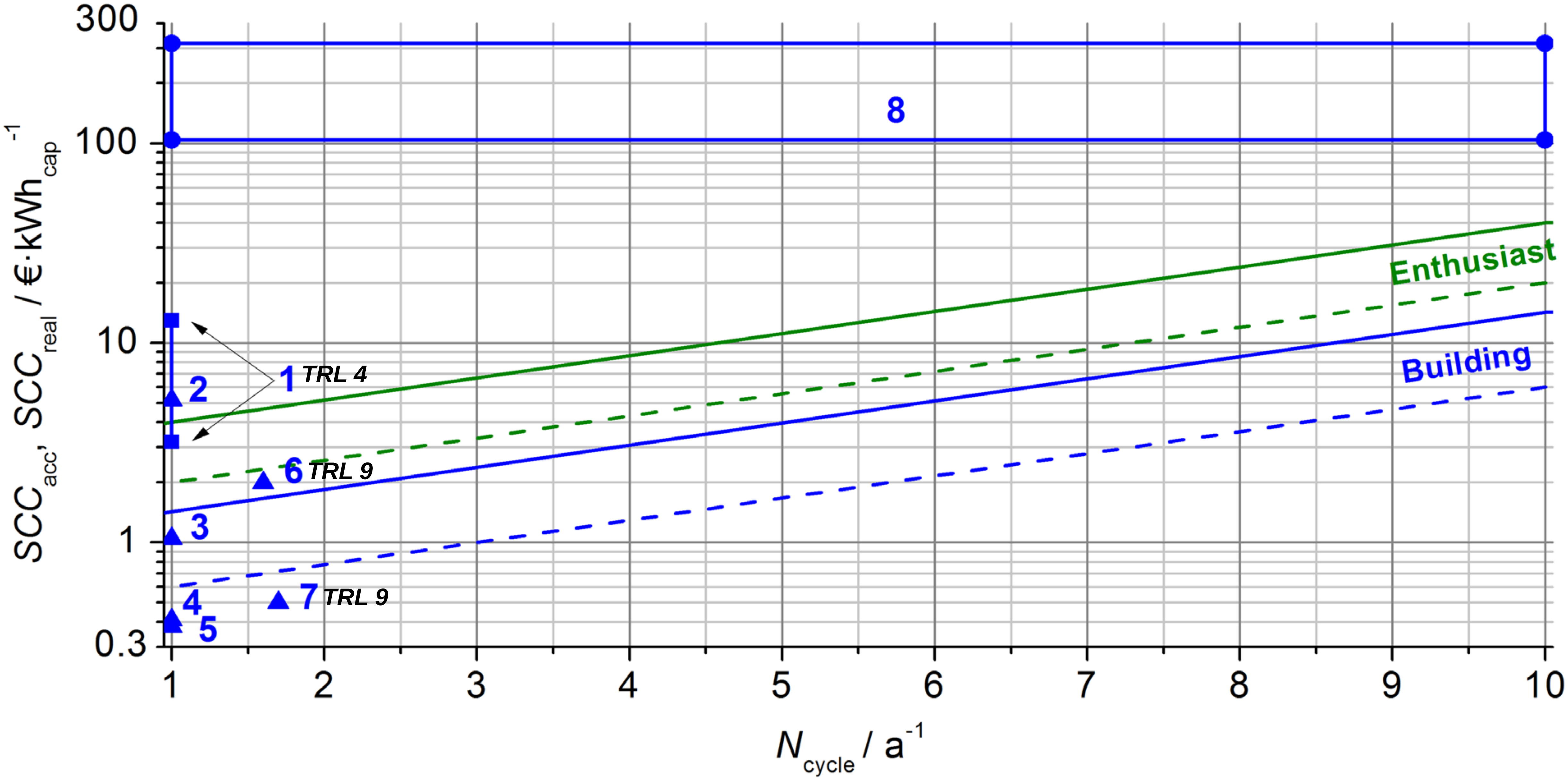
INC = investment costs
(material
+ storage container / reactor
+ charging/discharging device)

SC = installed storage capacity

Top-Down & Bottom-Up approach

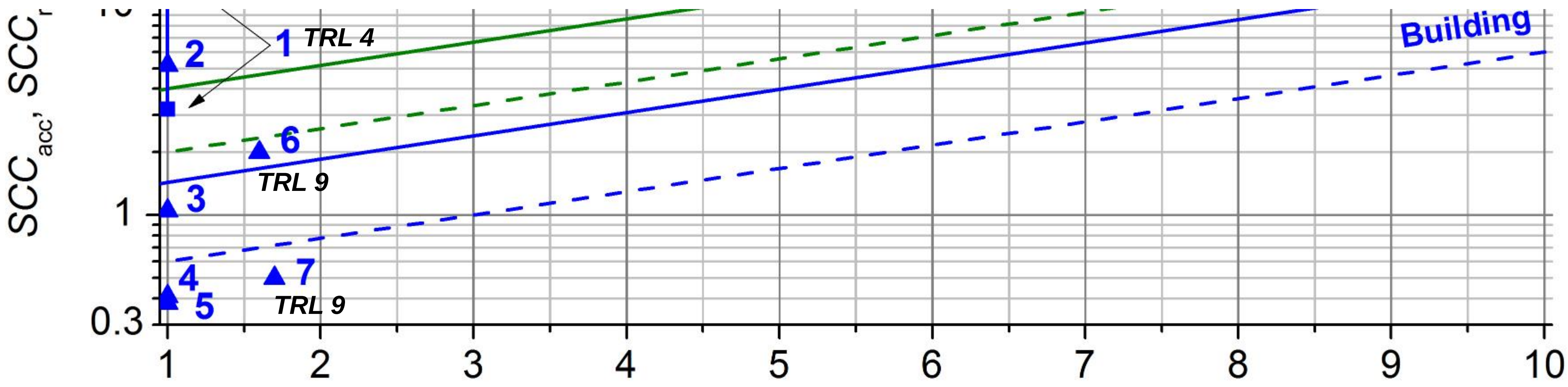
Long-term storages for **building** applications

