



Simultaneous energy efficiency and acoustic evaluation of heat pump systems using dynamic simulation models

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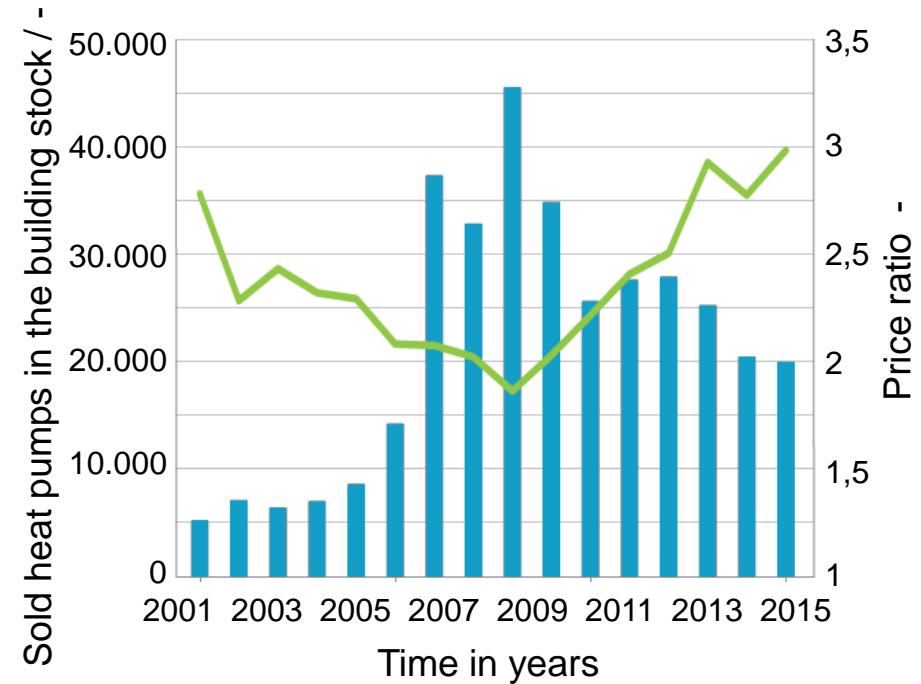
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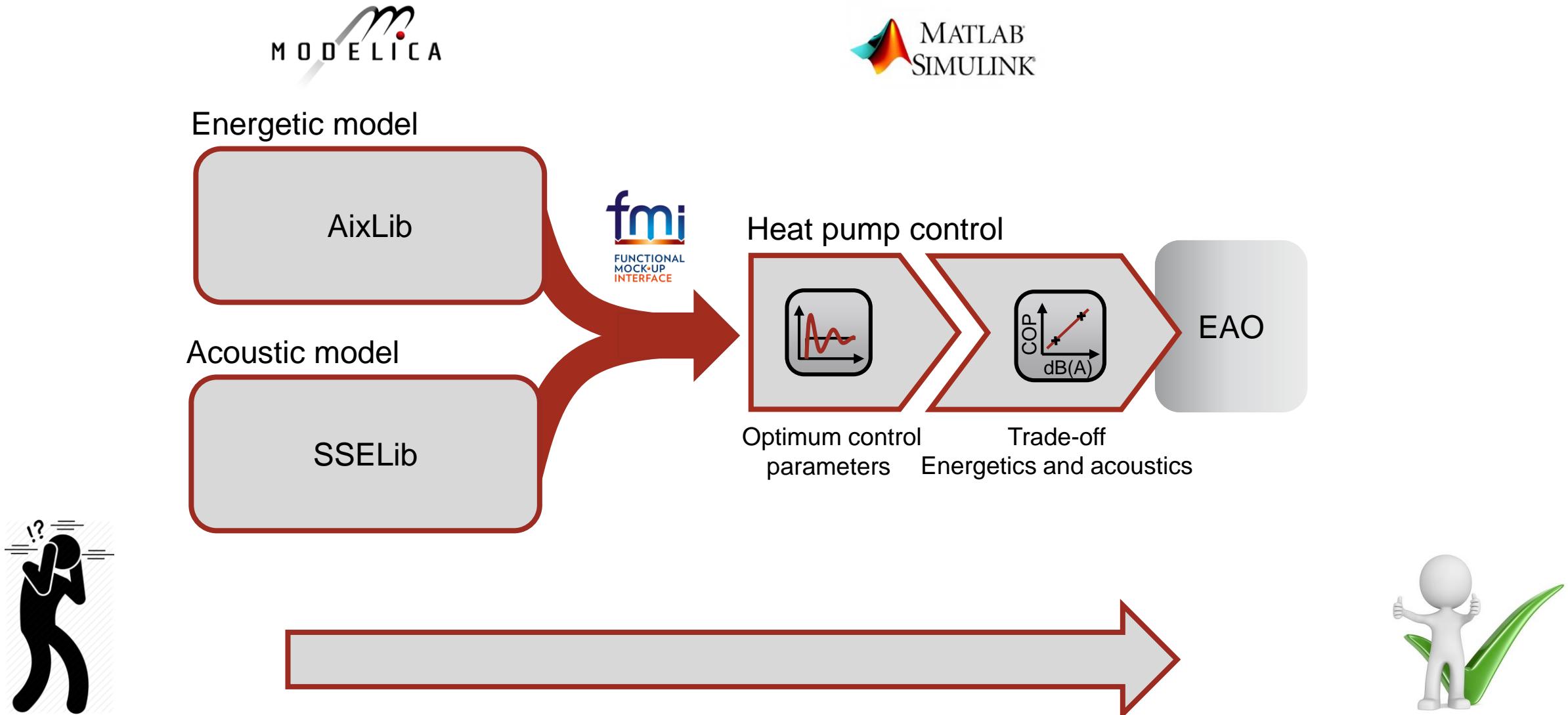
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Introducing heat pumps in the German building stock

