Optimal Coordination of Heat Pump Compressor and Fan Speeds and Subcooling Over a Wide Range of Loads and Conditions

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Learning objectives

- **Explain the heat pump static optimization problem and method.**
- **Demonstrate the benefits of static optimization for different optimization parameters.**
- **Demonstrate the benefits of heat pump sizing optimization for a specific example with two-speed and variable-speed compressor heat pump.**

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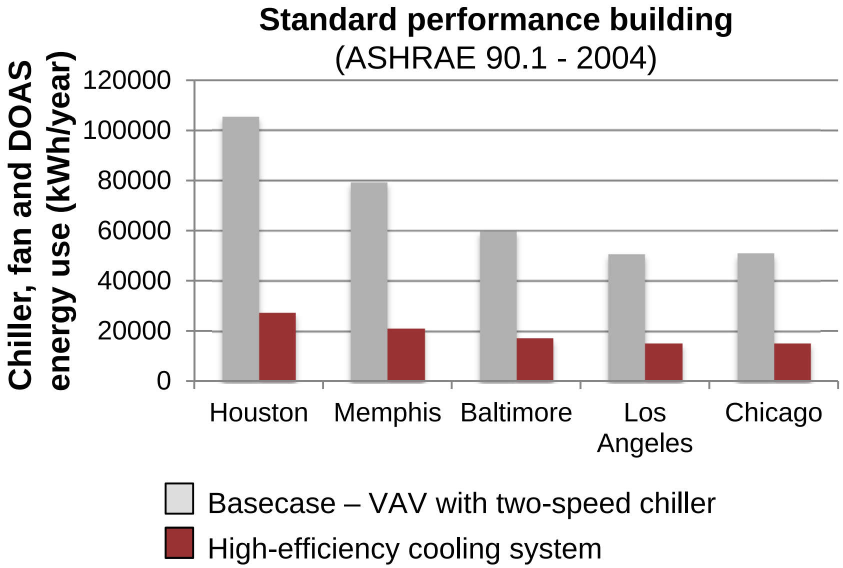
Motivation

Low-lift cooling technology

- **Radiant hydronic cooling** – reduces transport energy and increases evaporating temperature
- **Thermal storage** – reduces condensing temperature, peak loads and daytime loads
- **Variable speed drive** compressor and fans – reduce flow losses and allow efficient operation at part load
- **Dedicated outdoor air system** – provides ventilation air and dehumidification
- **Building thermal model identification** – allows accurate prediction of cooling loads for pre-cooling control
- **Smart building control** – enables monitoring, system identification and predictive control

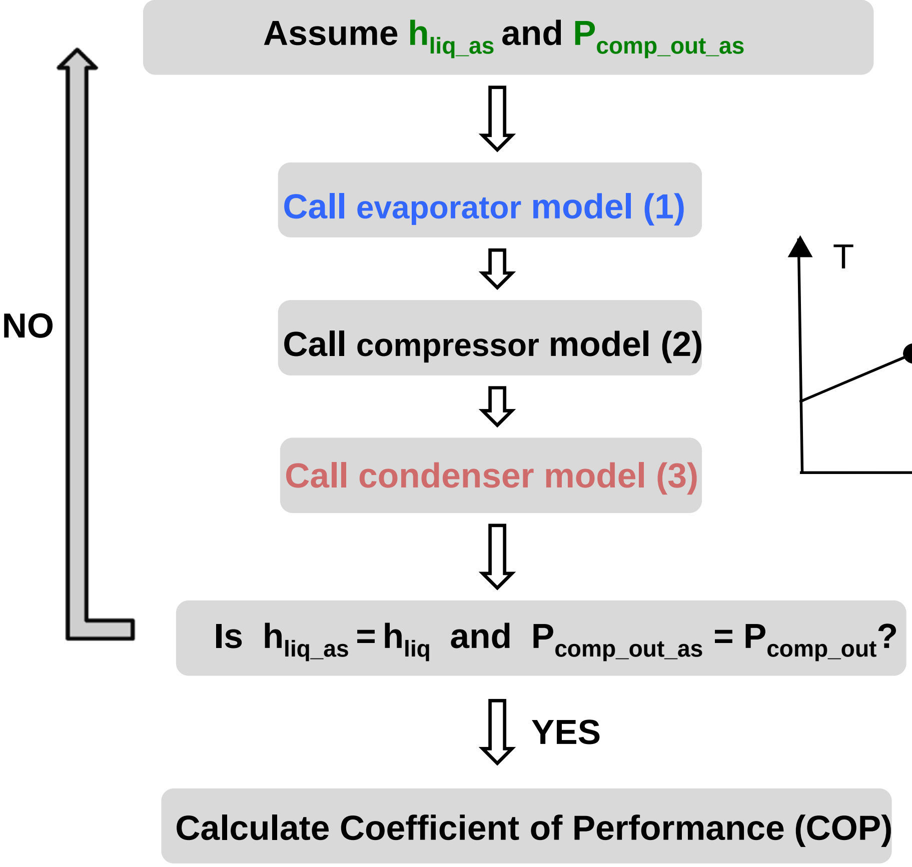
➔ 30 – 70 % savings in annual energy for cooling*