▲= sensible ● = PCM ■ = TCM



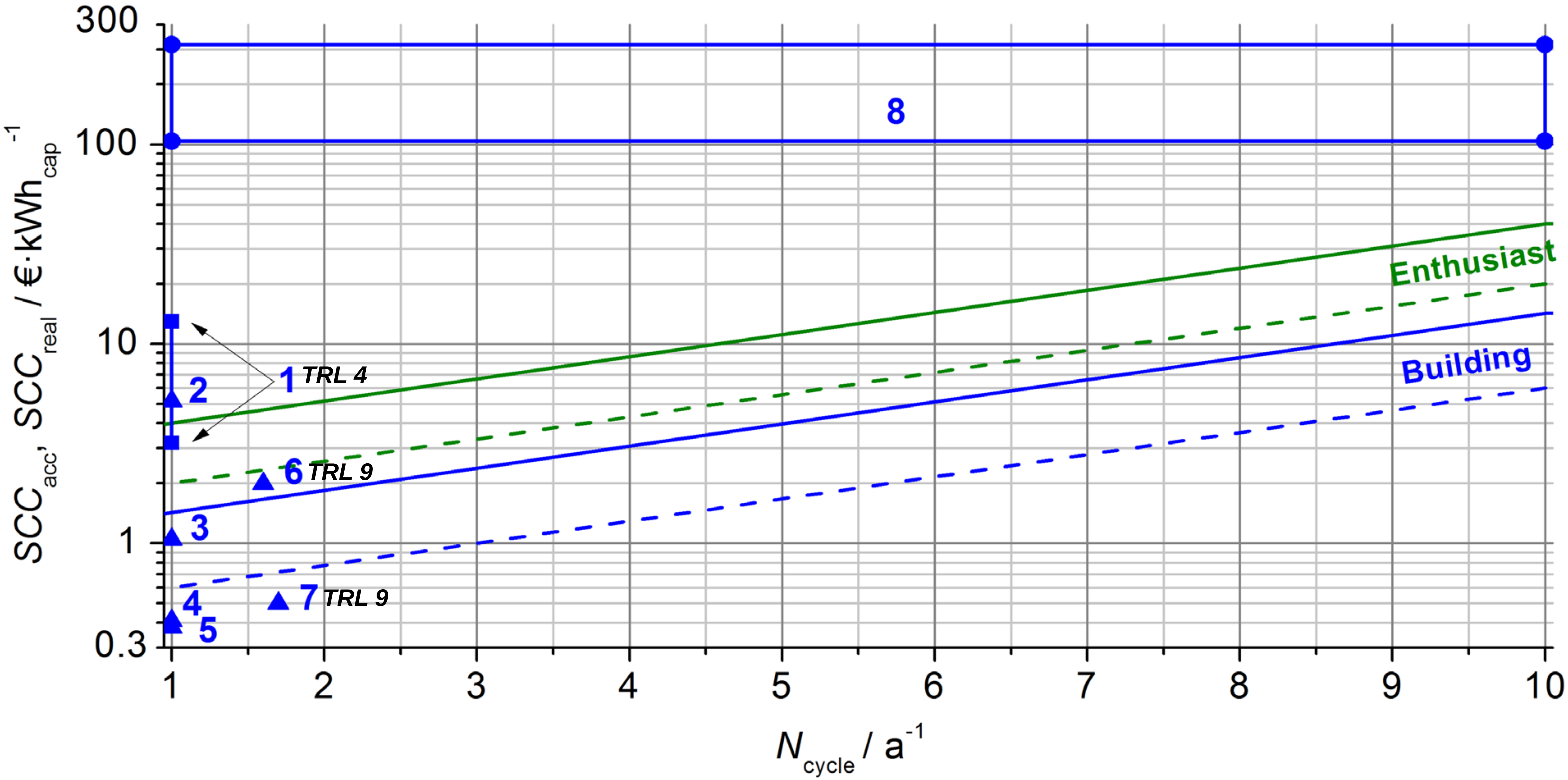
Long-term storages for **building** applications

ZAE BAYERN



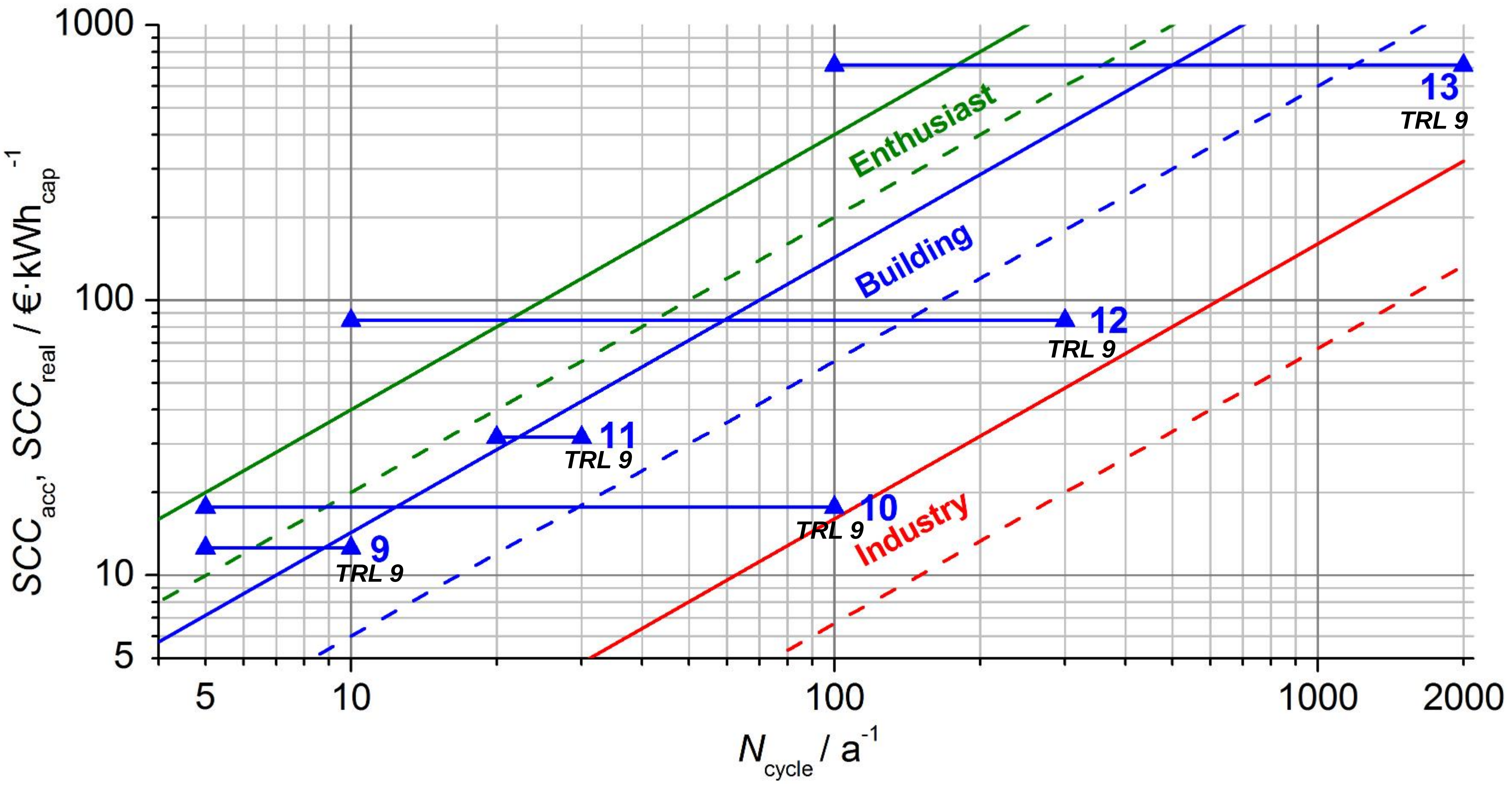
storage	description	N_{cycle} / a^{-1}	*INC* / €	*SC* / kWh_{cap}	SCC_{real} / €·kWh_{cap}^{-1}
1: NaOH storage (EMPA)	Seasonal heat storage based on closed NaOH sorption	1	8,000 – 32,400	2,500	3.20 – 13.0
2: Ottrupgård, 1995	Hot water; 1,500 m³; 35 – 60 °C	1	225,500	43,500	5.18
3: Sunstore 2, 2003	10,000 m³ water; 35 – 90 °C	1	671,100	638,000	1.05
4: Sunstore 3, 2013	60,000 m³ water; 10 – 90 °C	1	2,281,900	5,570,000	0.38
5: Sunstore 4, 2012 (PlanEnergi)	75,000 m³ water; 10 – 90 °C	1	2,671,100	6,960,000	0.41
6: Ackermannbogen (ZAE Bayern)	6,000 m³ water; 20 – 90 °C	1.6	942,400	472,400	1.99
7: Attenkirchen (ZAE Bayern)	Hot water + borehole heat exchanger; ≙7,000 m³; 10 – 90 °C	1.7	327,300	654,600	0.50
8: SAT storage (DTU, Univ. of Graz)	Seasonal heat storage, super-cooled sodium acetate trihydrate	1 – 10	2,700 – 4,120	13 – 26	104 - 317