- Price conflict
 - ≡ Heat pump vs. boiler
- Goals
 - ≡ Energy efficient
 - ≡ Emission efficient
 - ≡ Comfortable
- New challenges
 - ≡ System dynamics → Decrease in efficiency
 - ≡ Noise emissions → Decrease in comfort
- Approach
 - ≡ Coupling of energetic and acoustic modelling in Dymola
 - Energetic-acoustic-optimal operation (EAO)



Methodology

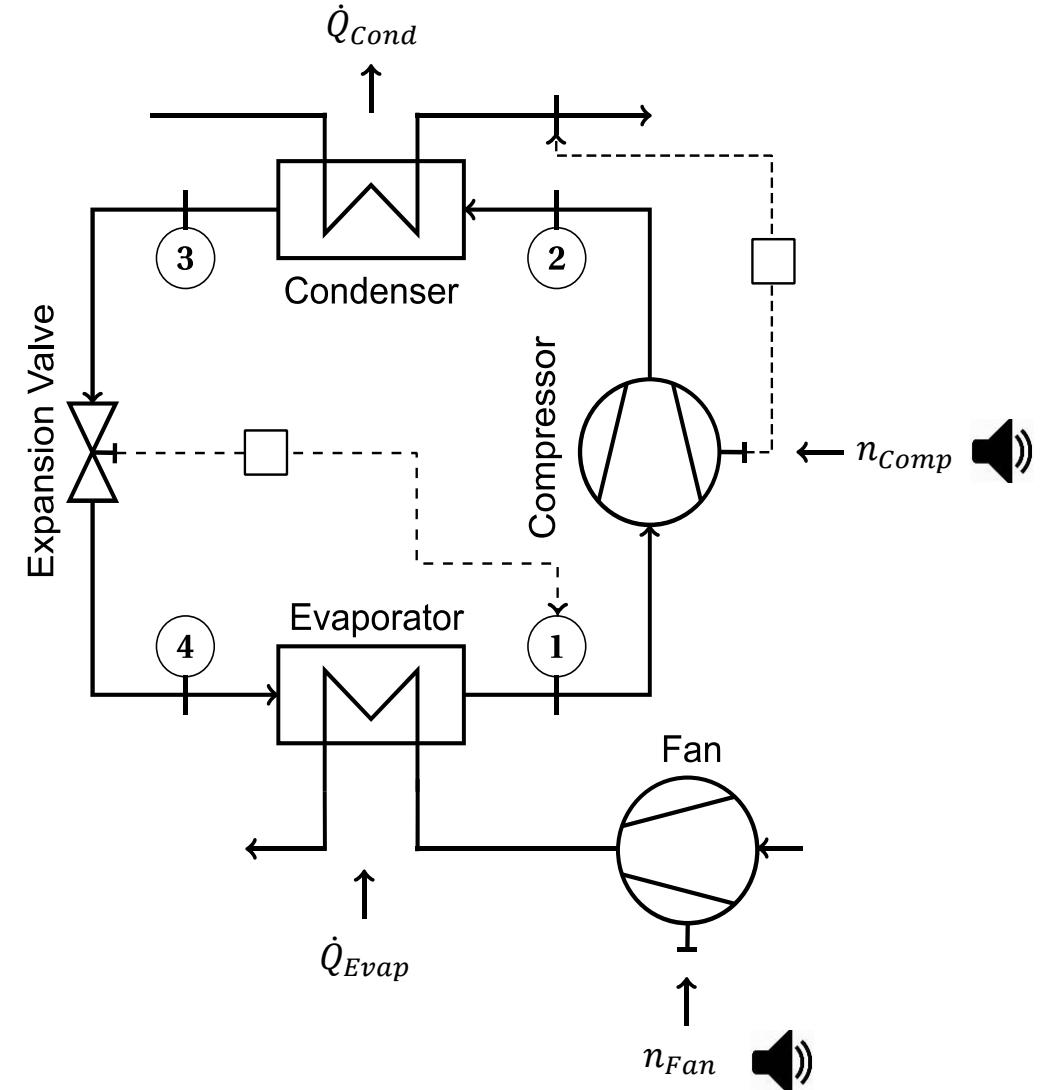


Energetic Modelling

Vapor compression system

