Energy Efficient Cooling with new Absorption Chiller Technology in Solar Cooling Systems and CHPC-Plants

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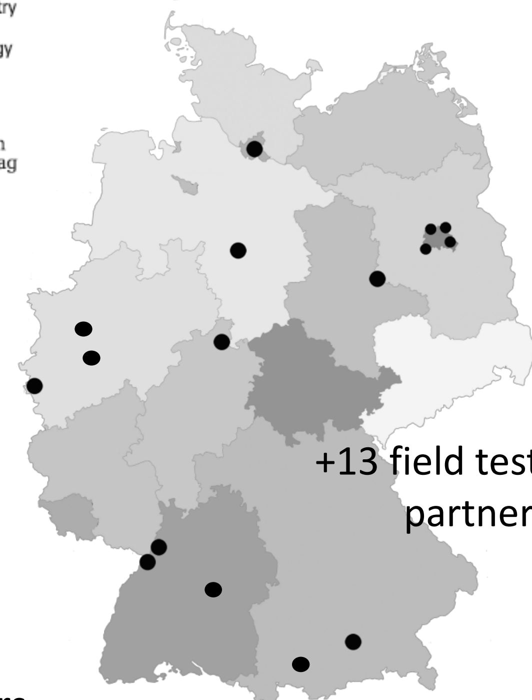
1. Field test projects in absorption chiller cooling technology
2. Absorption chiller control standard/extended
3. Overall monitoring and hydraulic concept
4. Operation and performance results
5. Conclusion




Field Test Trigeneration

- Project „EnEff Wärme: Absorptionskälteanlagen für KWKK Systeme" (FAkS)
- 15 field tests throughout Germany
- Installation of 25 absorption chillers
- Trigeneration (cooling/heating/el. supply)
- Research and optimization upon:
  - construction
  - system integration (co-/trigeneration)
  - controll concepts / supply security
- Detailled monitoring (system/chiller)
- Commissioning in 2013/2014

Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag




Absorption chiller system /KRGC


Absorption chiller system /AHIT

research partners

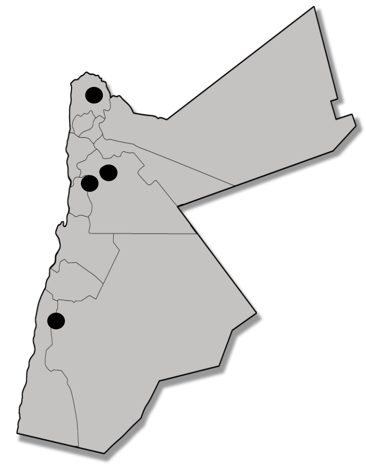
BTGA Bundesindustrieverband Technische Gebäudeausrüstung e.V.
TECHNISCHE UNIVERSITÄT DRESDEN
ZAE BAYERN Bayerisches Zentrum für Angewandte Energieforschung
AGFW
ILK Dresden

Solar Cooling Systems

Supported by:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

- Project „Solar Cooling in Industrie and Commerce" (SCIC)
- 4 solar cooling installations throughout Jordan
- Demonstration – Know-How Transfer – Promotion
  - Consulting role during planning/procurement/installation phase
  - Local capacity building and personel training
  - Commissioning 2015/2016 / monitoring
- Project successfully ended in 2017



Absorption chiller type Bumblebee in German Jordan University

Solar collector field in Royal Culture Centre

field test and project partners

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

MILLENNIUM ENERGY INDUSTRIES

MINISTRY OF ENVIRONMENT

GJU

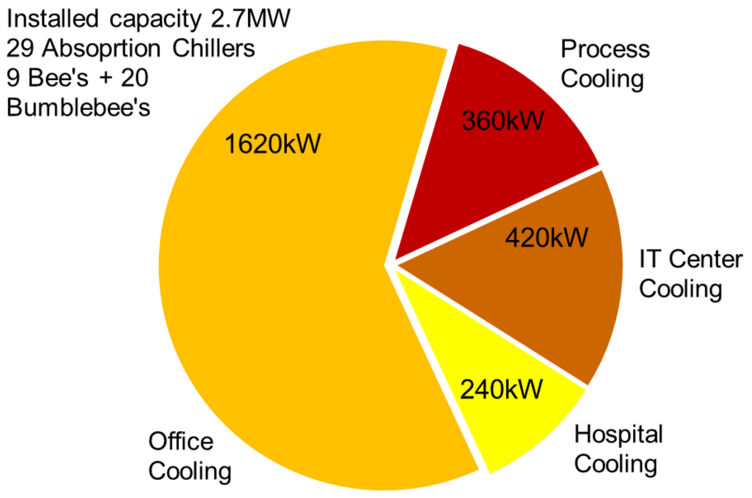
PETRA Guest House

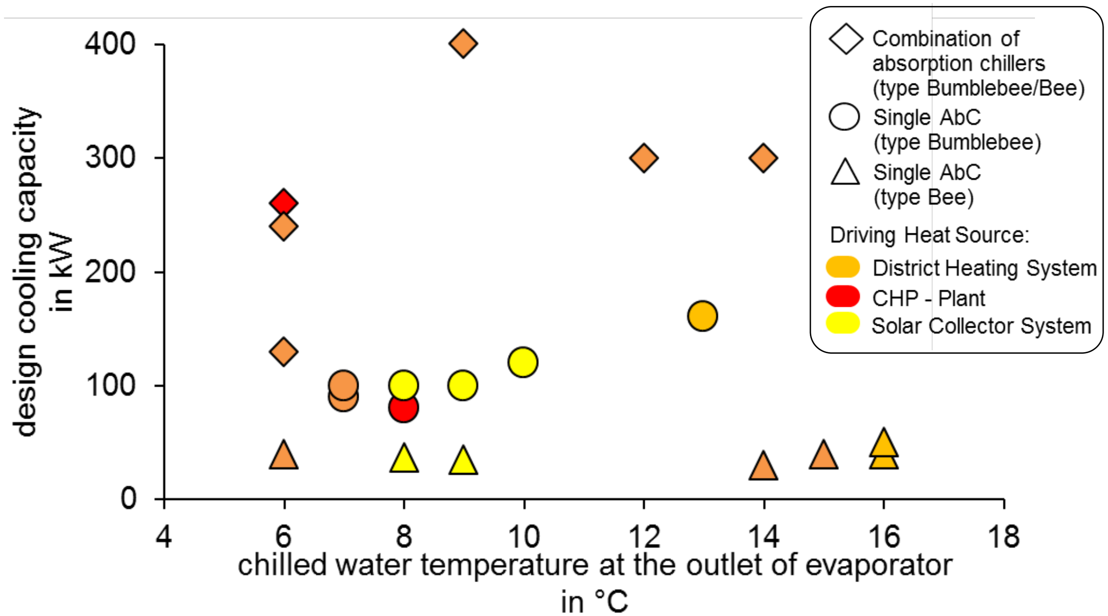
Installed Absorption Chiller Technology

Specifications (nominal)	Bee	Bumblebee
Coefficient of Performance (COP)	0,79	0,82
cooling capacity	**50kW**	**160kW**
chilled water temperature in-/outlet	21/16°C	
heat capacity	63kW	200 kW
hot water temperatur in-/outlet	90/72°C	