Long-term storages for building applications



→ Seasonal storage only economical via large hot water storages (at present)

Hot water storages < 30 m³



→ Storages can be integrated in a variety of systems with different N_{cycle}

Hot water storages < 30 m³

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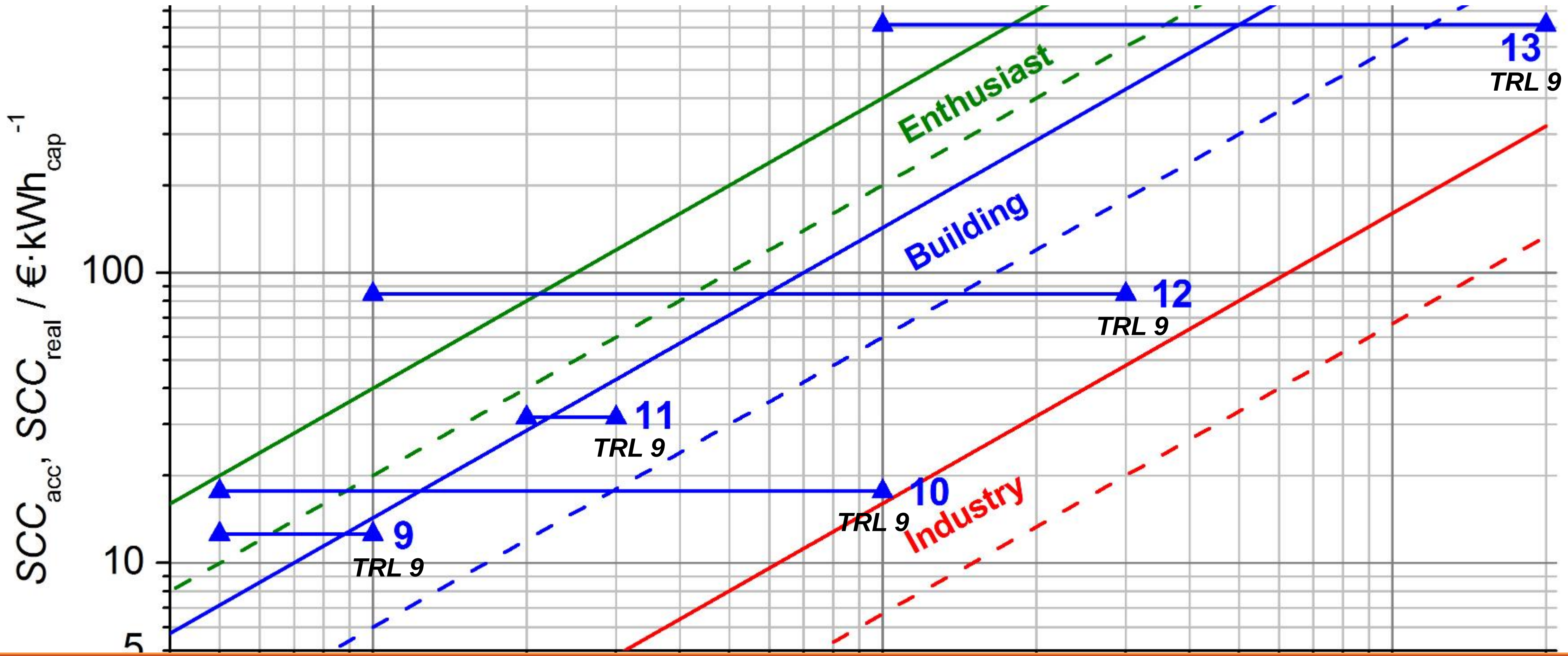
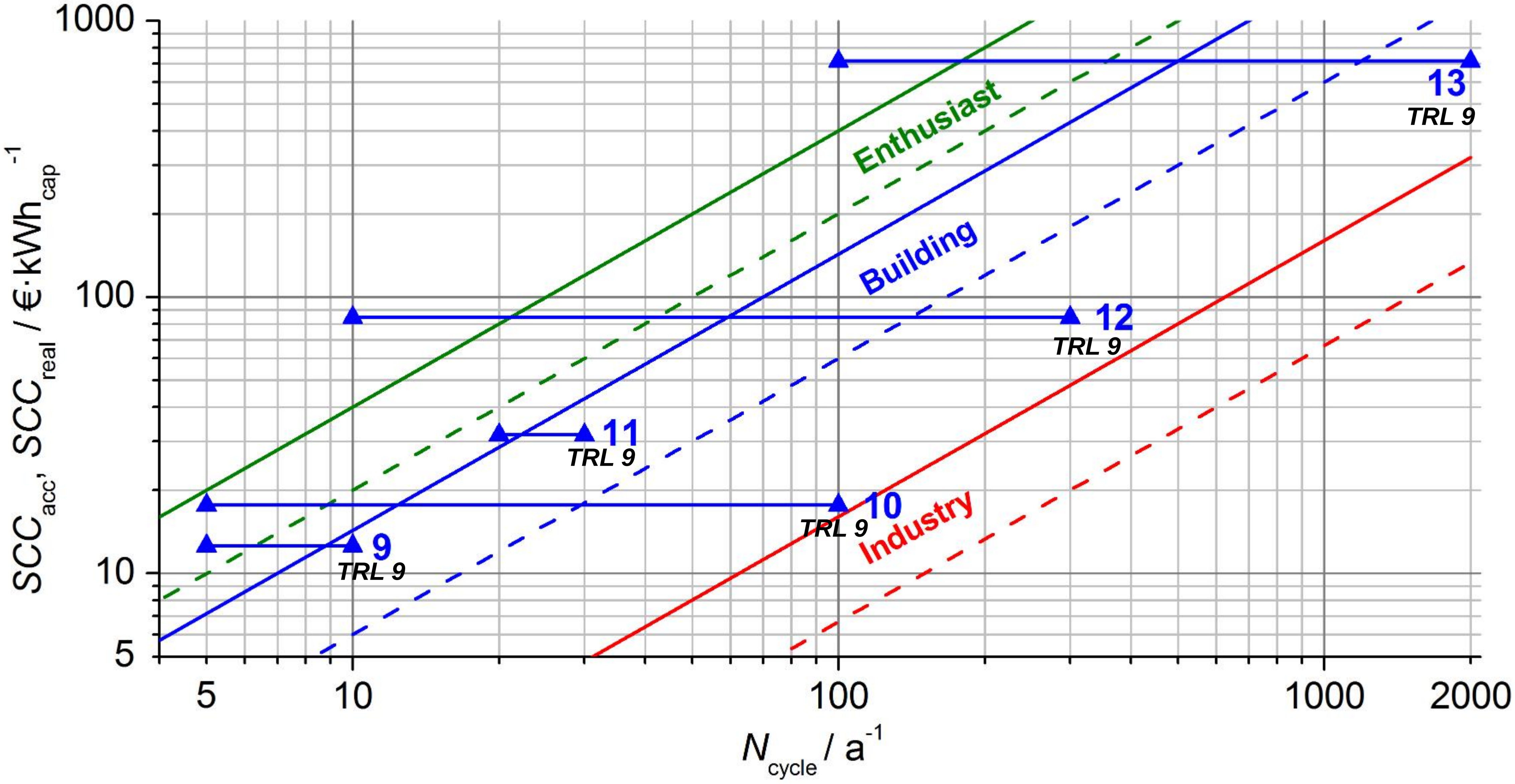