- Air-to-water heat pump (ASHP)
- Compressor
 - ≡ Efficiency based
- Heat Exchanger (Condenser, Evaporator)
 - ≡ $\epsilon - NTU$
- Expansion Valve
 - ≡ Efficiency based
- Simple PI control

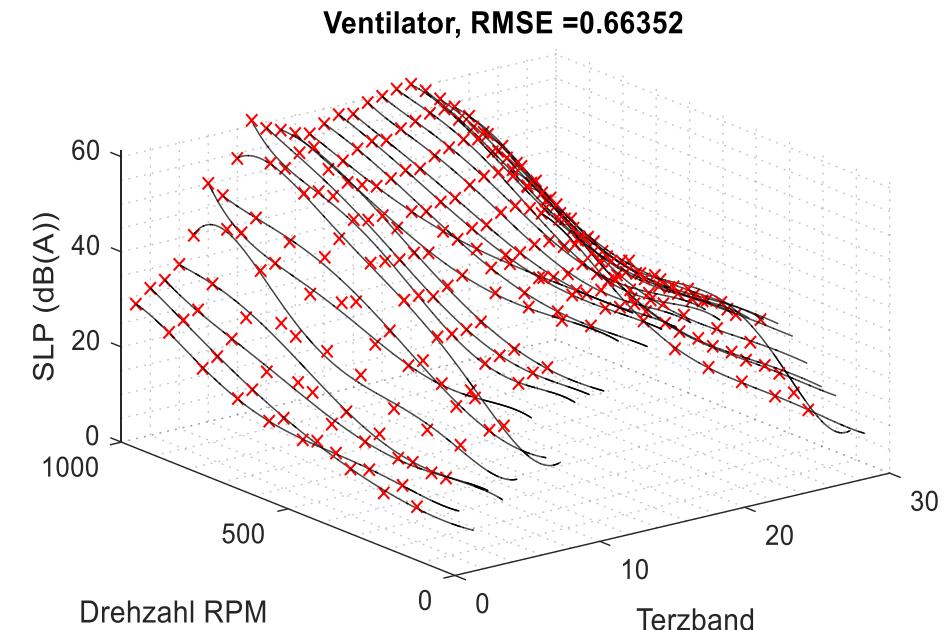
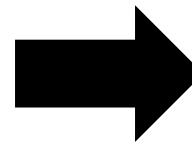
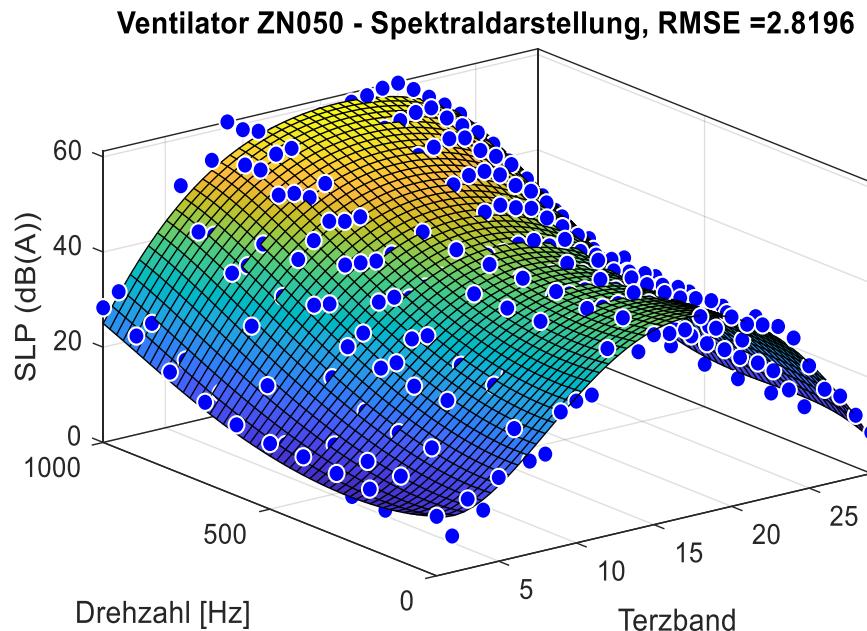
Control input	Controlled variable
Compressor fan speed	Supply temperature
Expansion valve opening	Superheating
Fan speed	-