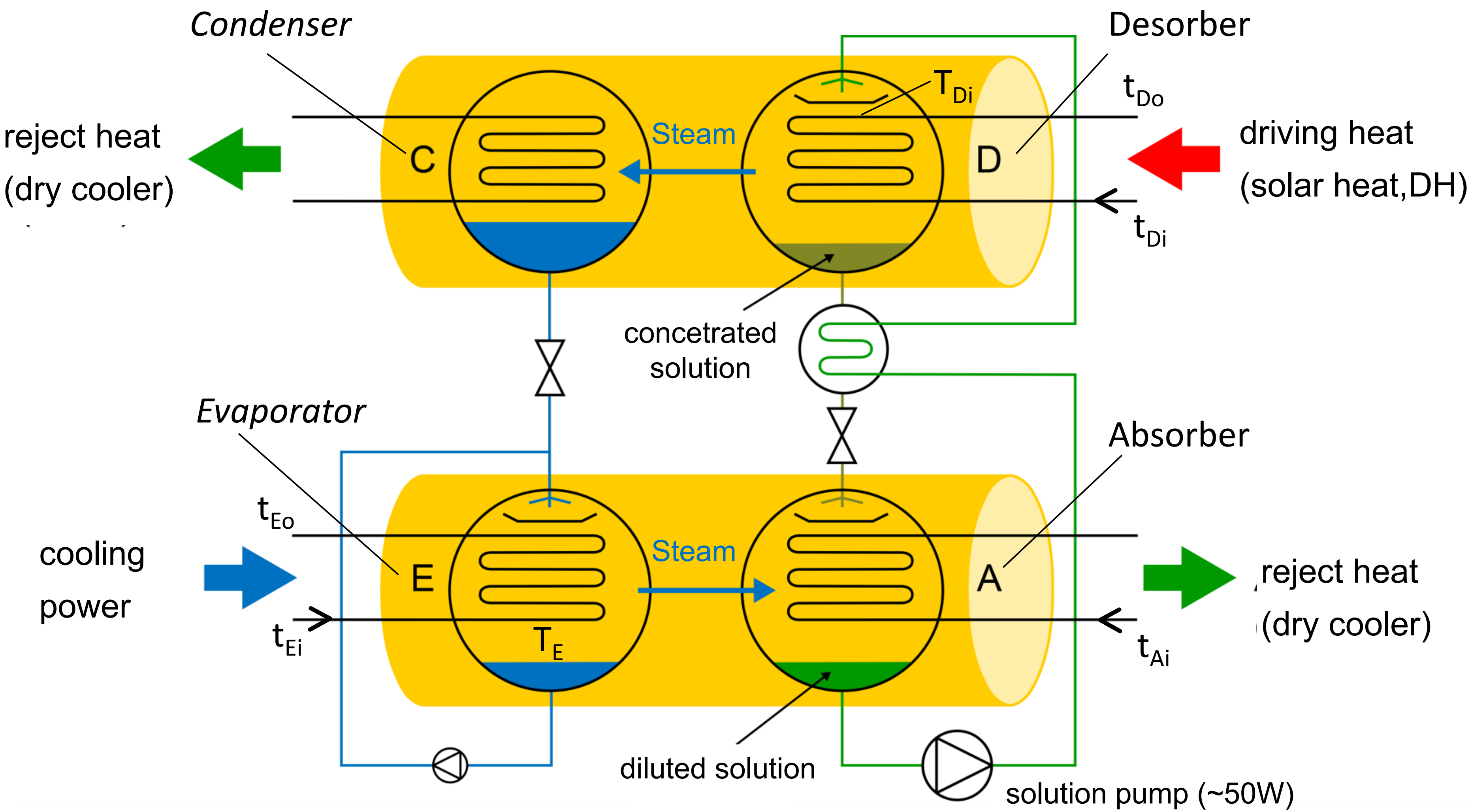
working pair $H_2O/LiBr$

Absorption chiller Bee prototype & market unit





Working Principle Absorption Chiller

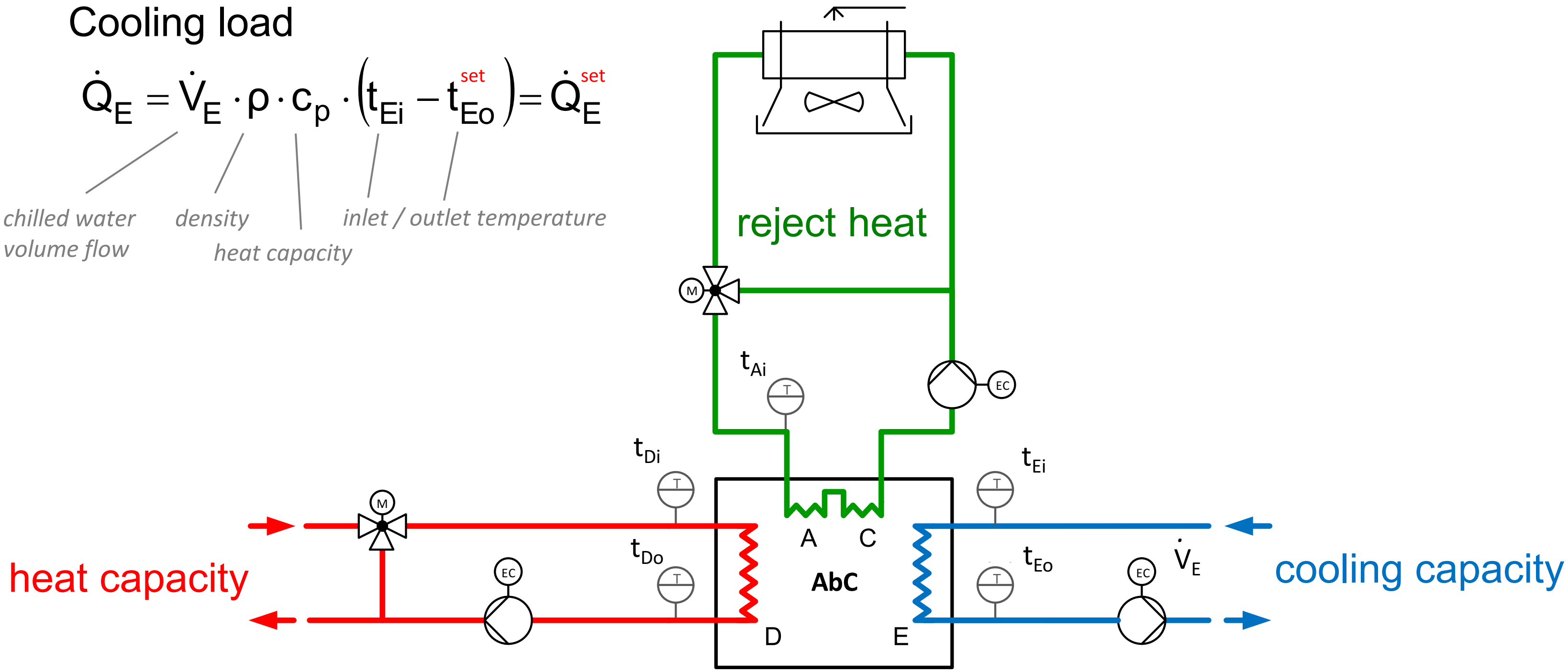


Introduction Absorption Chiller Control

Cooling load

$$\dot{Q}_E = \dot{V}_E \cdot \rho \cdot c_p \cdot \left(t_{Ei} - t_{Eo}^{set}\right) = \dot{Q}_E^{set}$$

chilled water volume flow · *density* · *heat capacity* · *inlet / outlet temperature*



hot water circuit

cooling water circuit

chilled water circuit

A: Absorber D: Desorber

C: Condenser E: Evaporator

Introduction Absorption Chiller Control

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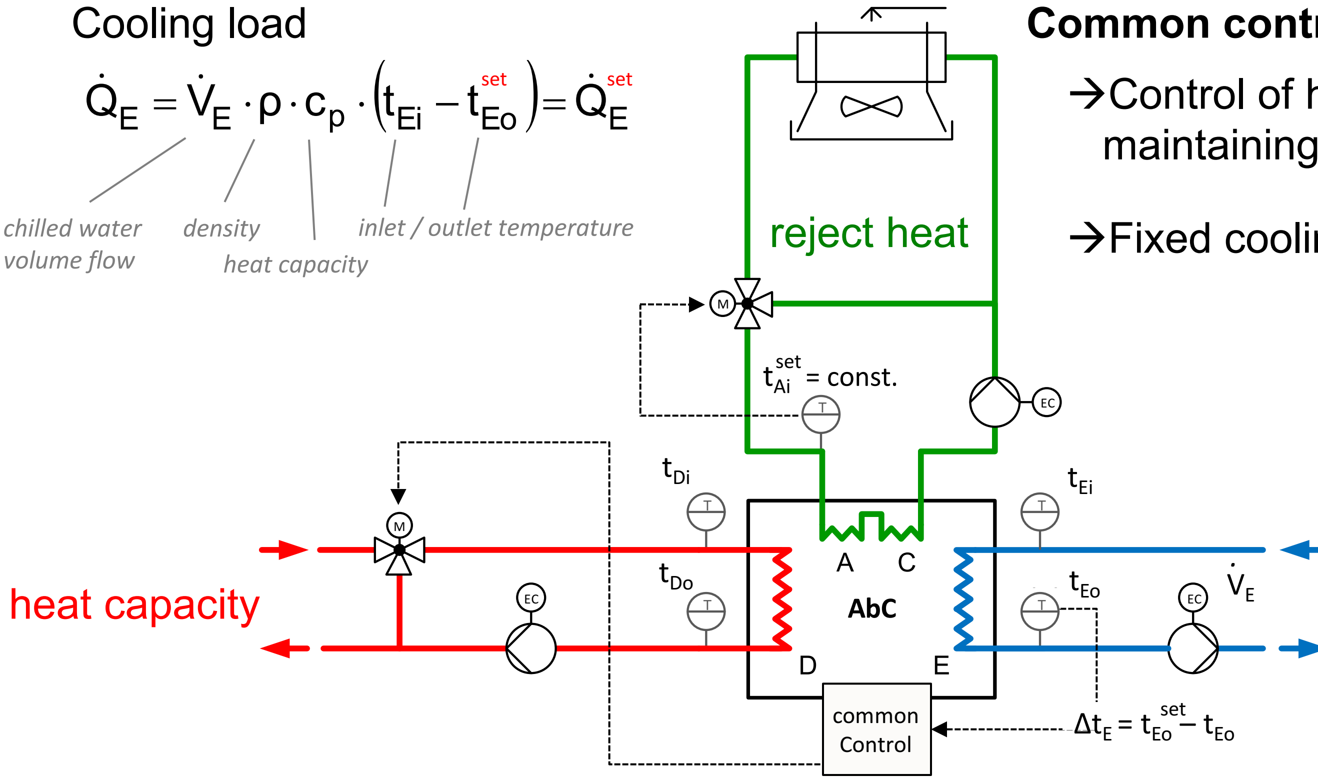
chilled water volume flow *density* *heat capacity* *inlet / outlet temperature*

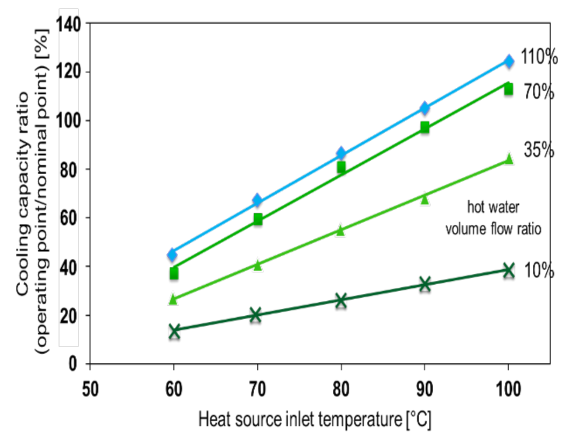
Common control:

→Control of hot water inlet temperature for maintaining cooling capacity $\dot{Q}_E = \dot{Q}_E^{set}$