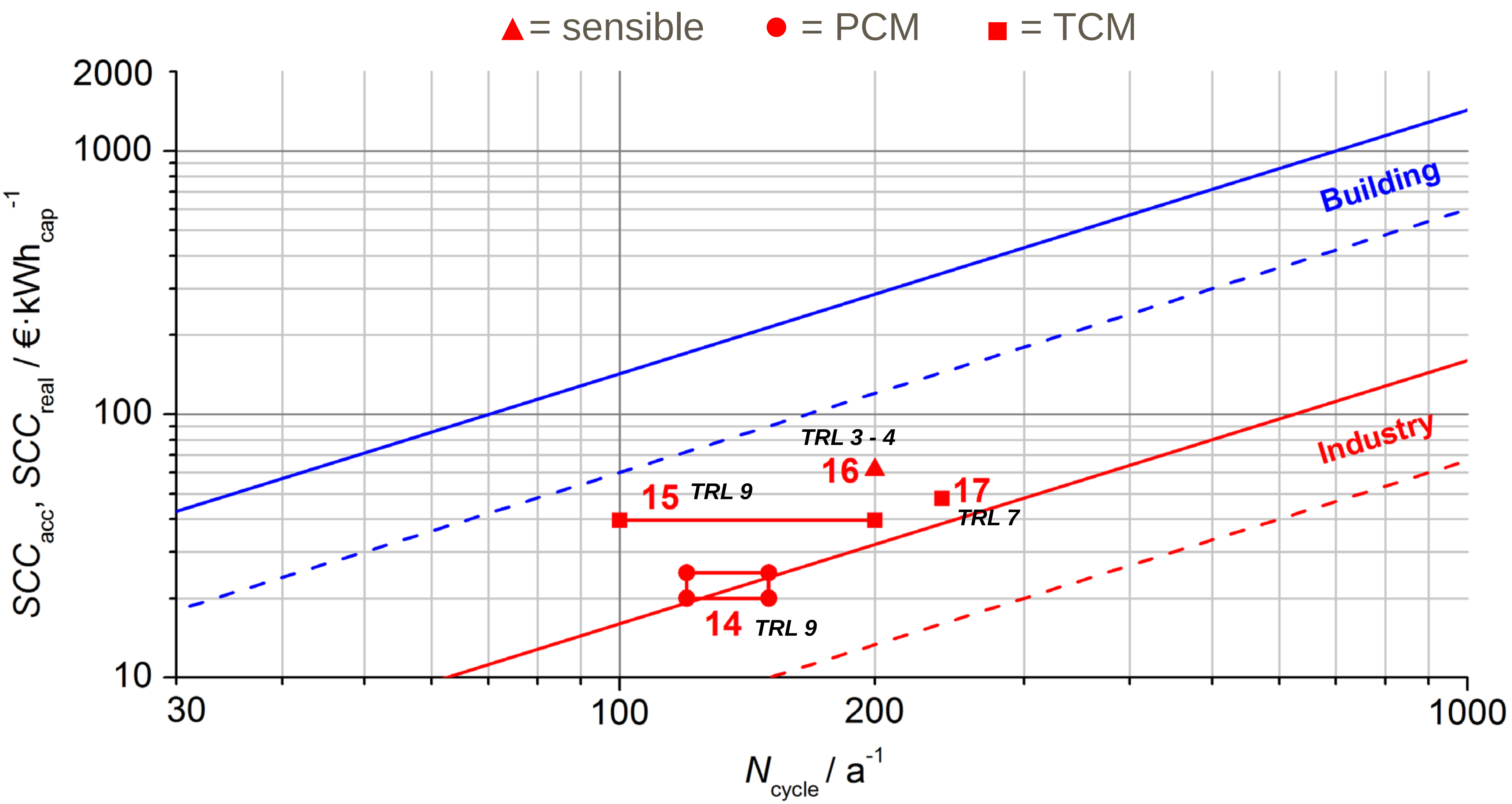
storage	description	N_{cycle} / a^{-1}	INC / €	SC / kWh_{cap}	SCC_{real} / €·kWh_{cap}^{-1}
9: VSI – 30 m³ (ZAE, Hummelsberger)	Vacuum super insulated water storage; 30 m³; 5 – 95 °C	5 – 10	37,888	3.020	12.5
10: allSTOR VPS/3 2000/3-7 (Vaillant)	2,000 l water; 5 – 95 °C	5 – 100	3,559	202	17.6
11: VSI – 5 m³ (ZAE, Hummelsberger)	Vacuum super insulated water storage; 5 m³; 5 – 95 °C	20 – 30	15,962	504	31.7
12: actoSTOR VIH RL 500-60 (Vaillant)	500 l water; 5 – 110 °C	10 – 300	4,953	58.7	84.4
13: actoSTOR VIH CL 20 S (Vaillant)	20 l potable water; 10 – 70 °C	100 – 2000	965	1.35	715