Acoustic Measurement Data

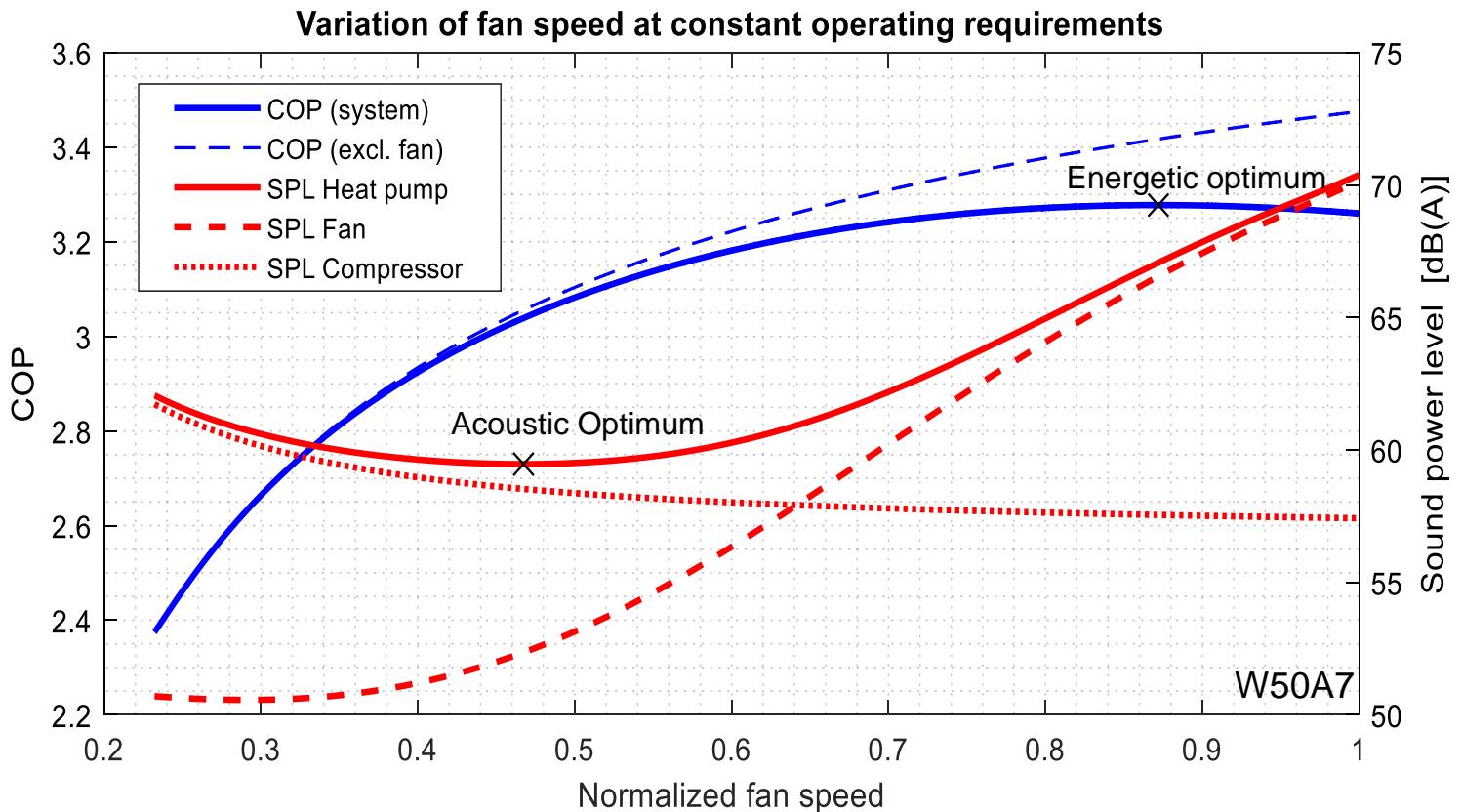
SilentHP - Austrian Institute of Technology