***** Pacific Northwest National Laboratory analysis: Office building prototype analysis for five US climates and three envelope performances (standard, mid and high)

Heat pump model

Model flowchart



Assume h_{liq_as} and $P_{comp\_out\_as}$

Call evaporator model (1)

Call compressor model (2)

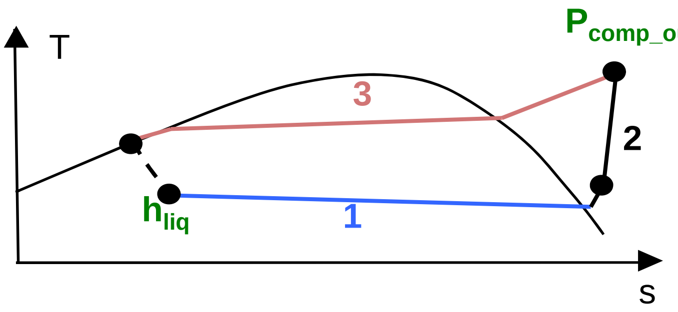
Call condenser model (3)

Is $h_{liq\_as} = h_{liq}$ and $P_{comp\_out\_as} = P_{comp\_out}$?

NO

YES

Calculate Coefficient of Performance (COP)

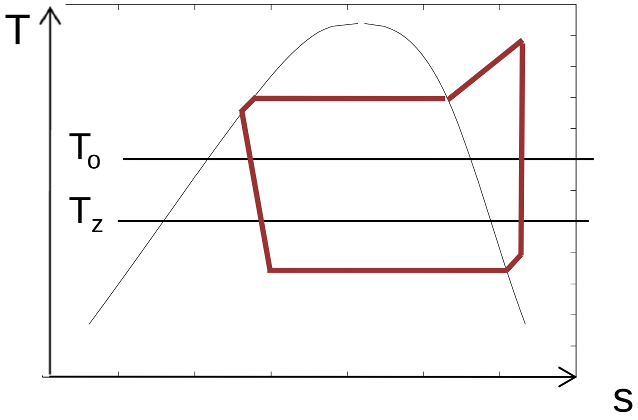


$$COP = \frac{Q_e}{E_{comp} + E_{evap,fan} + E_{cond,fan}}$$

Zakula T., Gayeski N., Armstrong P. and Norford L . 2011. Variable-speed Heat Pump Model for a Wide Range of Cooling Conditions and Loads. *HVAC&R Research* 17(5).