Hot water storages < 30 m³

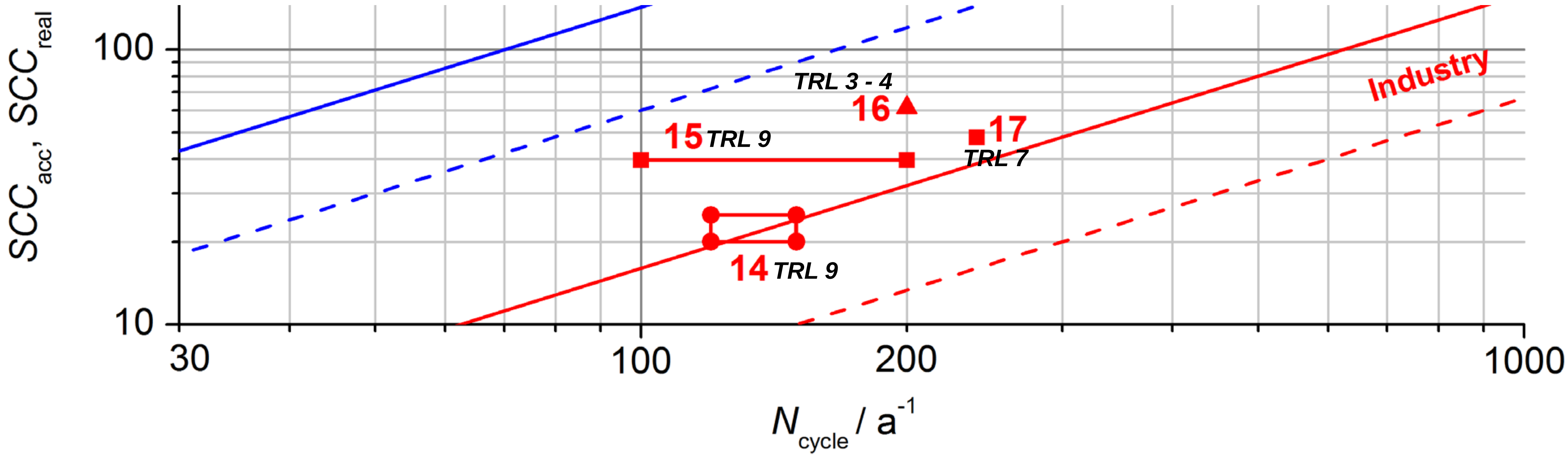


→ Attractive for industrial applications if N_{cycle} is high

Short-term storages for industrial applications

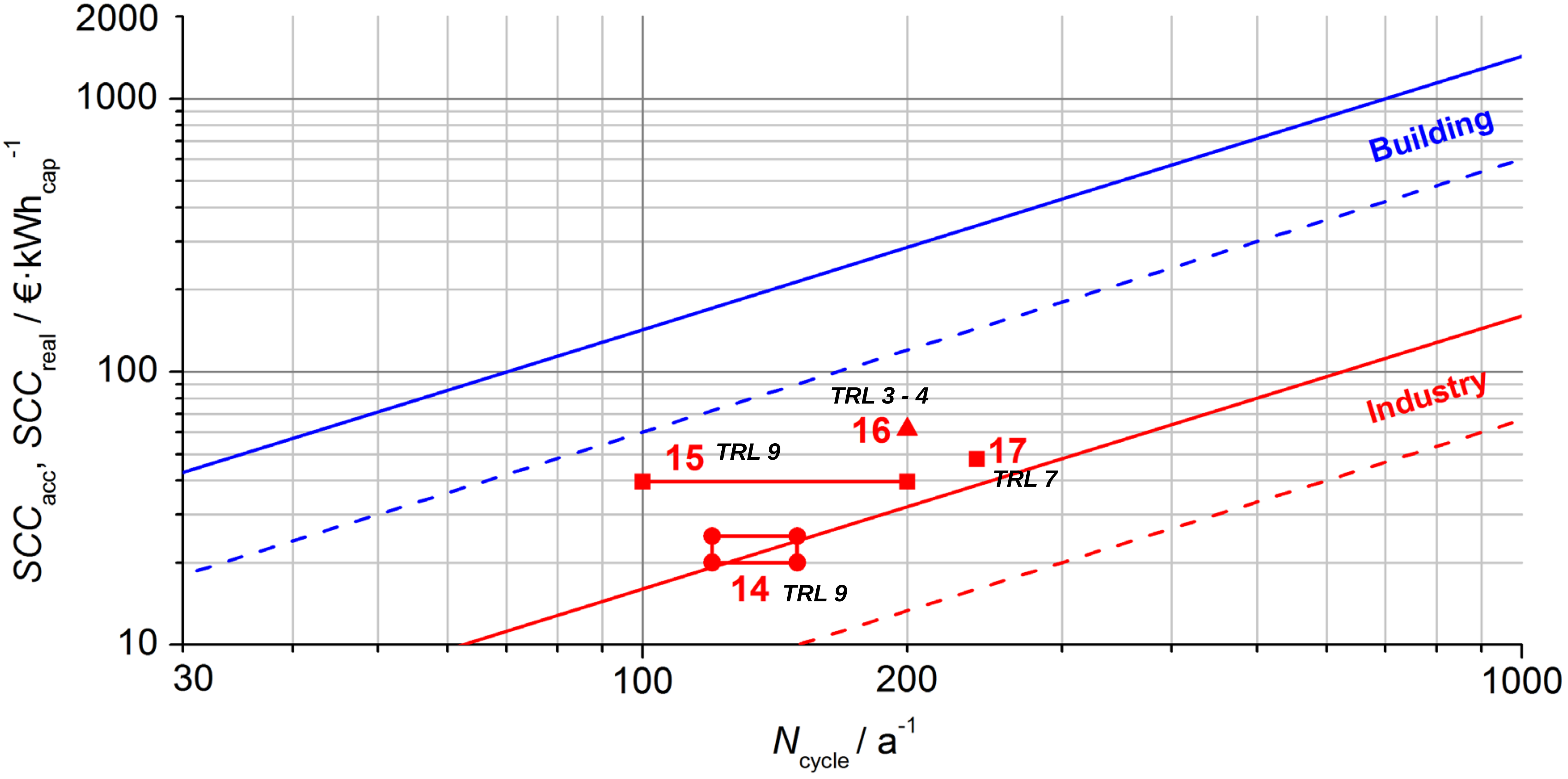


Short-term storages for industrial applications



storage	description	N_{cycle} / a^{-1}	*INC* / €	*SC* / kWh_{cap}	SCC_{real} / €·kWh_{cap}^{-1}
14: Ice storages (Cristopia)	Storages with spherical nodules filled with water / ice	120 – 150	-	5,000 – 10,000	20 – 25
15: SAT mobile storage (Univ. Bayreuth, LaTherm)	Mobile PCM storage (sodium acetate trihydrate); 40 – 90 °C	100 – 200	99,000	2,500	39.6
16: Dual media storage (ZAE Bayern, Gießerei Heunisch)	Sensible storage; stone + heat transfer oil; up to 300 °C	200	400,000	6,500	61.5
17: Mobile sorption heat storage (ZAE Bayern)	2 x 14 t zeolite, industrial waste heat recovery	240	440,000	9,200	47.8