- Coupling of the acoustic signature via the rotational speed of their corresponding components
- Polynomial fit to increase simulation speed



Conflict of interests: Energy efficiency vs. noise

- Calculated sound power levels (SPL)
- Acoustic optimum identified
- Energetic optimum identified
- Development of EAO suitable



Extremum-Seeking-Control (ESC)

■ Model-free, real-time optimization

■ Functional principle

- ≡ Perturbation of control input (fan speed)
- ≡ Measuring system output (objective function)
- ≡ Determine gradient $\frac{dy}{d\hat{u}}$
- ≡ Drive control input to minimum/maximum of objective function

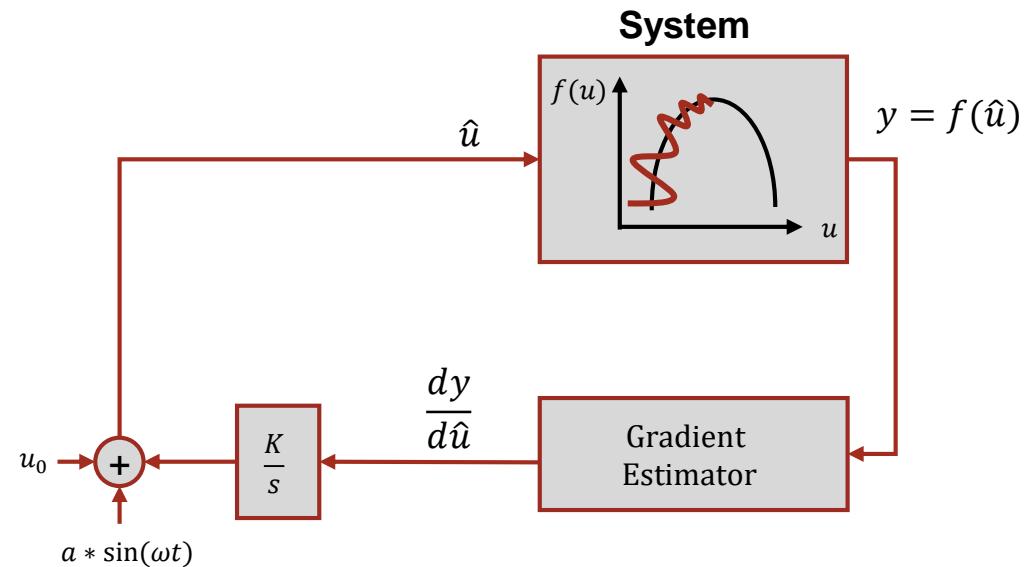
u – fan speed

y – objective function e.g. $P_{Compressor}$

■ Gradient Estimator

- ≡ Combination of high-pass and low-pass filters
- ≡ Recursive-least-squares Estimator
- ≡ Kalman filter