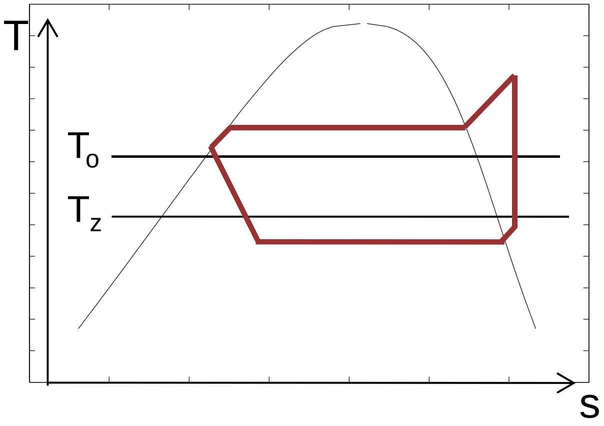
Heat pump static optimization

What are the optimal fan and compressor speeds and condenser subcooling for minimum power consumption if cooling rate, room temperature and outside temperature are given?



Compressor power HIGH

Fan power LOW

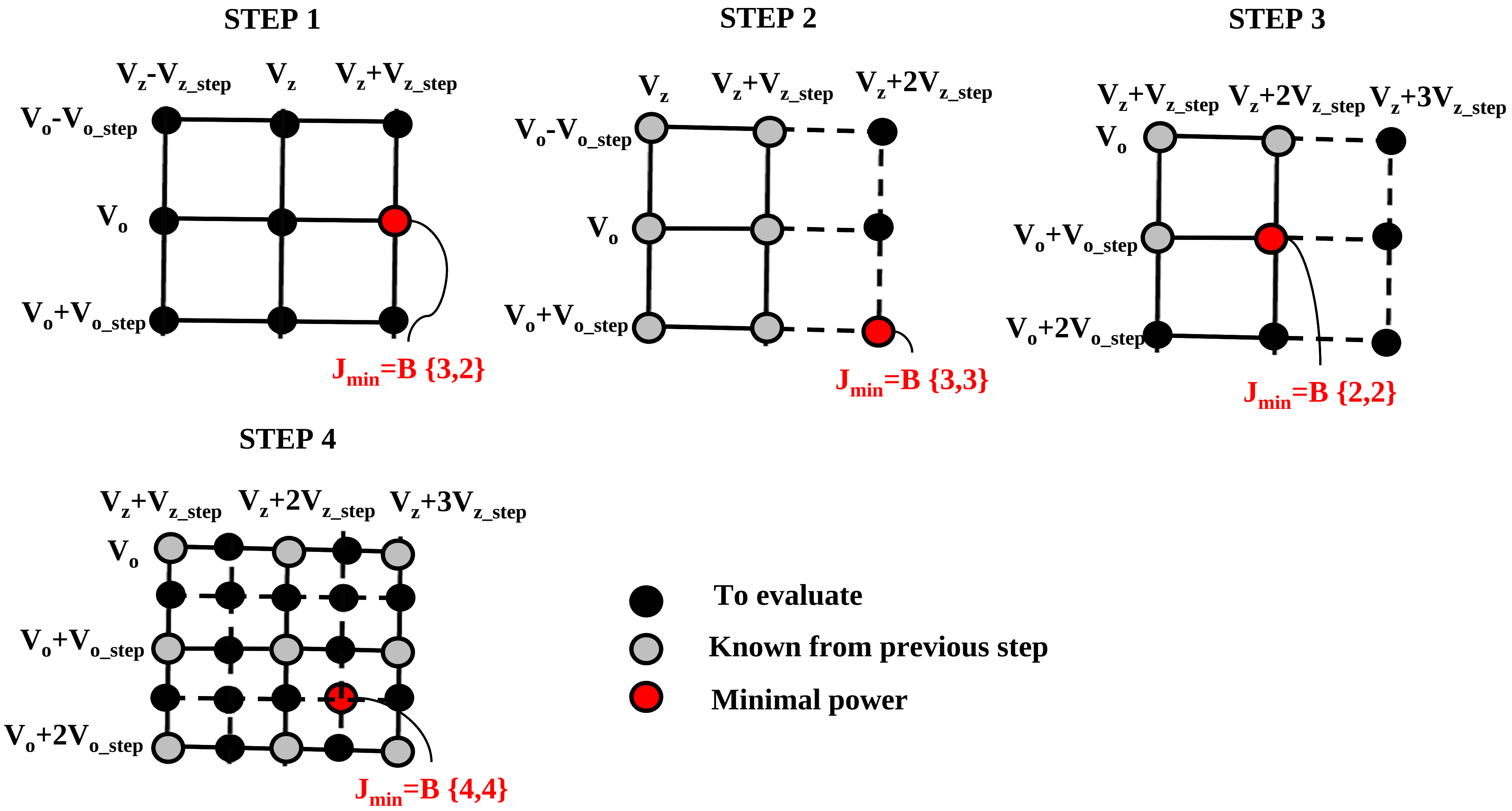


Compressor power LOW

Fan power HIGH

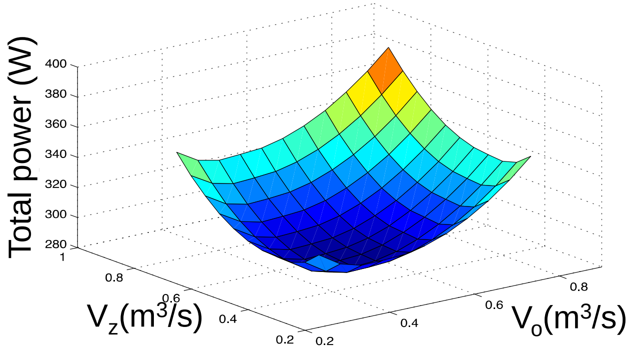
Heat pump static optimization