→Fixed cooling water inlet temperature

$$t_{Ai}^{set} = const.$$





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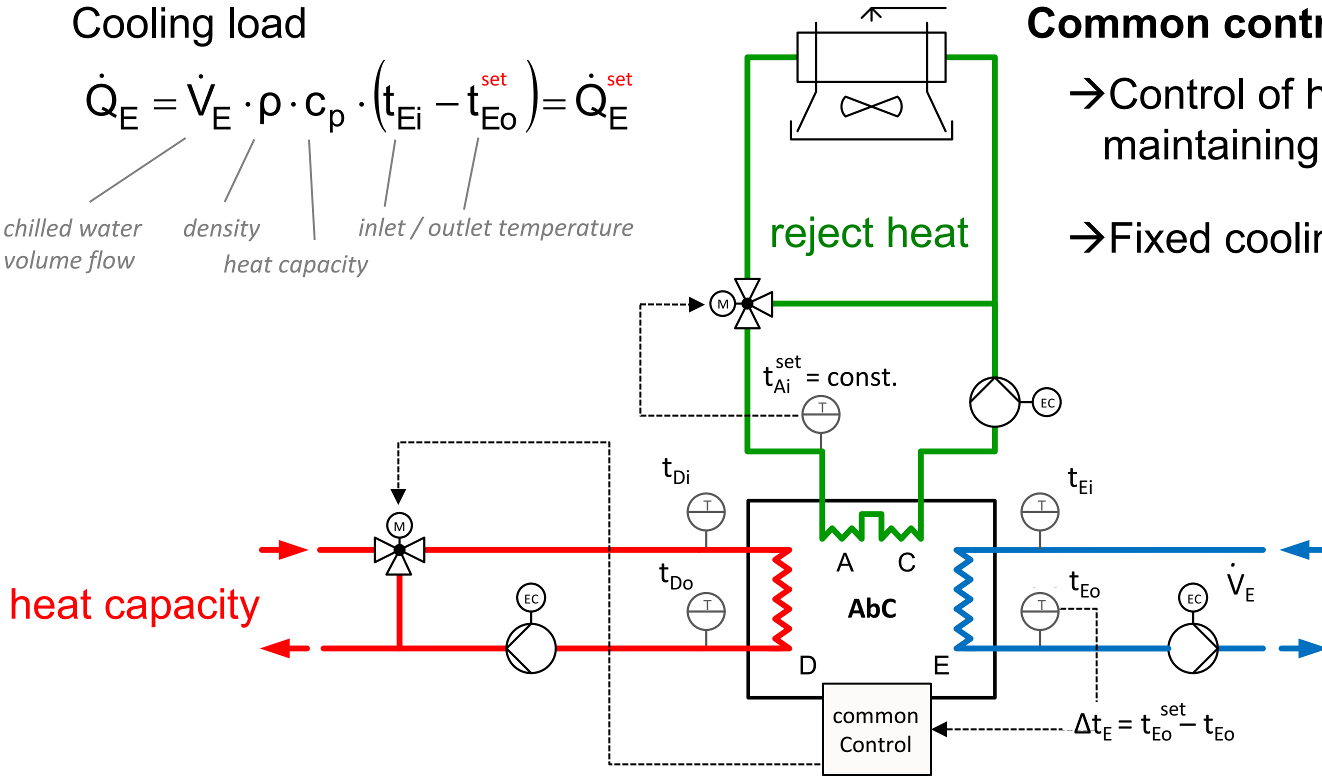
chilled water volume flow — *density* — *heat capacity* — *inlet / outlet temperature*



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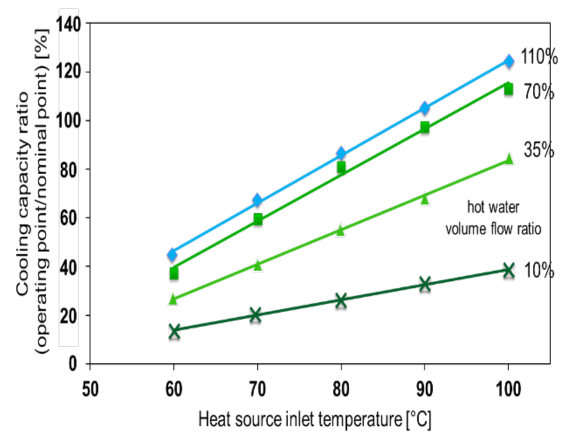
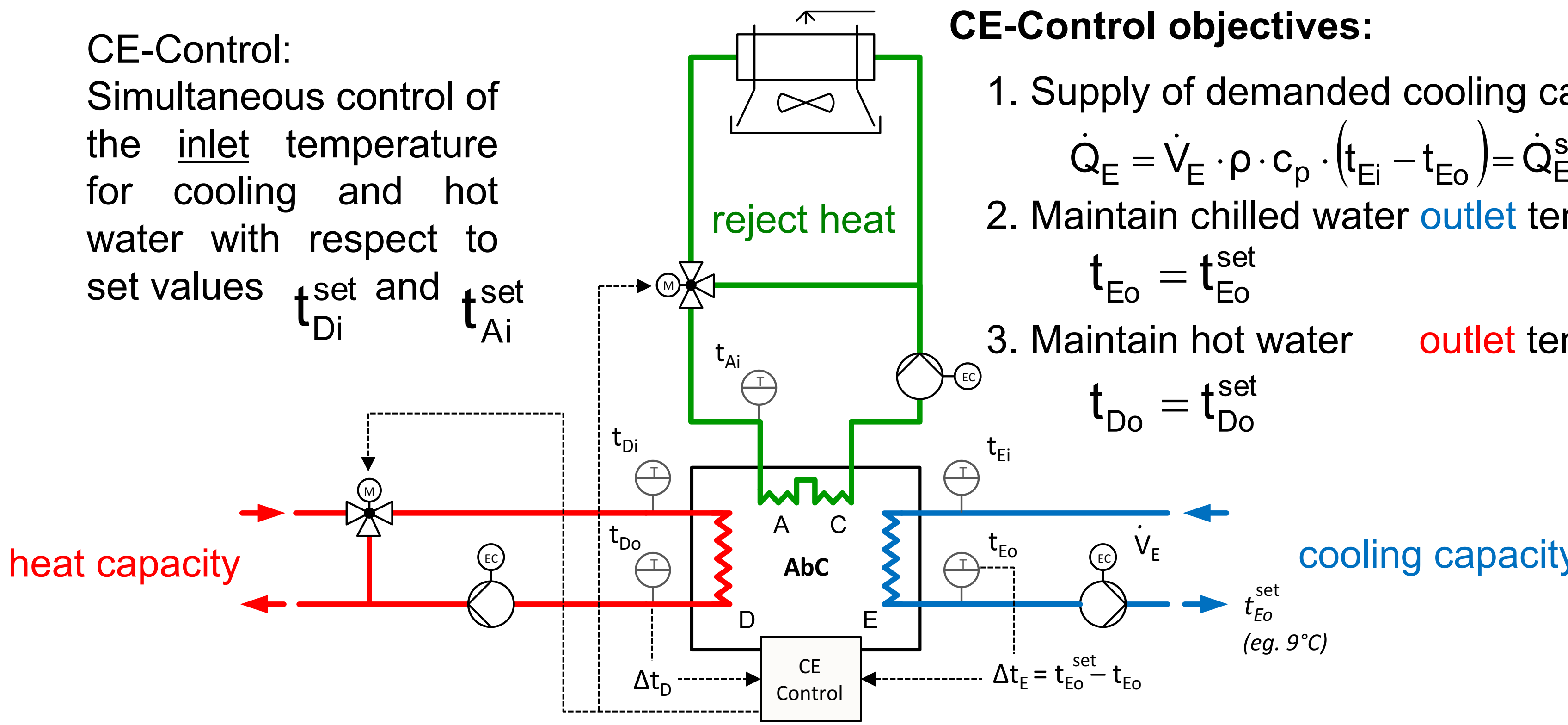


- hot water circuit
- cooling water circuit
- chilled water circuit

A: Absorber D: Desorber
C: Condenser E: Evaporator

Introduction Absorption Chiller Control

CE-Control:
Simultaneous control of the inlet temperature for cooling and hot water with respect to set values t_{Di}^{set} and t_{Ai}^{set}



CE-Control objectives:

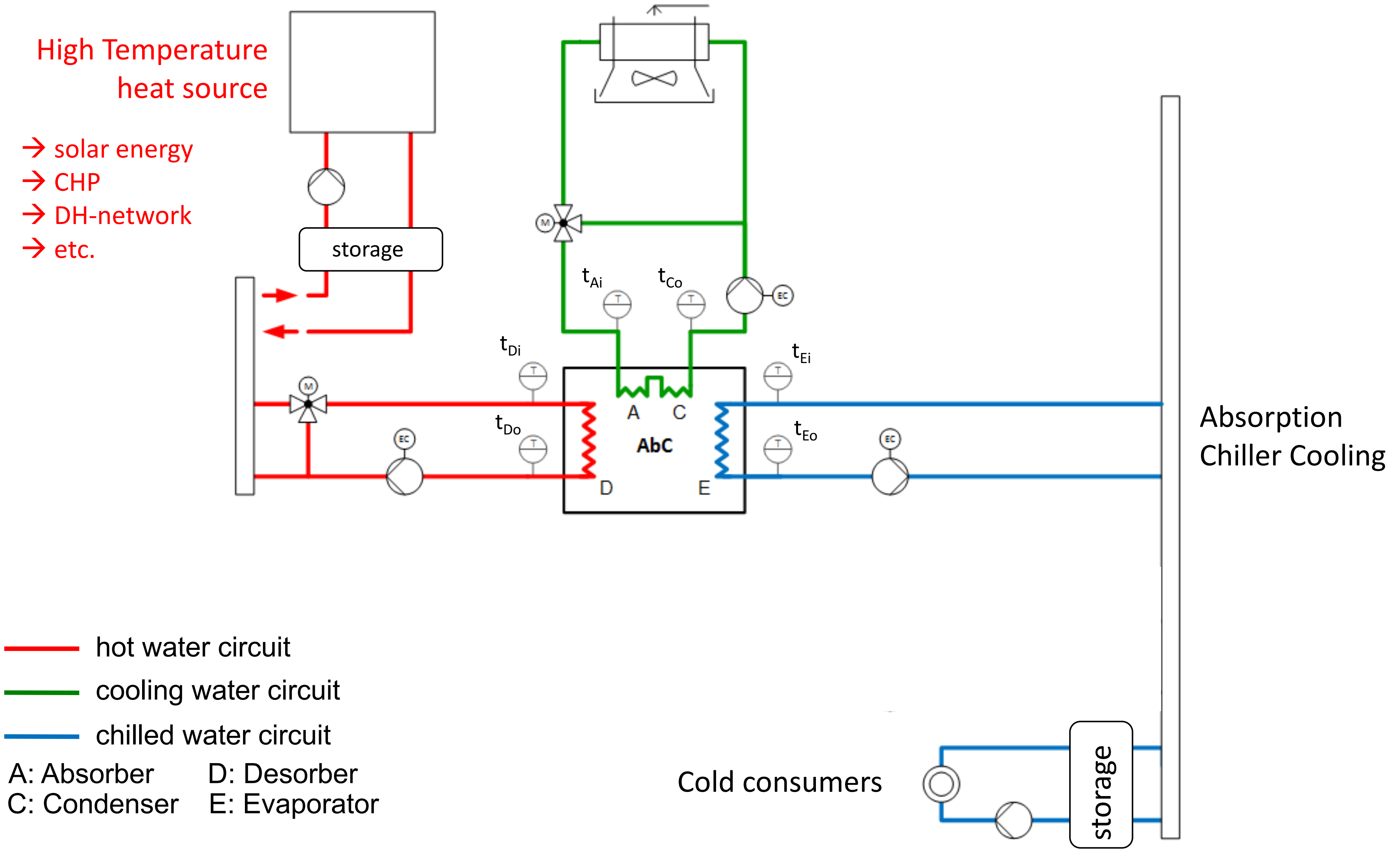
1. Supply of demanded cooling capacity
$$\dot{Q}_E = \dot{V}_E \cdot \rho \cdot c_p \cdot \left(t_{Ei} - t_{Eo}\right) = \dot{Q}_E^{set}$$
2. Maintain chilled water outlet temperature
$$t_{Eo} = t_{Eo}^{set}$$
3. Maintain hot water outlet temperature
$$t_{Do} = t_{Do}^{set}$$