} Increased convergence time



Objective function: Energy efficiency vs. sound emission

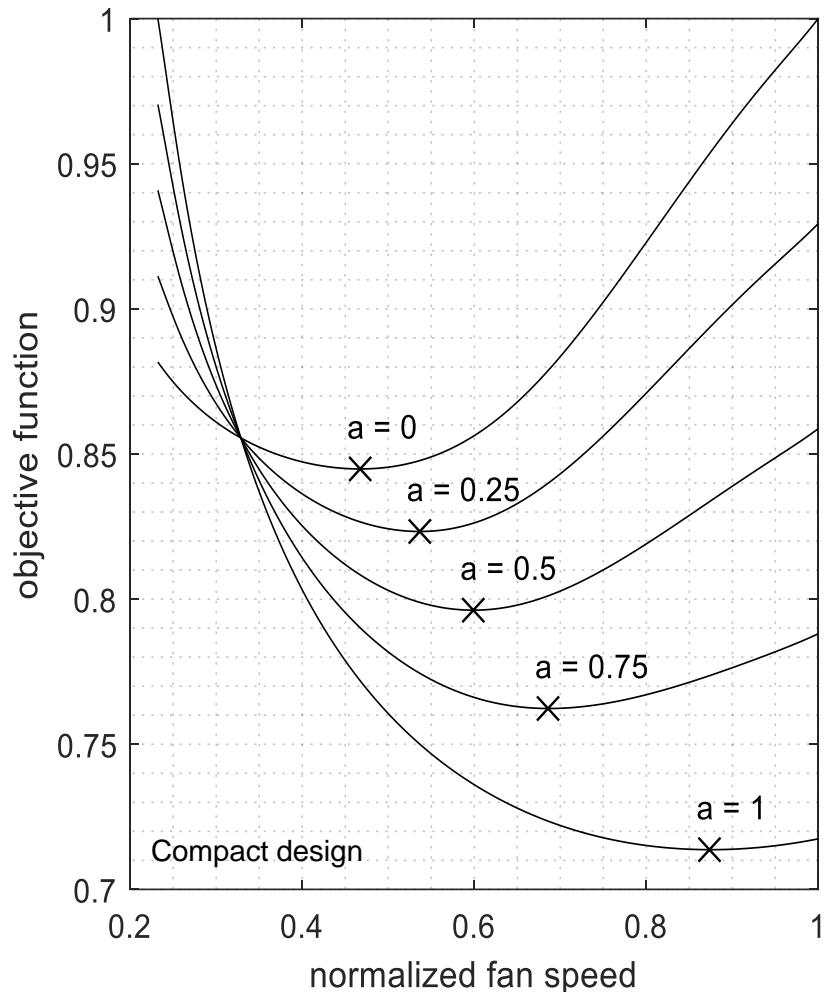
■ Objective function

$$\min \quad a * \underbrace{\frac{P_{el,Compressor} + P_{el,Fan}}{\sum P_{i,max}}}_{\text{Energetic}} + b * \underbrace{\frac{\sum SPL_i}{\sum SPL_{i,max}}}_{\text{Acoustic}}$$