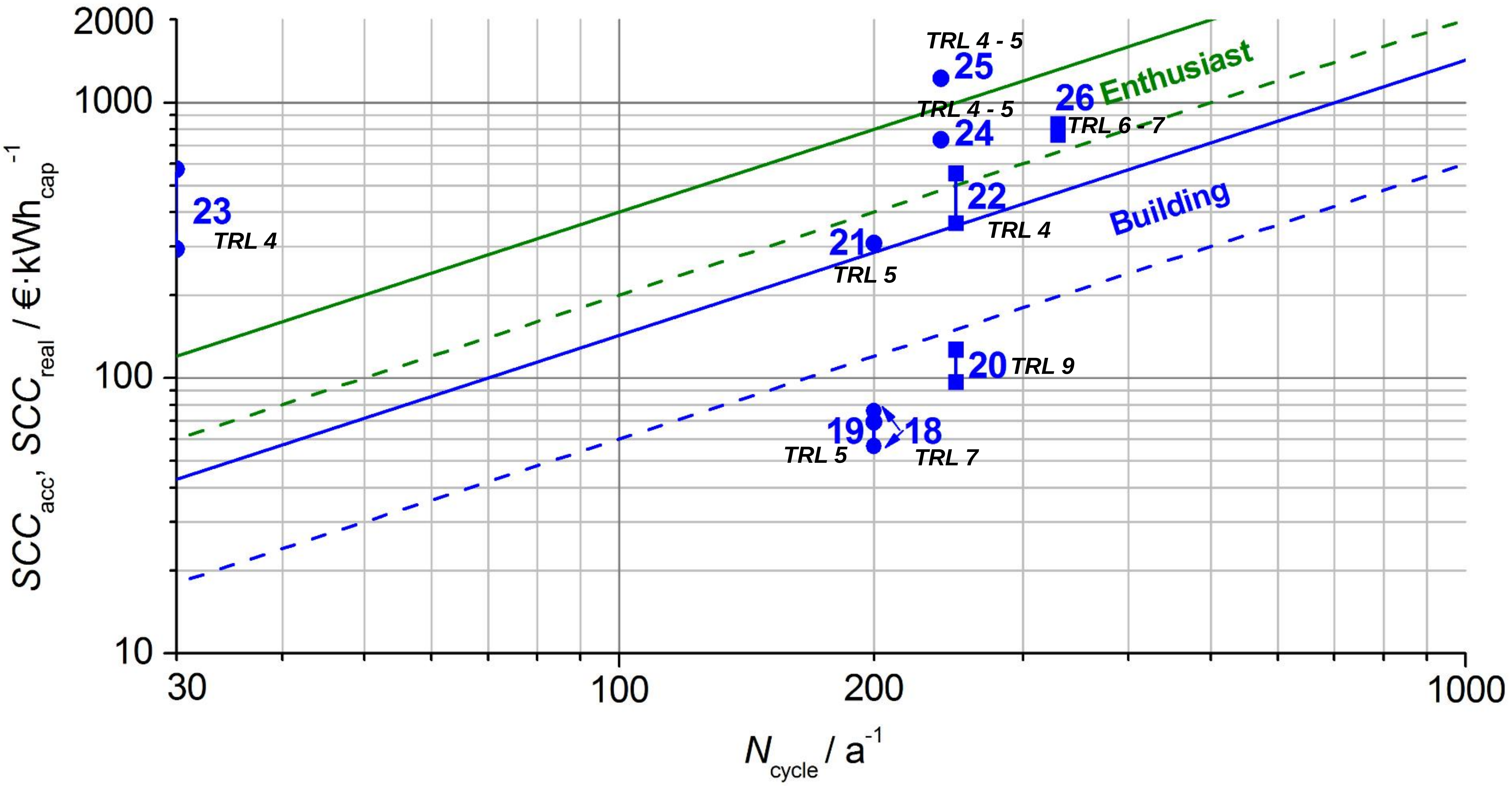
Short-term storages for industrial applications