→ fully automatic operation

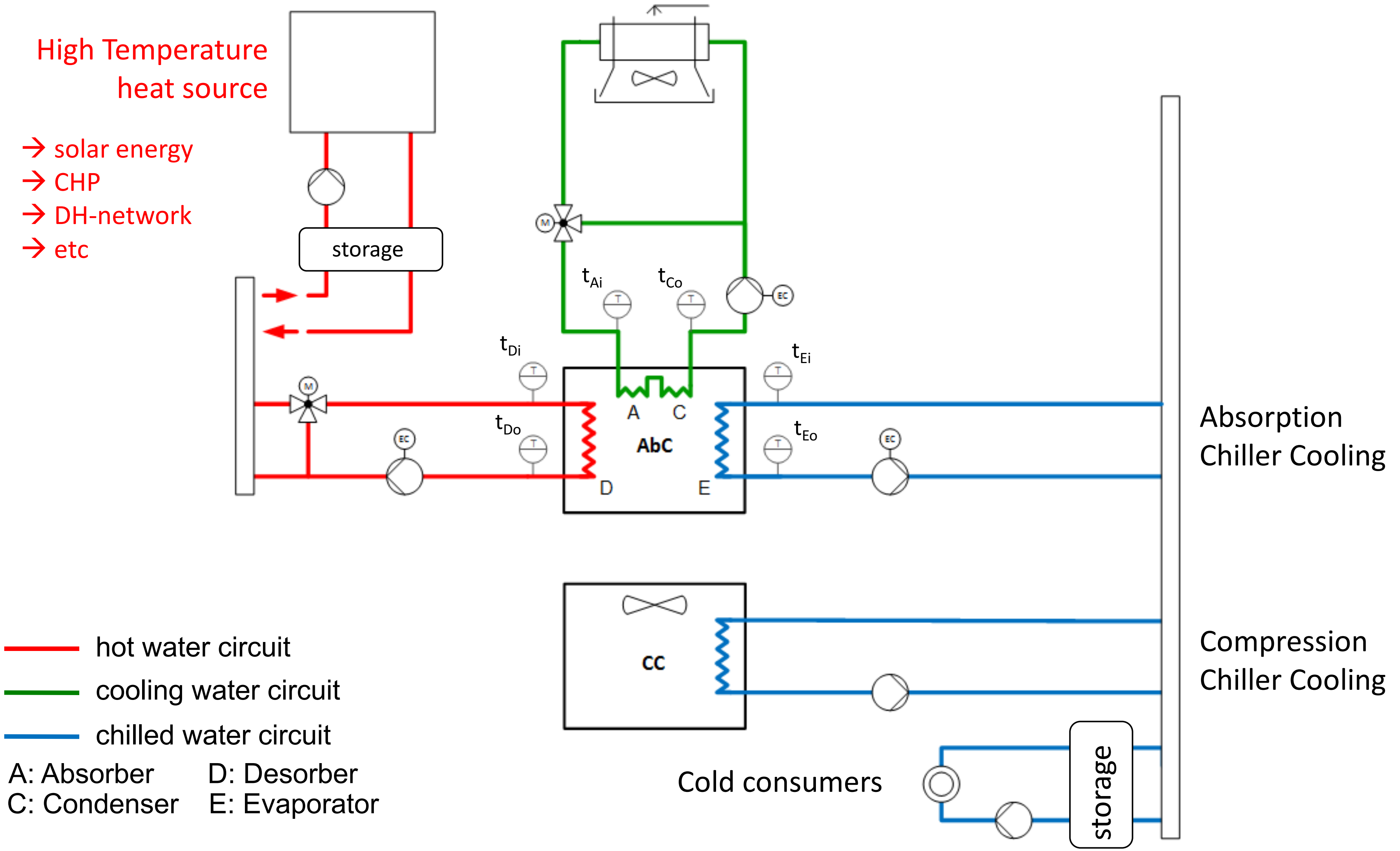
→control of external/internal actuators

→power controlled / intrinsically safe

Simplified PID



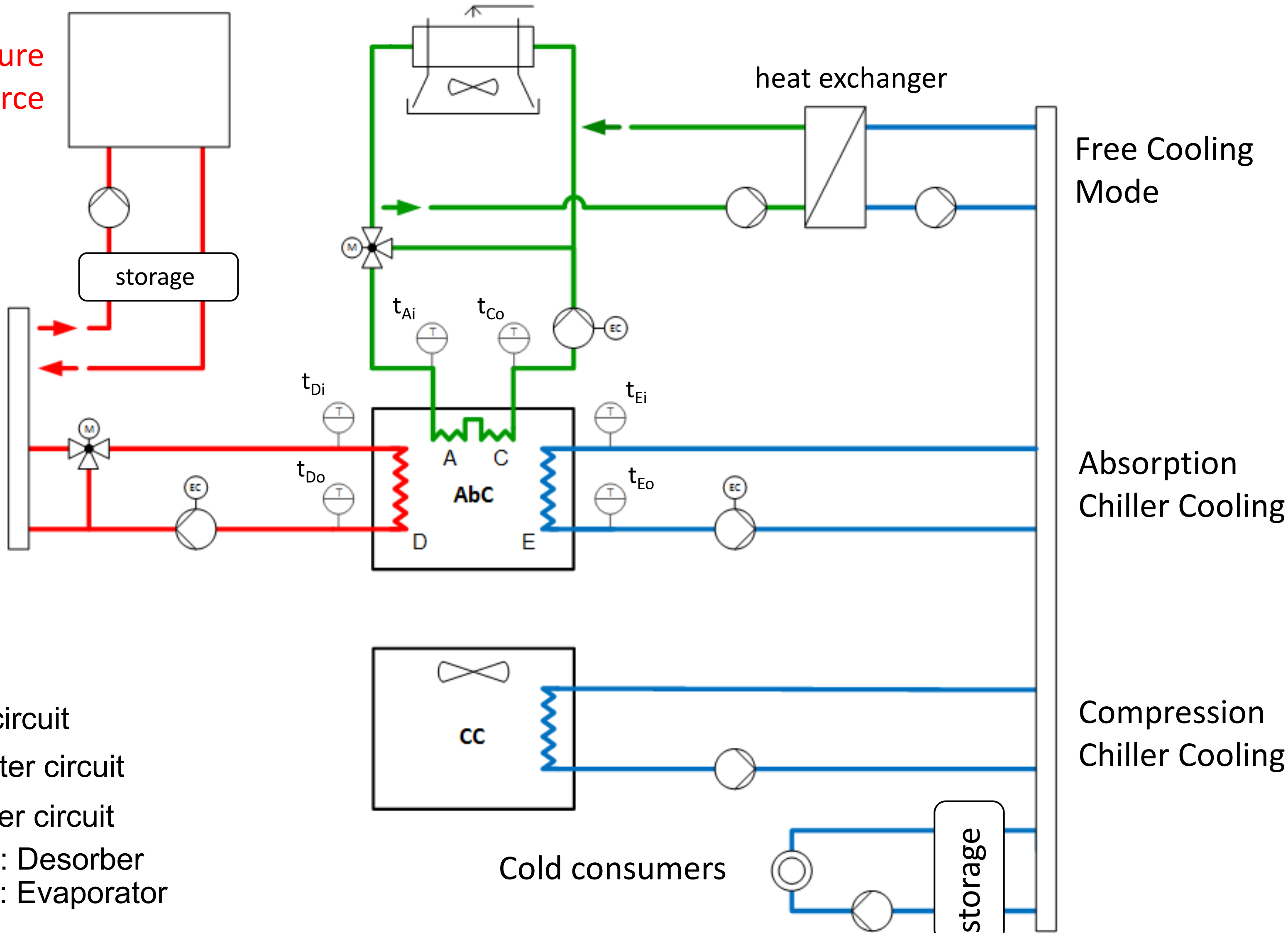
Simplified PID



Simplified PID

High Temperature
heat source

- → solar energy
- → CHP
- → DH-network
- → etc



hot water circuit
cooling water circuit
chilled water circuit

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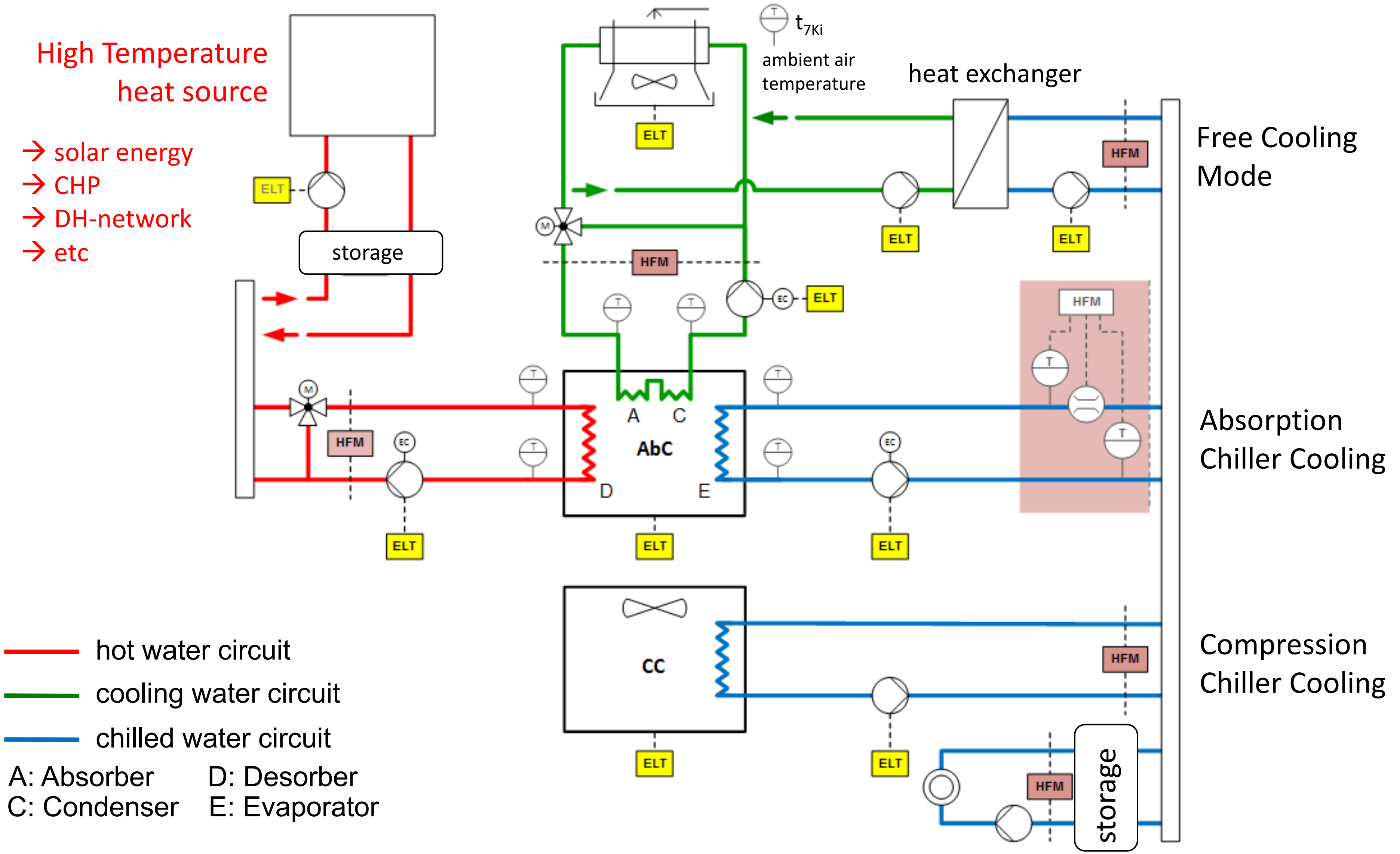
