Simulative Evaluation of Demand Response Approaches for Waterbeds

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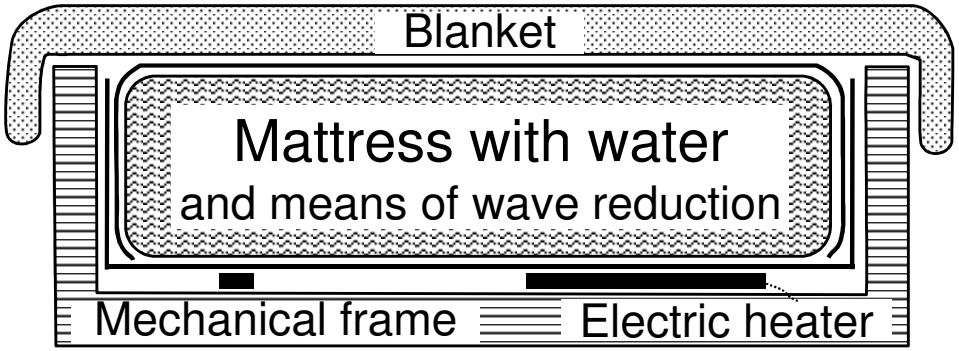
Objectives

- Demand response (DR): Shift power consumption of electrical loads in time a needed (based on price)
  - Increasing amount unregulated solar / wind farms
  - Goal: Make loads consume power when a lot available
- Waterbeds
  - Heating: ≈ 1,5 kWh / day
    - May be shifted for hours
  - ≈ 1.000.000 in Germany
    - Total nominal load: ≈ 300 MW



- What is the performance of DR control algorithms for waterbeds?
  - Simulative evaluation

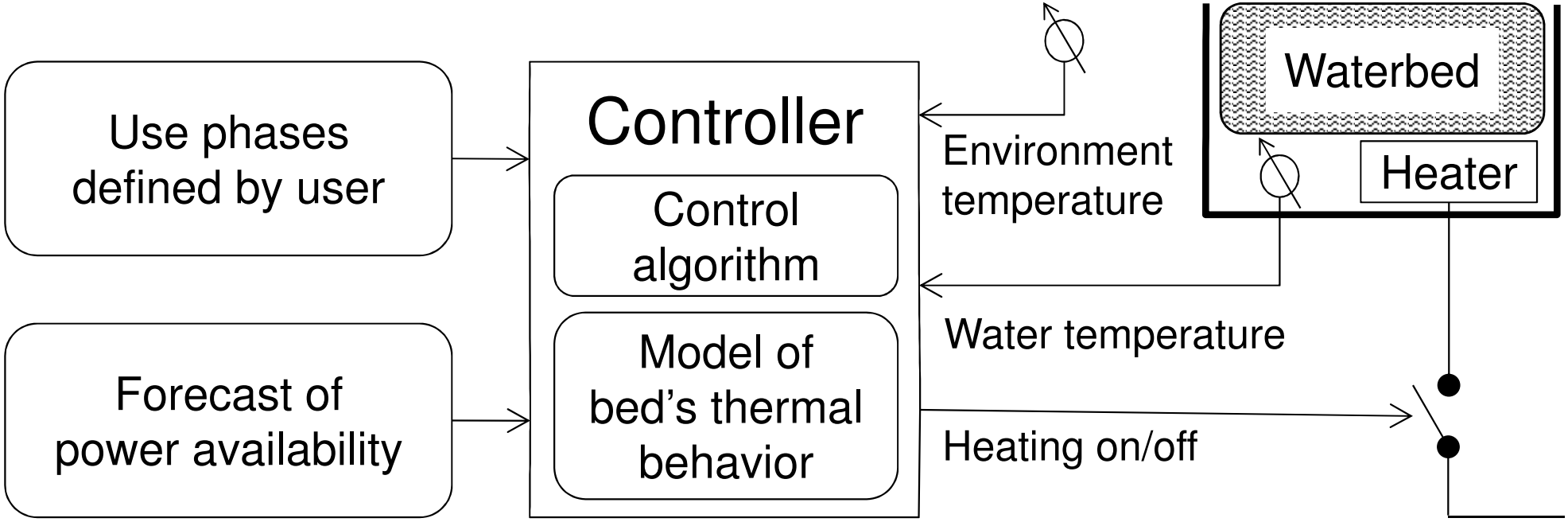
Contributions of DR to power balancing

Phase	Response Time	Mechanism	DR approaches	In Germany
Planning	Day ahead	Estimate consumption + renewables, trade electricity, schedule power plants	actual price statistics	ø 68GW
Operation	Instantly	Generators relational inertia	$P \sim -\frac{df}{dt}$	?
	< 30 s	Primary control: $P \sim -\Delta f$	$P \sim -\Delta f$ load shedding	0.8 GW / 3 GW
	< 15 min	Secondary control	DSM market	2 GW
	< 23 min	Tertiary control	DSM market New class?	2 GW
	< 1h	Suppliers hours reserve	DSM market	?