→ Ice storages cost effective, other technologies within reach

Short-term PCM & TCM storages for building applications

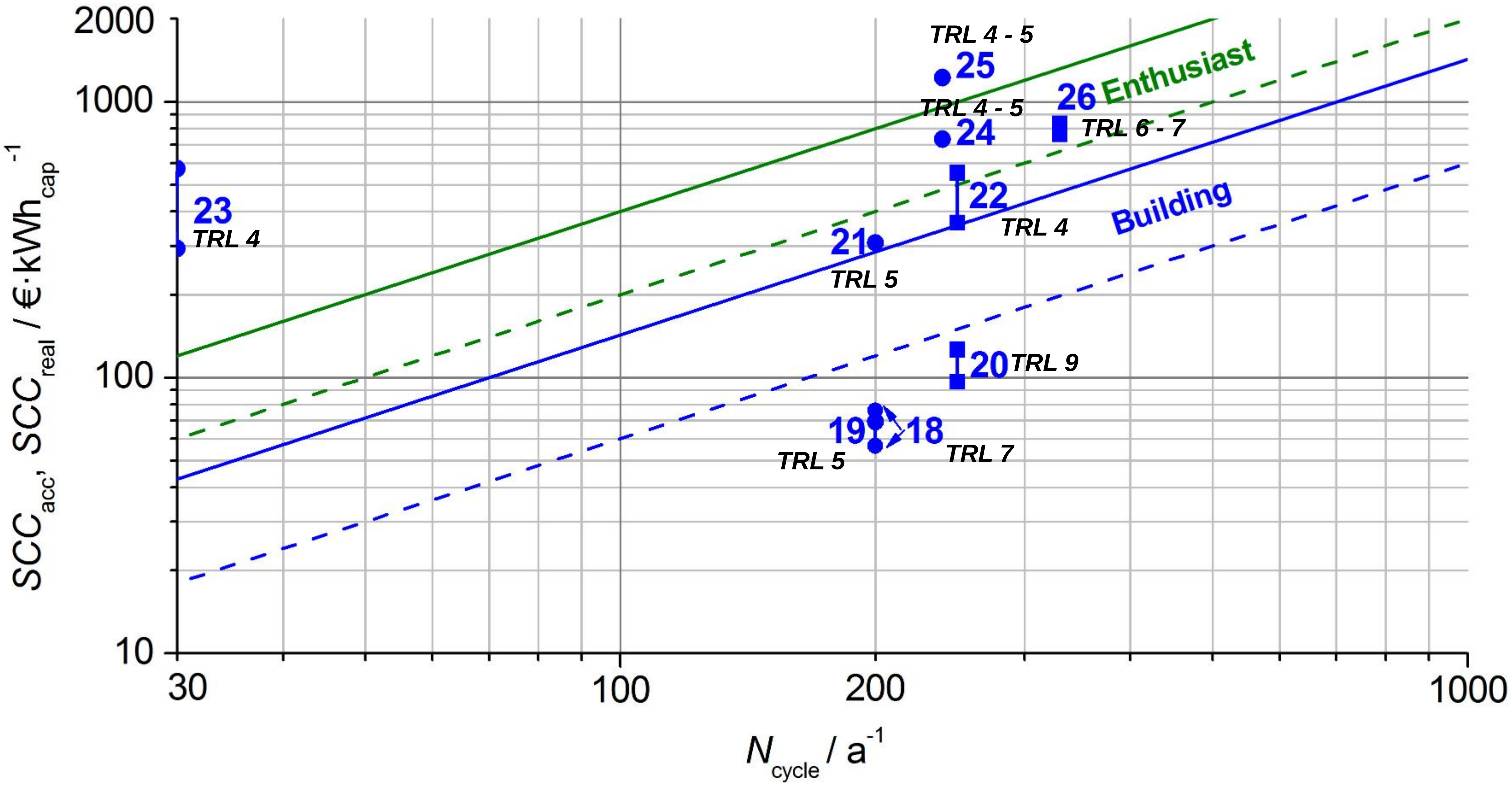
● = PCM ■ = TCM



Short-term PCM & TCM storages for **building** applications

storage	Description	N_{cycle} / a^{-1}	*INC* / €	*SC* / kWh$_{cap}$	*SCC*$_{real}$ / €·kWh$_{cap}^{-1}$
18: SolarHeatCool+ PCM (ZAE Bayern)	1 m³ PCM storage ($CaCl_2 \cdot 6H_2O$); 22 – 36 °C	200	4,700 – 6,300	83	56.6 – 75.9
19: TubeICE (VITO)	PCM tubes (salt hydrate + graphite); 30 – 70 °C	200	900	13	69.2
20: Dishwasher (ZAE Bayern)	Dishwasher, sorption drying (1.5 kg zeolite)	250	29 – 38	0.3	96.7 – 127
21: RT58 storage (VITO)	0.2 m³ PCM storage (RT58); 30 – 70 °C	200	1,850	6	308
22: LiBr storage (ZAE Bayern)	Sorption storage (aqueous LiBr); domestic appl.	250	31,000 – 47,000	85	365 – 553
23: PCM-Air (Univ. Zaragoza)	Free-cooling; PCM-Air heat exchanger; RT27	30	2,000 - 3,900	6.8	294 – 574
24: VDSF (Univ. Lleida)	Free cooling; ventilated double skin facade + PCM (SP21)	240	5,133	7	733
25: Hydroquinone storage (Univ. Lleida)	Solar applications; hydroquinone as PCM; 145 – 187 °C	240	16,768	13.7	1,223
26: RT60 storage (Univ. Basque Country)	Plate based PCM storage (RT60); domestic micro-CHP installation	330	5,500 – 6,000	7.2	764 – 833

Short-term PCM & TCM storages for **building** applications



→ Some storages already cost effective,

others at lower TRL with higher investment costs

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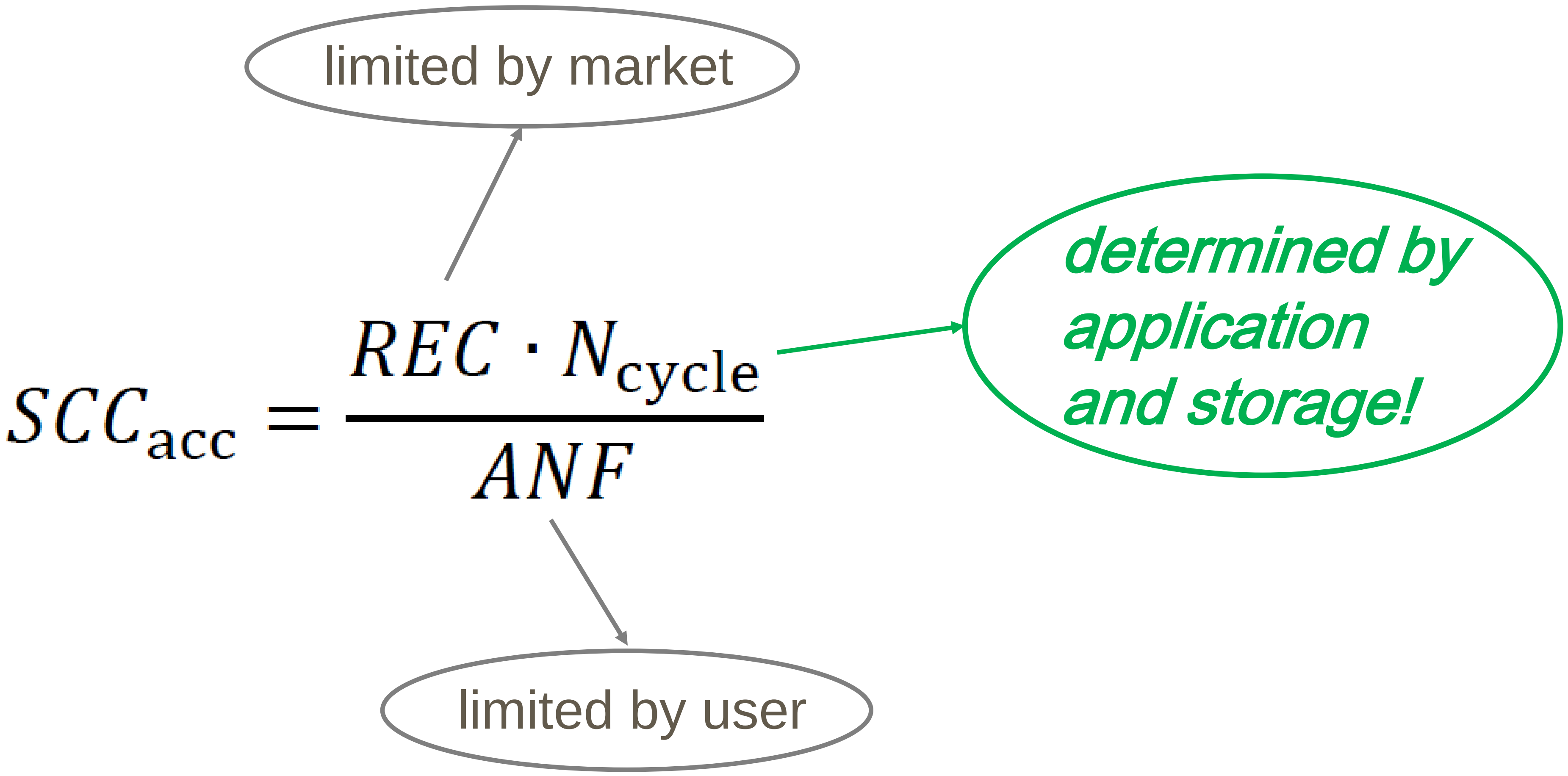
What are the major influencing factors on the cost effectiveness?