Simplified PID



Extended Absorption Chiller Control

Strategy 1

volume flow control evaporator circuit

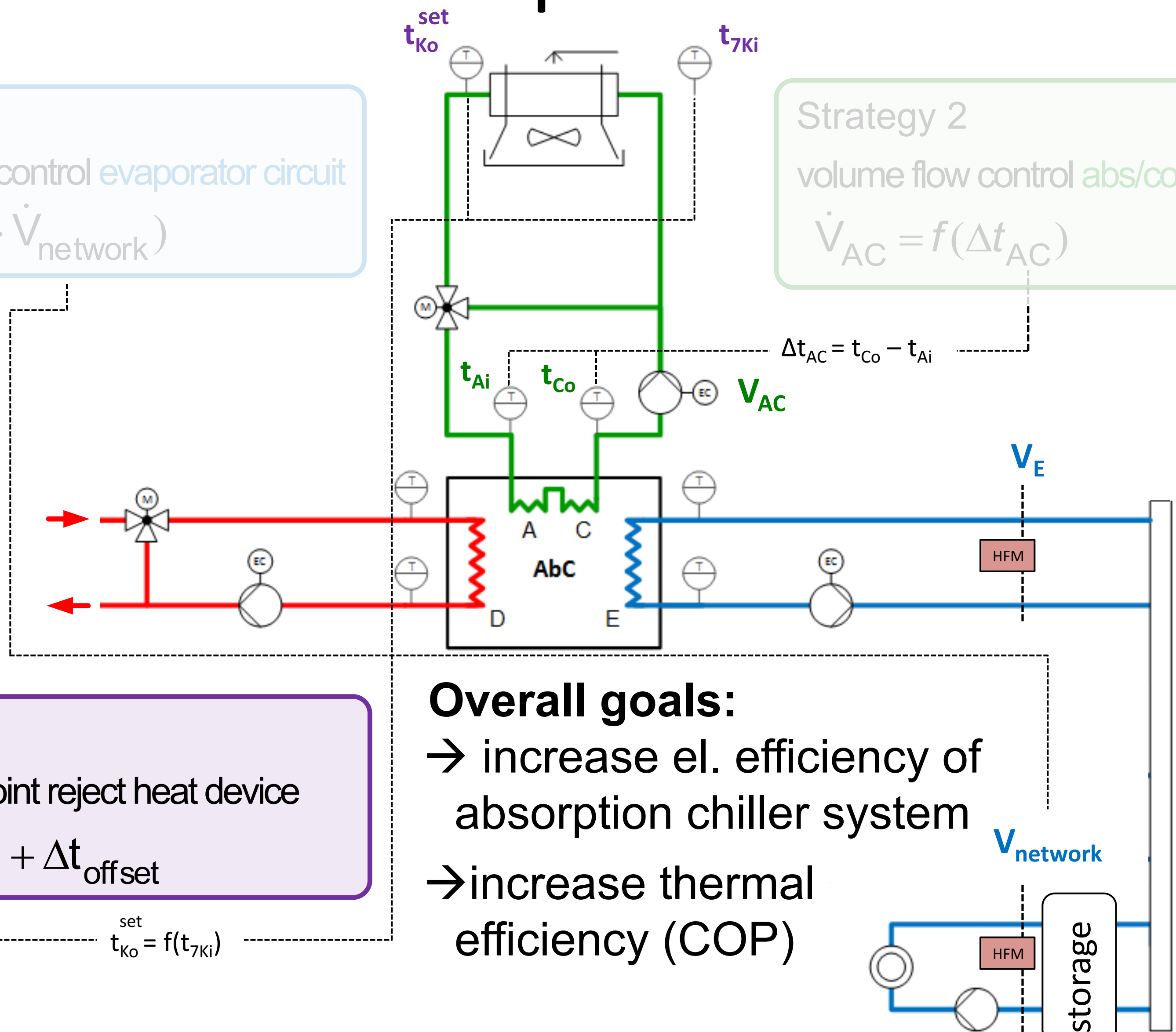
$$\dot{V}_E = f(g \cdot \dot{V}_{network})$$

g: gain factor

Strategy 2

volume flow control abs/conds circuit

$$\dot{V}_{AC} = f(\Delta t_{AC})$$



Strategy 3

control set point reject heat device

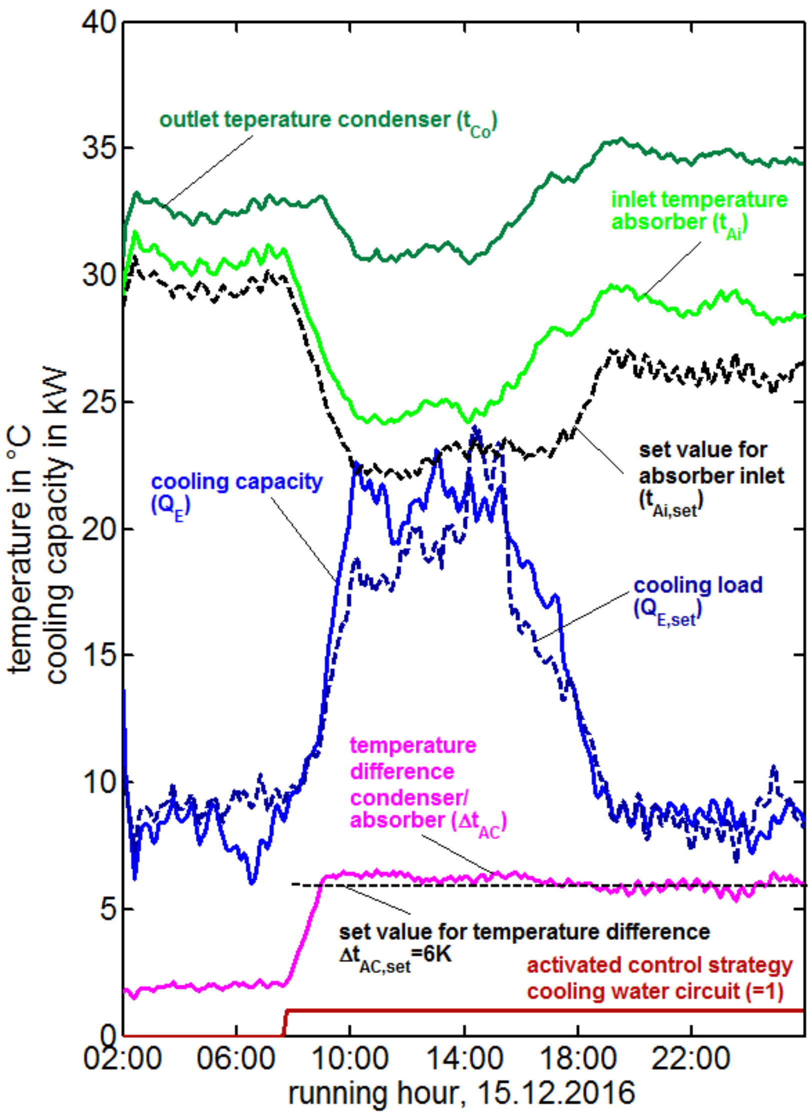
$$t_{Ko}^{set} = t_{7Ki} + \Delta t_{offset}$$