■ Acoustic term depends on installation type

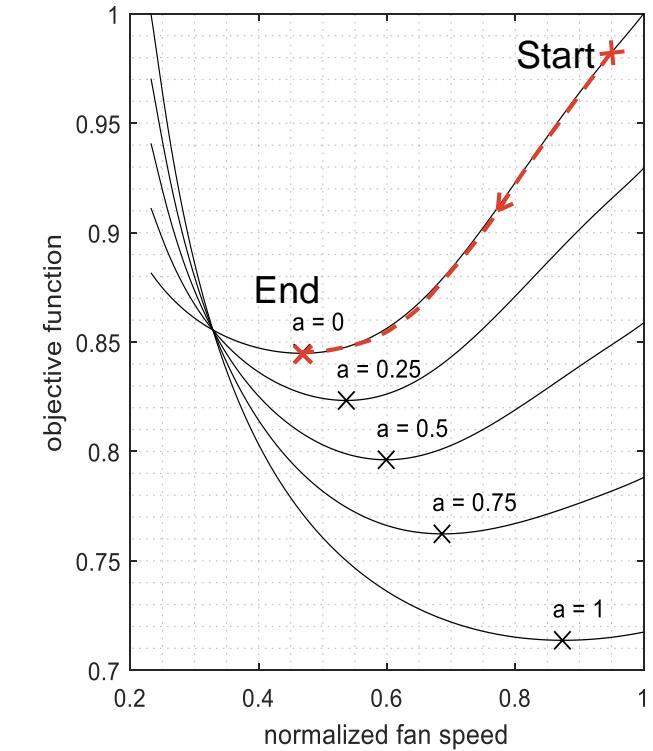
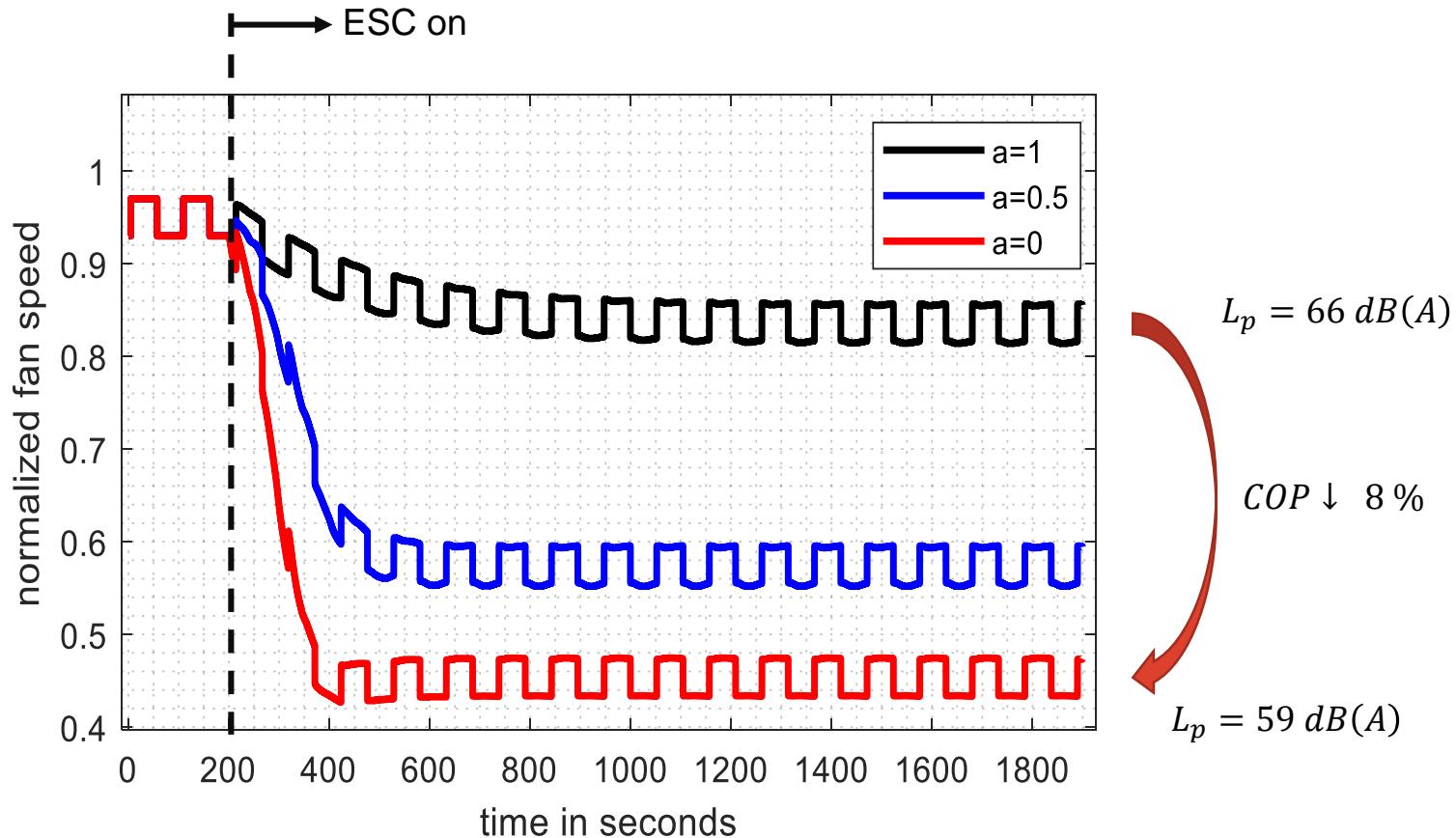
- Split design $\sum SPL_i = SPL_{Fan}$
- Compact design $\sum SPL_i = SPL_{Fan} + SPL_{Compressor}$

■ Parameter a and b → Trade-Off



Use Case: Fixed Conditions

- Activating ESC after 200 sec
- Different values for parameter a result in varying fan speeds according to objective function



Research findings

Summary

- Coupling of energetic and acoustic modelling was successful
- Implantation works in MatLab
- Energetic acoustic optimal operation identifies optimization potentials in design and operation

Outlook

- Testing control in the lab
- Evaluating different refrigerant models
- Introducing ecologic optimal control as third part