Top-Down Approach

Maximum acceptable storage capacity costs SCC_{acc}



limited by market

$$SCC_{acc} = \frac{REC \cdot N_{cycle}}{ANF}$$

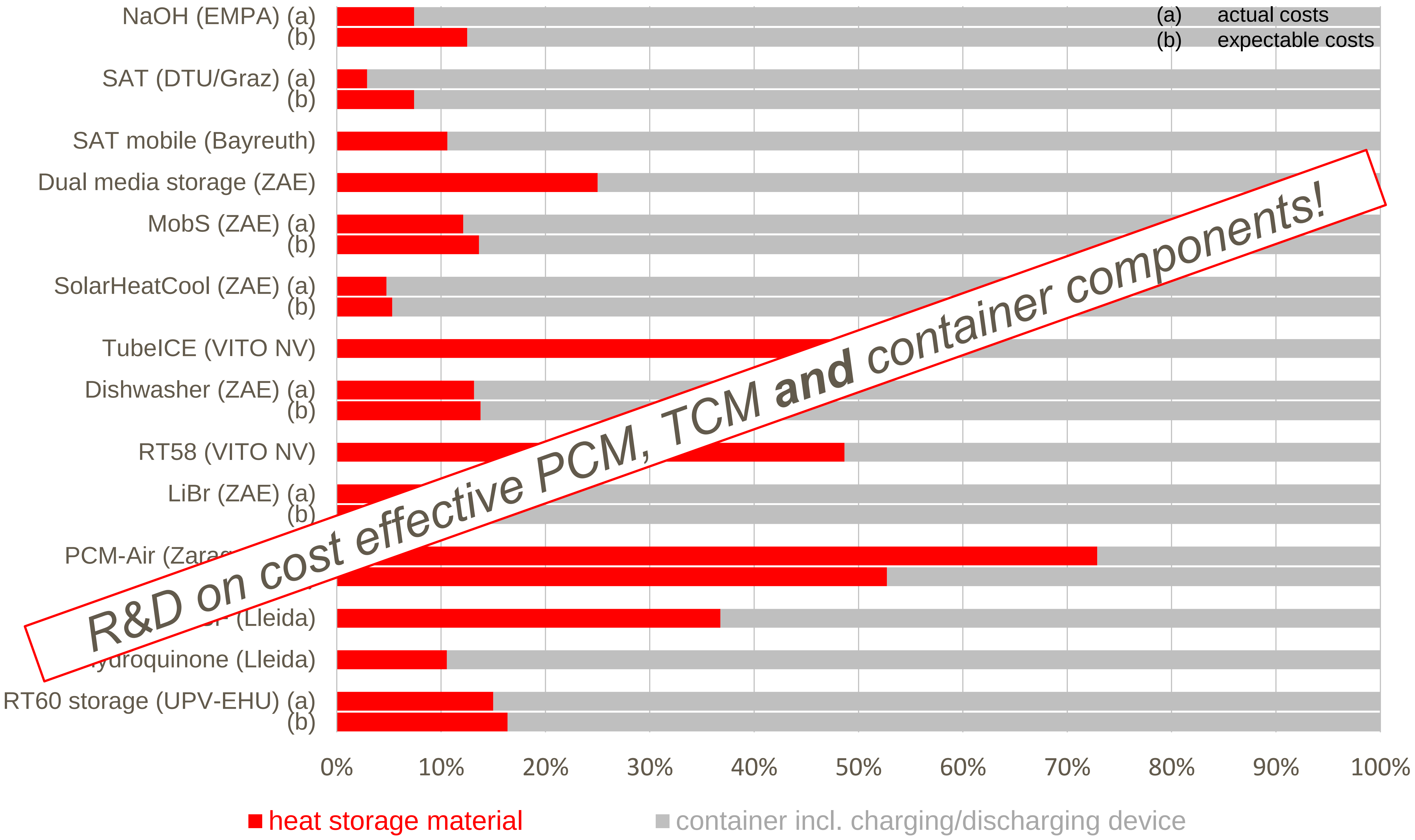
determined by application and storage!

limited by user

Bottom-Up Approach

Investment cost *INC* distribution

$$SCC_{\text{real}} = \frac{INC}{SC}$$



R&D on cost effective PCM, TCM **and** container components!

Summary

A simple tool for the economic evaluation of thermal energy storages

Top-down & Bottom-up approach:

Annual payment for storage investment

≤ !

Annual savings of reference energy costs

A simple tool for the economic evaluation of thermal energy storages

Top-down & Bottom-up approach:

$$\boxed{SCC_{\mathrm{real}} = \frac{INC}{SC}} \quad <! \quad \boxed{SCC_{\mathrm{acc}} = \frac{REC \cdot N_{\mathrm{cycle}}}{ANF}}$$

Most influencing: **Annual number of storage cycles *N*$_{\mathrm{cycle}}$**

Applications with high *N*$_{\mathrm{cycle}}$:

→ All storage technologies can be economical

→ Systems should be compared regarding physical and technical attributes (and TRL)

Thermal energy storages with additional benefits

- „Power“ storages (e.g. DHW storages)
- Stand-alone systems (e.g. self-sufficient solar energy supply)
- Comfort applications (e.g. PCM in textiles / transport boxes, self-cooling beer barrel with zeolite)
- Increasing flexibility (e.g. CHP + district heating/cooling + TES:
  decoupling of electricity and heat/cold production → higher electricity sales)

Contributors and publications

Rathgeber, C., Hiebler, S., Lävemann, E., Dolado, P., Lazaro, A., Gasia, J., de Gracia, A., Miró, L., Cabeza, L.F., König-Haagen, A., Brüggemann, D., Campos-Celador, Á., Franquet, E., Fumey, B., Dannemand, M., Badenhop, T., Diriken, J., Nielsen, J.E., Hauer, A.

IEA SHC Task 42 / ECES Annex 29 open access papers:

Energy Procedia Volume 91, Pages 197-217 & 226-245
Proceedings of the 4th International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2015)

New phase 2017 – 2019
Task/Annex 58/33

PCM	TCM
Subtask 1: “Development of Improved TES Materials”	
Subtask 1P	Subtask 1T
Stefan Gschwander (ISE, DE)	Alenka Ristic (NIC, SI)
Subtask 2: “Material Testing under Application Conditions”	
Subtask 2P	Subtask 2T
Christoph Rathgeber (ZAE, DE)	Daniel Lager (AIT, AT)
Subtask 3: “Component Design for Innovative Materials”	
Subtask 3P	Subtask 3T
Ana Lázaro (Uni Zaragoza, ES)	Benjamin Fumey (EMPA, CH)
Subtask 4: “Energy Relevant Applications for an Application-oriented Development of Improved Storage Materials”	
Andreas Hauer (ZAE, DE) and Wim van Helden (AEE INTEC, AT)	

→ Kick-off meeting: April 5-7, Lyon

Thank you for your attention!

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