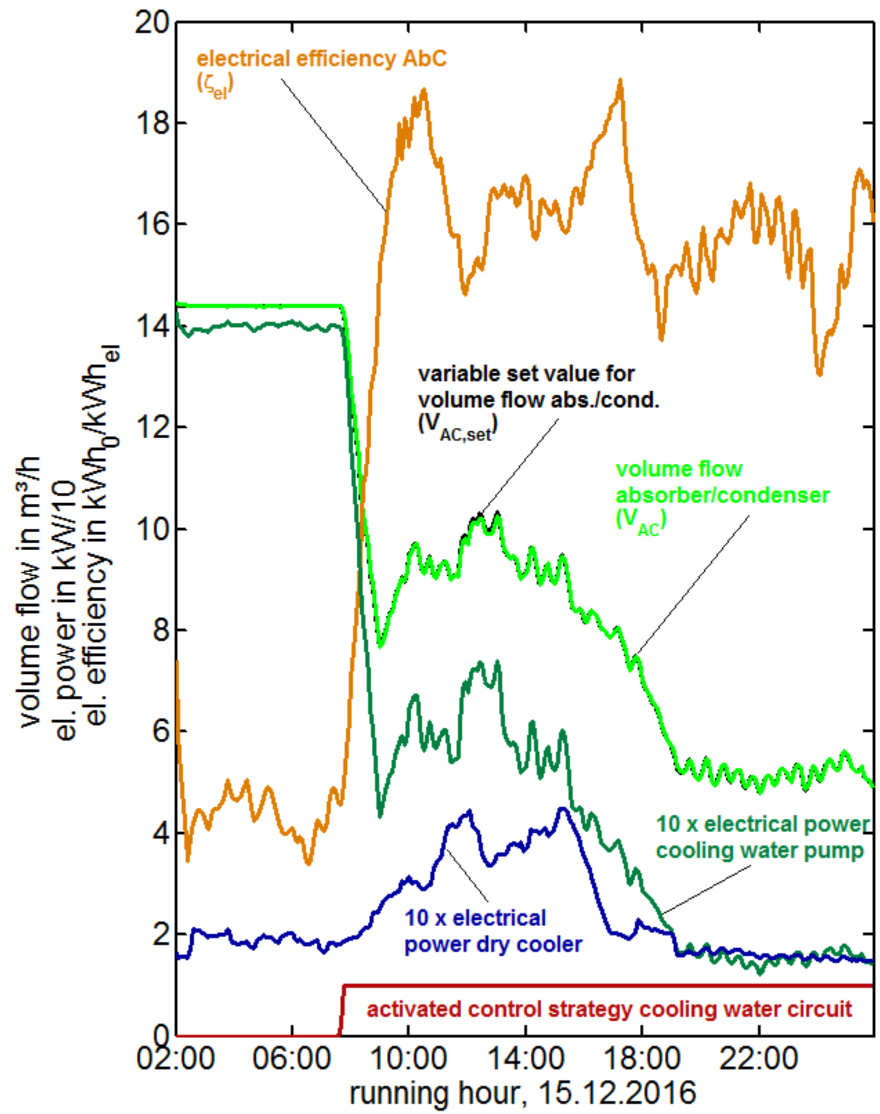
Overall goals:

→ increase el. efficiency of absorption chiller system

→ increase thermal efficiency (COP)

Performance Results with Strategy 2





Energy Performance Figures

specific electrical energy consumption

$$w_{k,i}^{\Delta\tau} = \frac{W_k^{\Delta\tau}}{E_{0,i}^{\Delta\tau}} \quad \left[\frac{kWh_{el}}{kWh_0}\right]$$

electrical / thermal efficiency

$$\zeta_{el,i}^{\Delta\tau} = \frac{E_{0,i}^{\Delta\tau}}{\sum W_{k,i}^{\Delta\tau}} = \frac{E_{0,i}^{\Delta\tau}}{W_i^{\Delta\tau}} \quad \left[\frac{kWh_0}{kWh_{el}}\right]$$

$$\zeta_{th,i}^{\Delta\tau} = \frac{E_{0,i}^{\Delta\tau}}{E_{2,i}^{\Delta\tau}} \quad \left[\frac{kWh_0}{kWh_2}\right]$$

chilled, cooling, hot: water circuit; AbC Control; reject heat device

$$w_{AbC}^{\Delta\tau} = \frac{\sum W_k^{\Delta\tau}}{E_{0,i}^{\Delta\tau}} = \frac{W_{Gr0}^{\Delta\tau} + W_{Gr1}^{\Delta\tau} + W_{Gr2}^{\Delta\tau} + W_{Gr3}^{\Delta\tau} + W_{Gr4}^{\Delta\tau}}{E_{0,i}^{\Delta\tau}}$$

specific primary energy consumption

$$pe_{k,i}^{\Delta\tau} = \frac{PE_{k,i}^{\Delta\tau}}{E_{0,i}^{\Delta\tau}} \quad \left[\frac{kWh_{pe}}{kWh_0}\right]$$

primany energy consumption

$$pe_i^{\Delta\tau} = \frac{PE_{el,i}^{\Delta\tau} + PE_{H,i}^{\Delta\tau}}{E_{0,i}^{\Delta\tau}} = \frac{\overbrace{\sum W_{k,i}^{\Delta\tau} \cdot PEF_{el}}^{\text{electr. driven components}} + \overbrace{E_{2,i}^{\Delta\tau} \cdot PEF_H}^{\text{desorber heat}}}{E_{0,i}^{\Delta\tau}}$$

primary energy factor electricity $\left[\frac{kWh_{pe}}{kWh_{el}}\right]$

primary energy factor heat $\left[\frac{kWh_{pe}}{kWh_2}\right]$

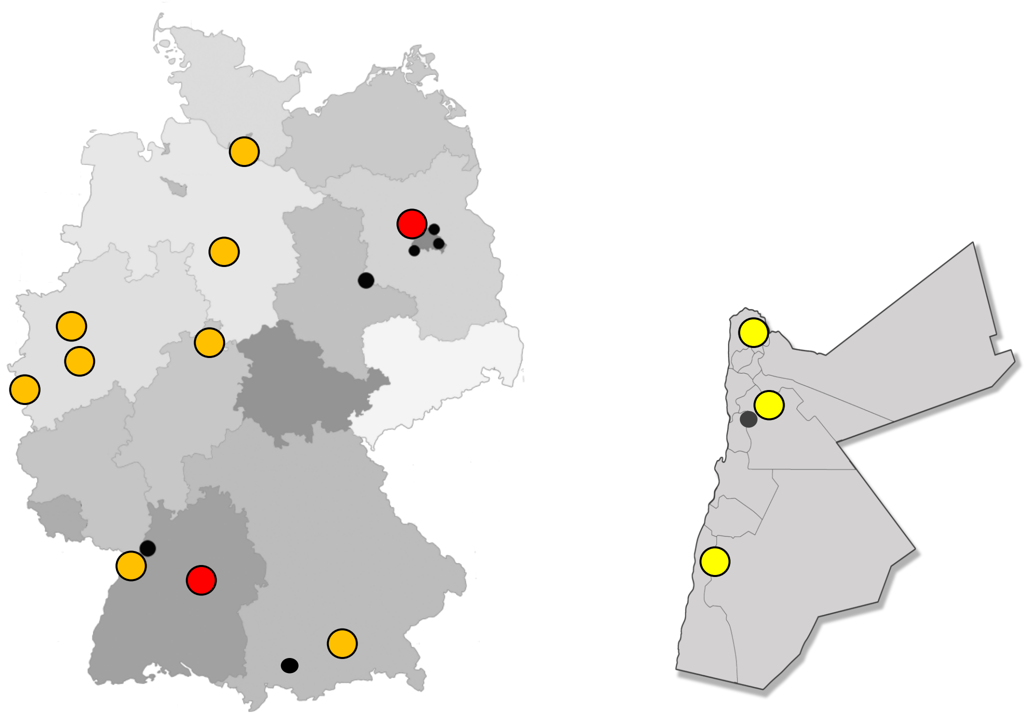
k: actuator (group)
i: AbC-No / System
Δτ=1day /time period

W: electrical energy
PE: primary energy
E_0: cooling E_2: driving heat

Field Test Selection

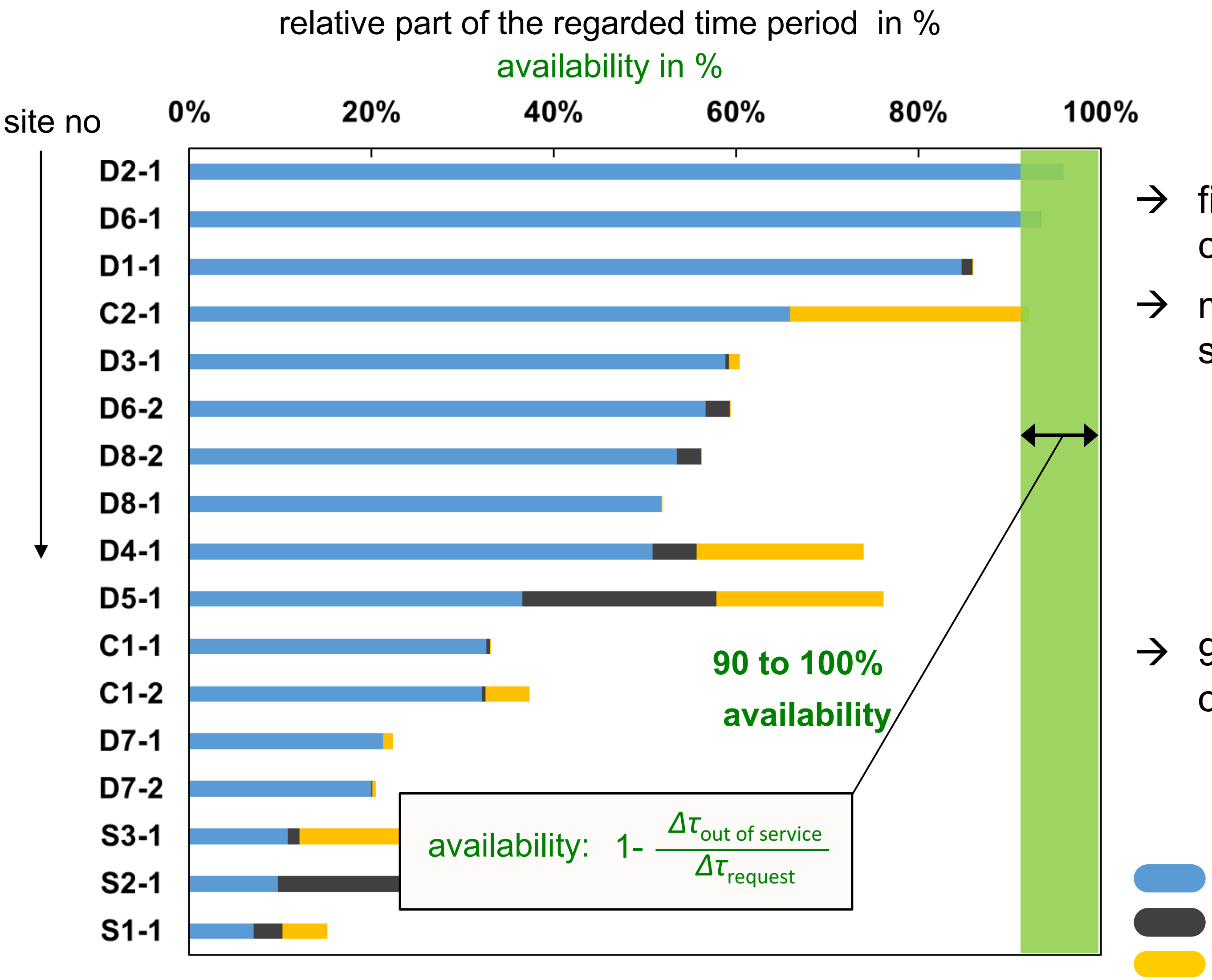
regarded absorption chiller systems:

- –8 absorption chiller systems connected to **district heating** (D1-1, …)



regarded absorption chiller systems				
Site No	Field Test Name	Driving Heat Source DH	CHP	Solar
D1-1	KFWK	X		
D2-1	HENK	X		
D3-1	LVRZ	X		
D4-1	ESTW	X		
D5-1	KRSW	X		
D6-1 D6-2	AHIT	X X		
D7-1 D7-2	ROKK	X X		
D8-1 D8-2	HHVE	X X		

Usage/ Availability/ Operativeness



regarded time period

Jan/2016 - Sep/2017

→ 15312 h

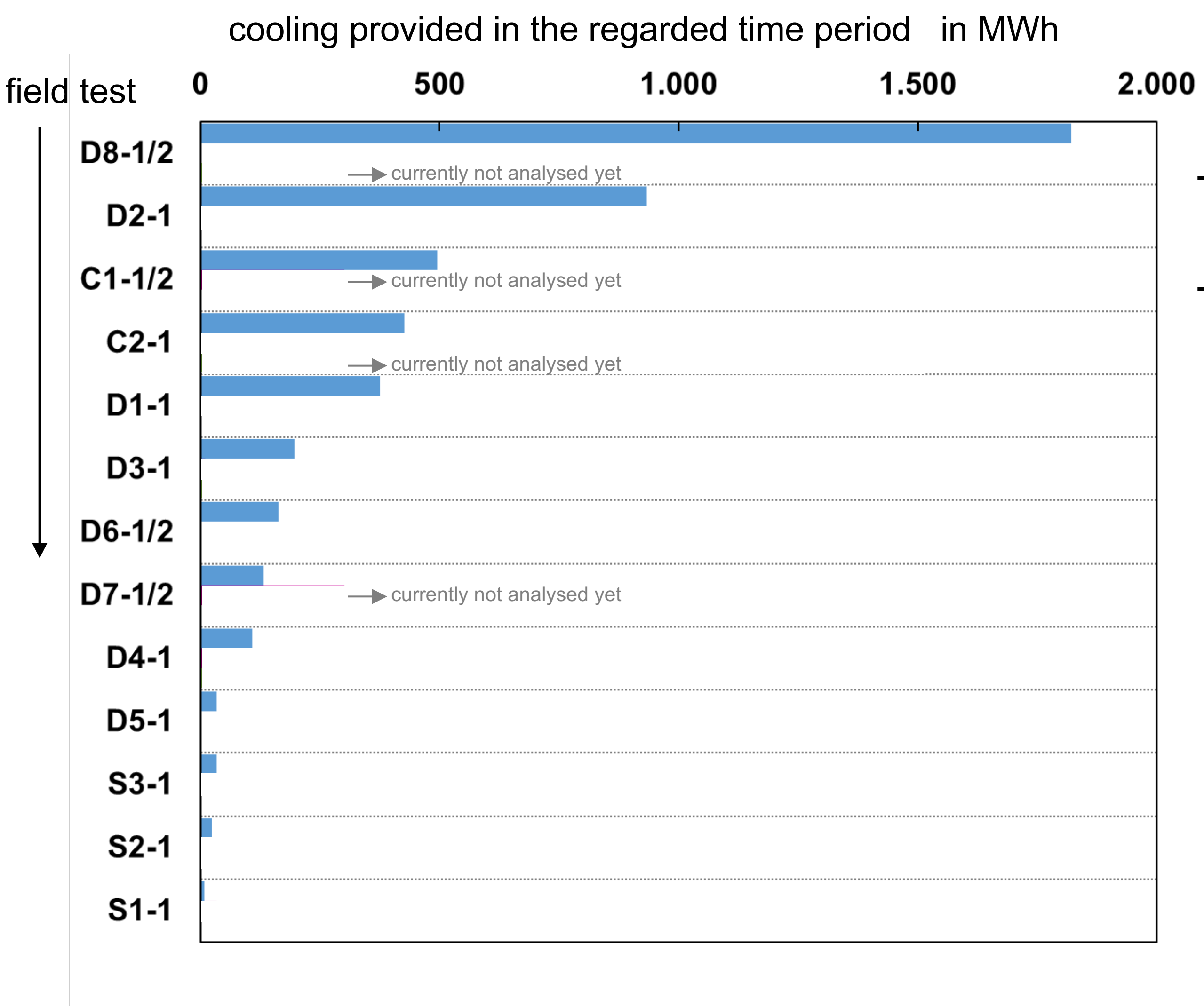
→ field tests with 24/7/365 cooling demand

→ maintenance/out of service intervalls due to:

- →software updates
- →chiller/system maintenance
- →AbC safety shutdown routines

→ 90-100% availability in over 80% of the systems

Field Test Cooling Work



regarded time period

Jan/2016 - Sep/2017
→ 15312 h

→ field tests with 24/7/365 cooling demand

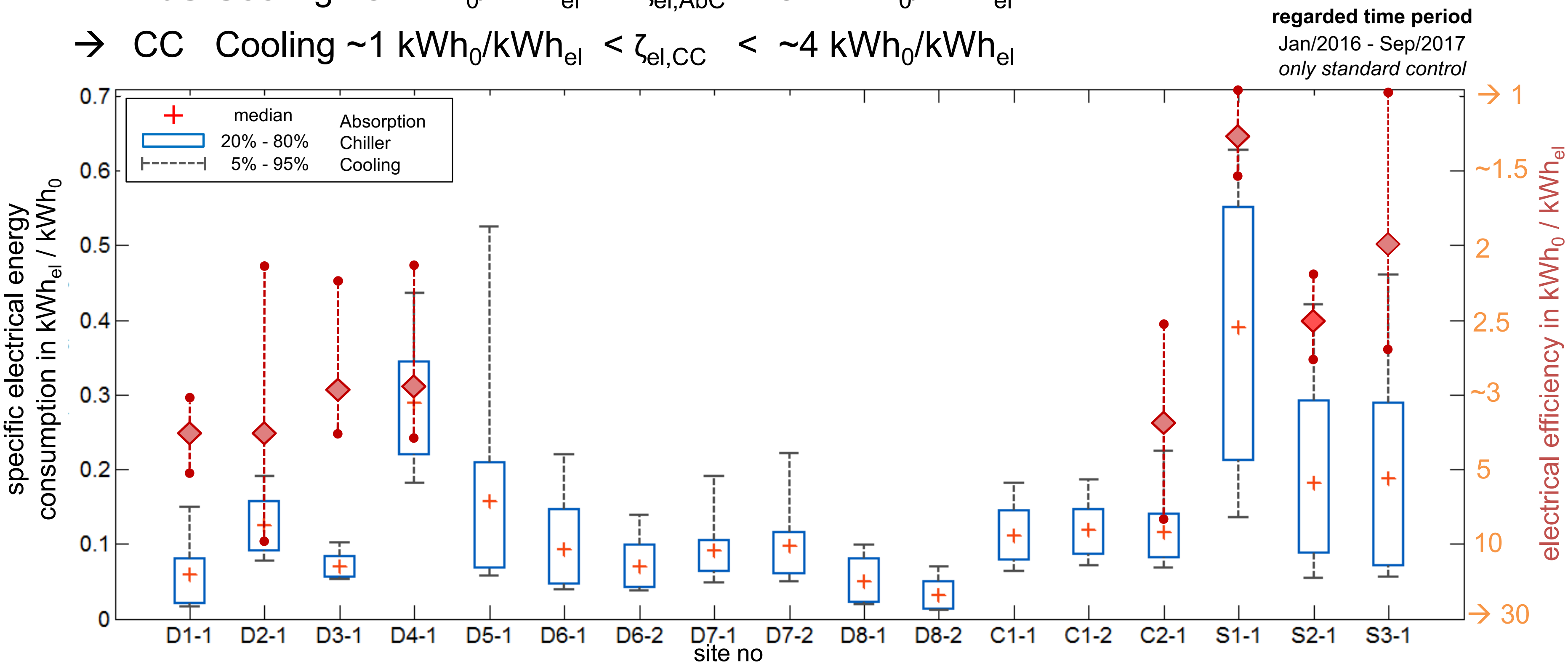
→ 4.8 TWh total cooling provided by regarded absorption chiller systems

Electrical Efficiency / Specific Values

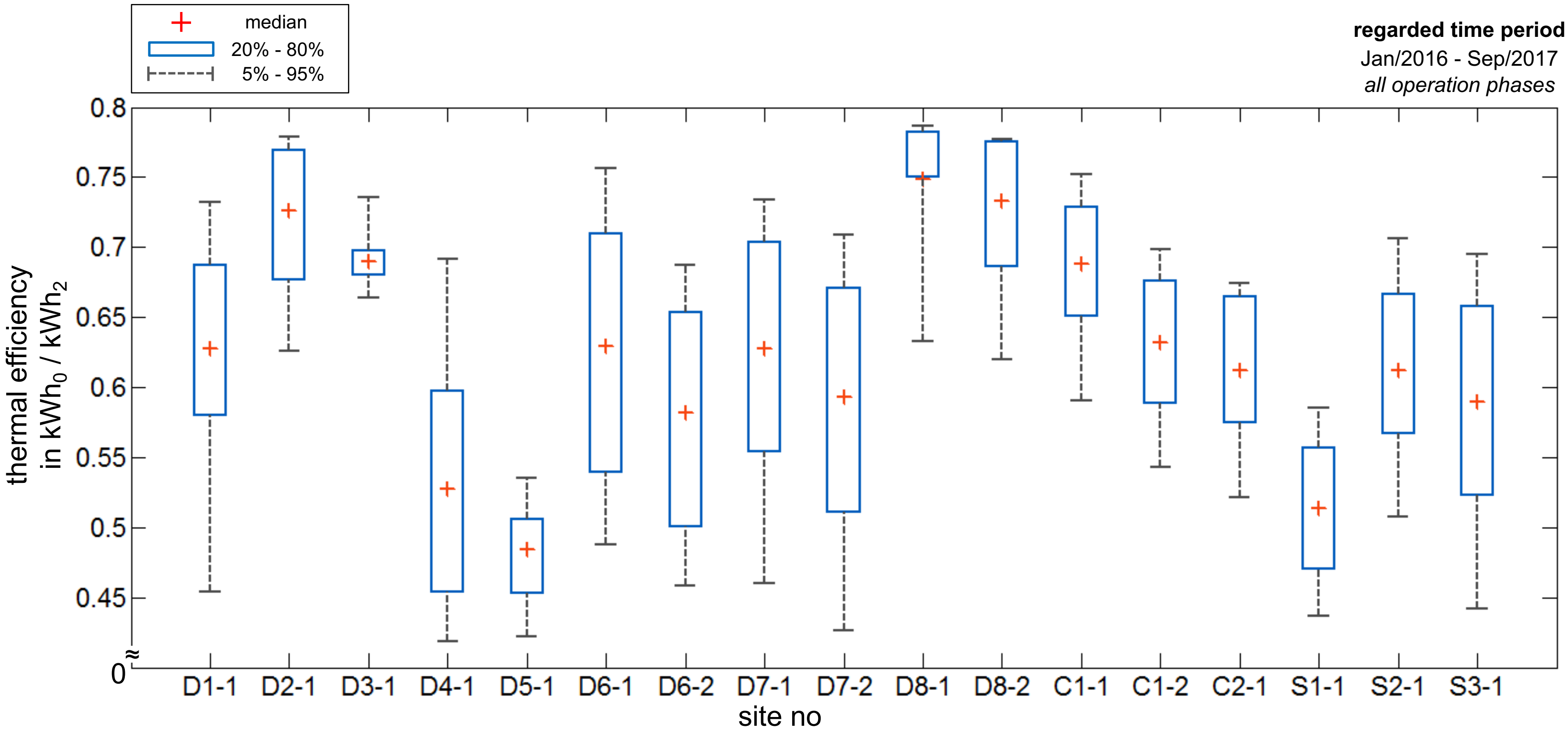
→ standard control (inactive extended control)