Requirements for DR with waterbeds

- User‘s requirements
  - Comfort temperature during use phases (≈ 28.5 °C ±0.5 °C)
    - Other times: No temperature constrains (day, nights bed unused)
    - Assumed: User defines use phases
  - Privacy: Protect temperature curves
    - When in bed / Having fever / 2 persons in bed
    - Privacy by design: Process data locally, do not store data
- Demand response
  - Correlate power consumption with power availability
  - Bed controller needs to know power availability
- Save energy with control scheme
  - Environmentally friendly & incentive for user
  - Approach: Reduce average temperature
    ⇒ Heat as late as possible before use phase

Basic approach



- Power availability via network or as statistical measure
- We use: Price from electricity exchange
  - High price means low availability (and vice versa)
  - Day-ahead index *Phelix* for Germany and Austria
  - Not assumed: User pays that price

The six control algorithms

- **Bang-Bang-Thermostat (BBT)**: Keep $T_{nom} \pm T_{hyst}$
- **Thermostat With Timer (TT)**: Adds timer-clock
- **Save Energy (SE)**: Heat as late as possible before use phase
- **Adapt-Nominal-Temperature (ANT)**: Adjust BBT's T_{nom} in comfort temperature range depending on current exchange price
- **ANT-With-Use-Phases (ANT-U)**: ANT with bigger range outside use-phases. No heating >24 h before use phase
- **Simplified Balancing (SB)**: Heuristics for cheapest heating times to get T_{nom} until beginning of next use phase.

- → Read paper for more details

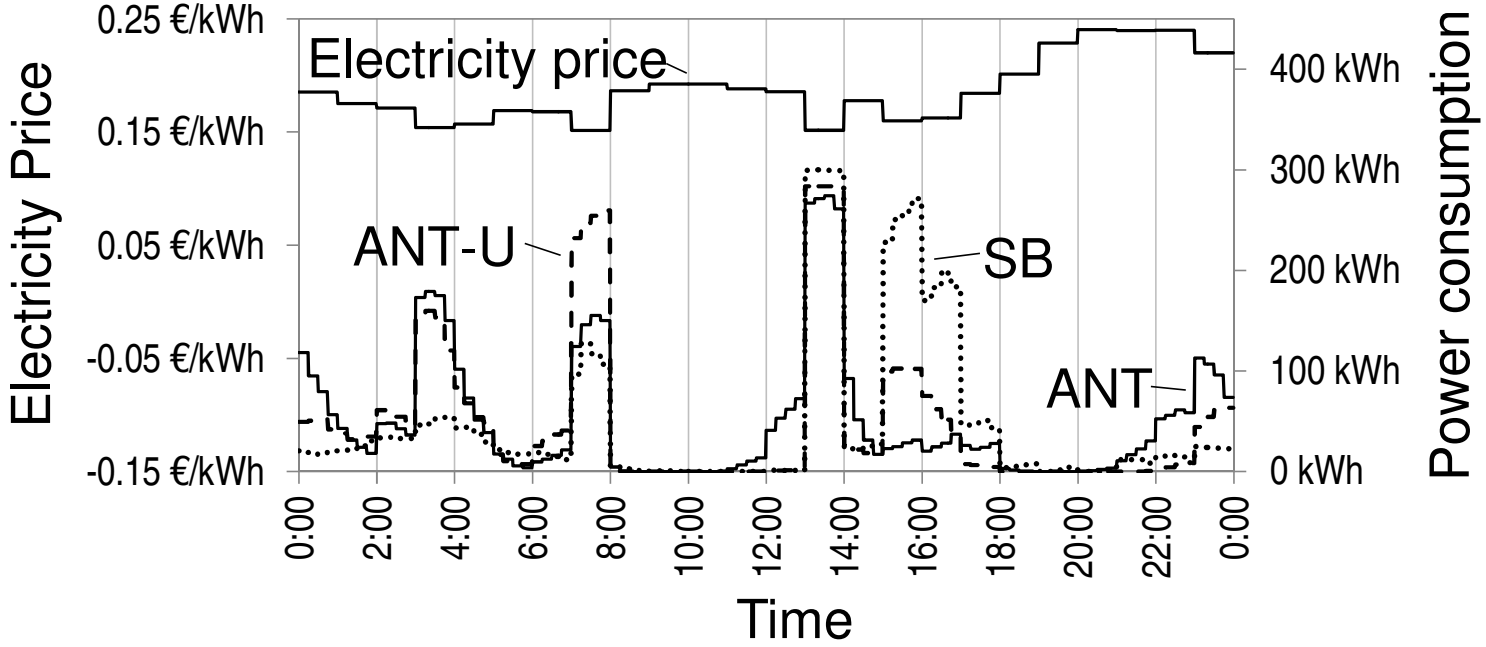
Effect for DR and Energy saving

- My waterbed simulated for one year (Feb. 2014 – Feb 2015)
- Assessment:
  (Energy saving, Avg.price@Phelix) in relation to BBT

	Actual Prices	Price statistics
BBT	(0%, 0%) ≙ (596 kWh, 0.0335 €/kWh)	
SE	(20%, 1%)	
SB	(15%, 18%)	(14%, 15%)
ANT-U	(13%, 17%)	(13%, 15%)
ANT	(-0.3%, 4%)	(-0.3%, 3%)
TT	-	(7%, -7%) – (3%, 10%)

Load Steps

- ANT, ANT-U, SB: Hazardous load steps with accurate clocks
- Simulation: 1000 beds (varying, realistic parameters), 1 year
- SB:
  - 99,5 % of loads
  - 169 load steps > 50% of loads during year



- 1.000.000 German Waterbeds: ~300 MW
  - My real implementation: Switching synchronized by < 3s
  - Can only be balanced with rotational inertia (primary control too slow)
- Solution: Inaccurate clocks or intentional randomization

Conclusions

- Waterbeds useful for demand response
  - My approaches: Support planning phase of power balancing
  - Local decisions protect privacy
  - Energy saving ≤ 20% (Realistic: 15%)
  - DR: Reduction average exchange price ≤ 20% (Realistic: 18%)
  - Using price statistics (not network) slightly reduced effect for DR
- Mind load steps! (Randomize switching events)
- Outlook: Load profile prediction (many beds) for electricity suppliers