→ AbC Cooling 5 kWh_0/kWh_{el} < $\zeta_{el,AbC}$ < 32 kWh_0/kWh_{el}

→ CC Cooling ~1 kWh_0/kWh_{el} < $\zeta_{el,CC}$ < ~4 kWh_0/kWh_{el}



Thermal Efficiency



Influence Flow Control on el. Efficiency

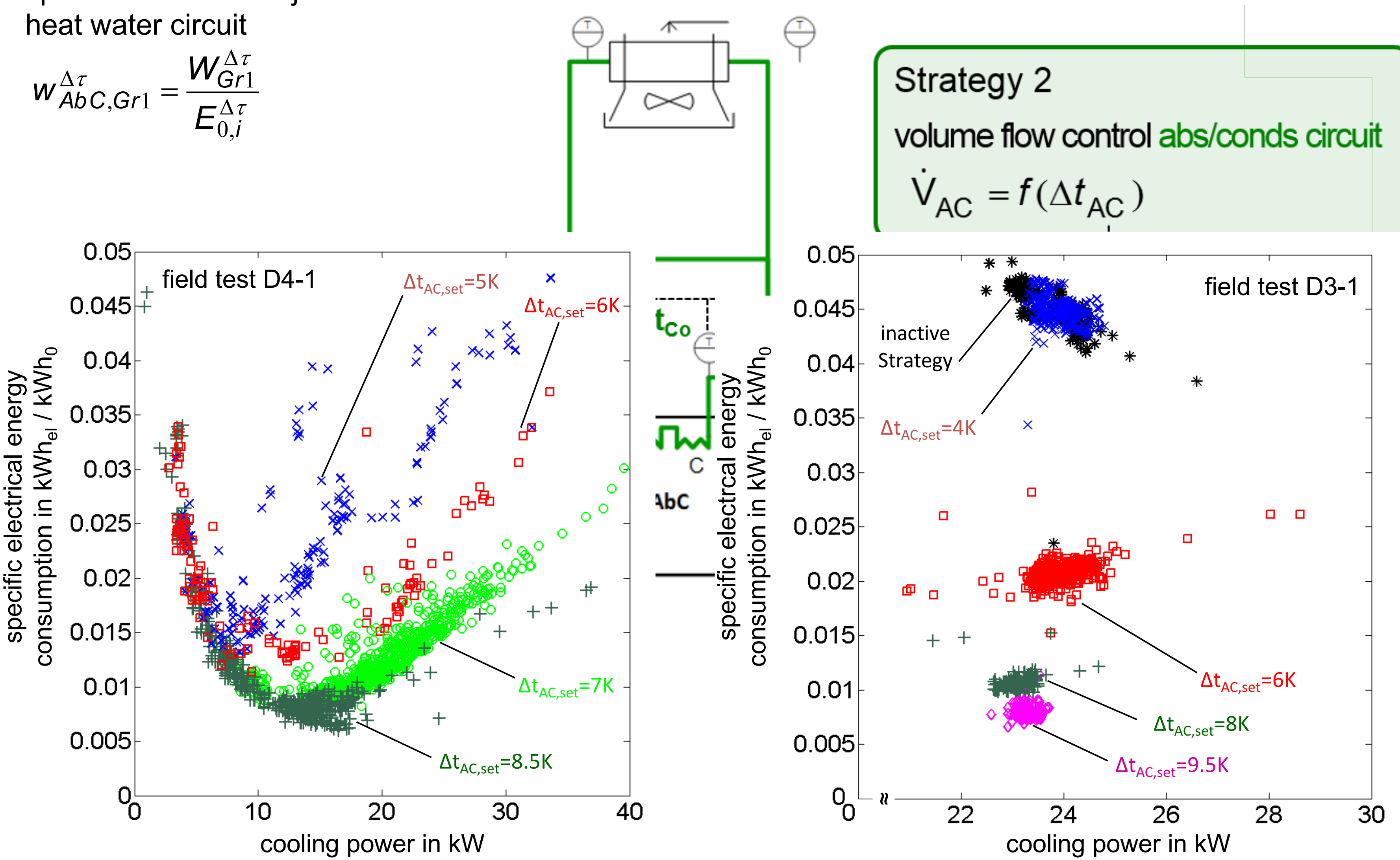
specific values for reject heat water circuit

$$w^{\Delta\tau}_{AbC,Gr1} = \frac{W^{\Delta\tau}_{Gr1}}{E^{\Delta\tau}_{0,i}}$$

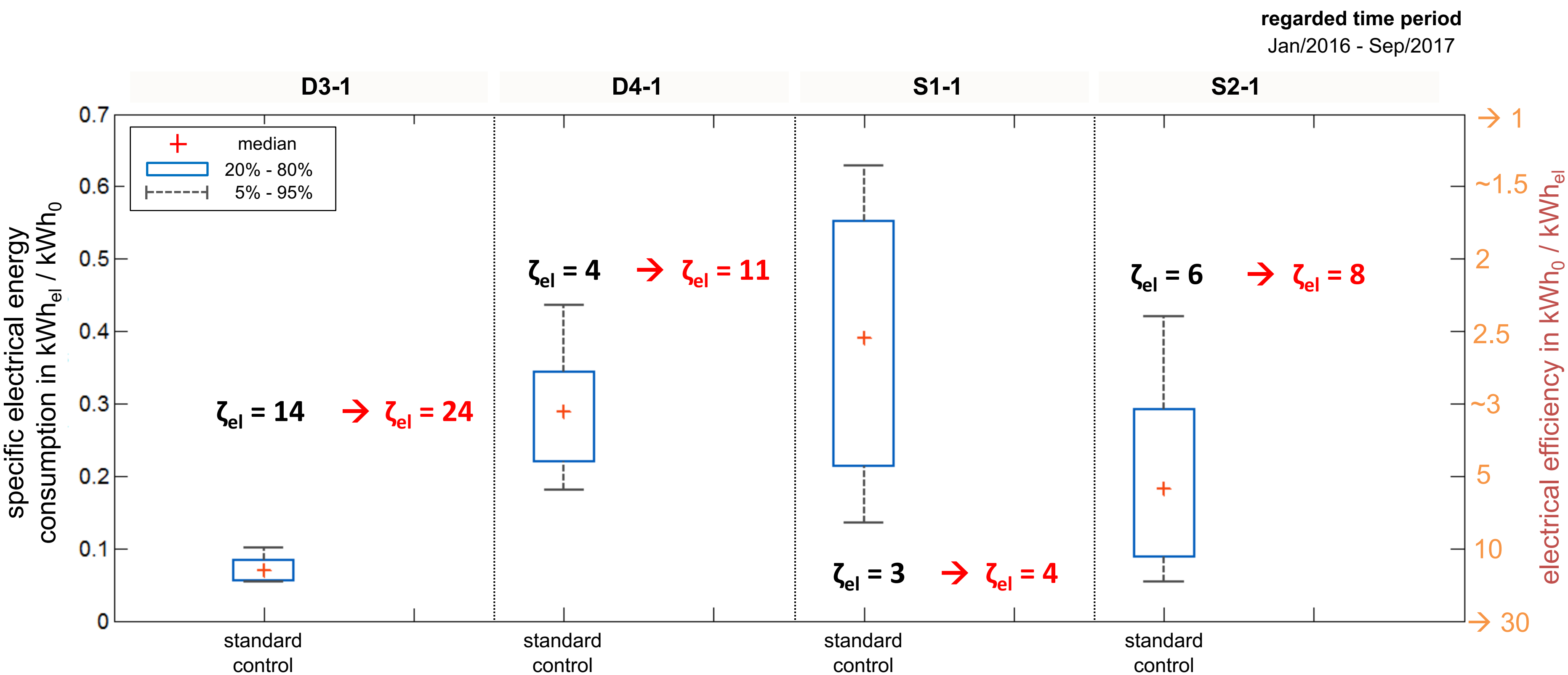
Strategy 2

volume flow control abs/conds circuit

$$\dot{V}_{AC} = f(\Delta t_{AC})$$



Standard vs. Extended Control



Conclusion

- Absorption chiller cooling with
  - District Heating systems
  - Combined Heat and Power Plants
  - Solar systems
- Succesful and stable operation of absorption chiller technology
  - in 15 field tests in Germany
    in 4 field tests in Jordan
    } 29 absorption chillers
  - el. efficiency: up to 30 kWh_0 / kWh_{el}
  - th. efficiency: up to 0.8 kWh_0 / kWh_2
  - 90%-100% availability
- Increase of electrical efficiency by volume flow control (extended control)
- High potential for efficiency increase matched by introducing new control strategies

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