Adaptive grid-search optimization algorithm

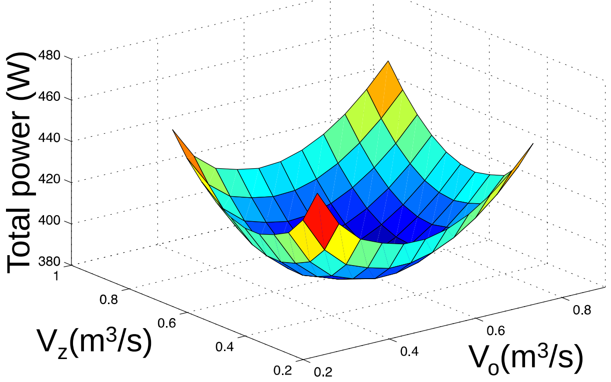


Heat pump static optimization

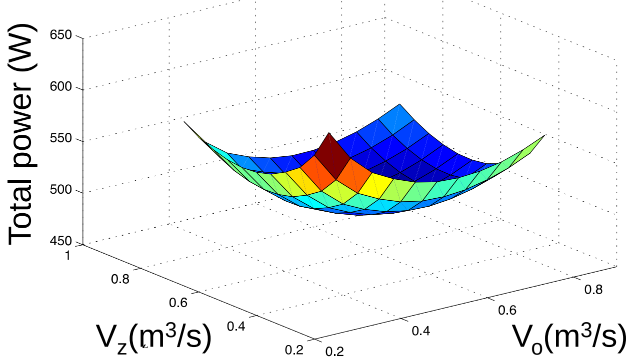
Finding the optimal evaporator ($V_{z\ opt}$) and condenser ($V_{o\ opt}$) air flows for minimum power consumption if cooling rate (Q_e), room temperature and outside temperature are given.



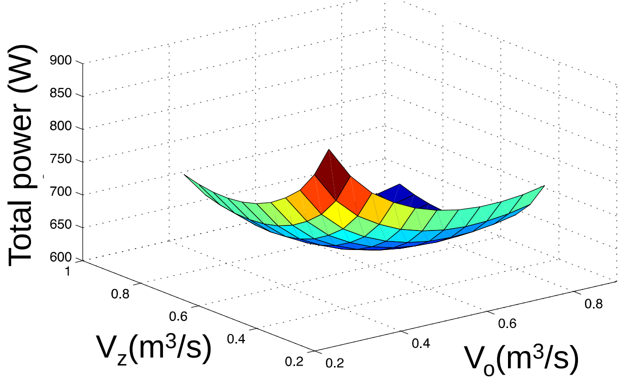
Given: Q_e = 2.0 kW



Given: Q_e = 2.4 kW



Given: Q_e = 2.8 kW

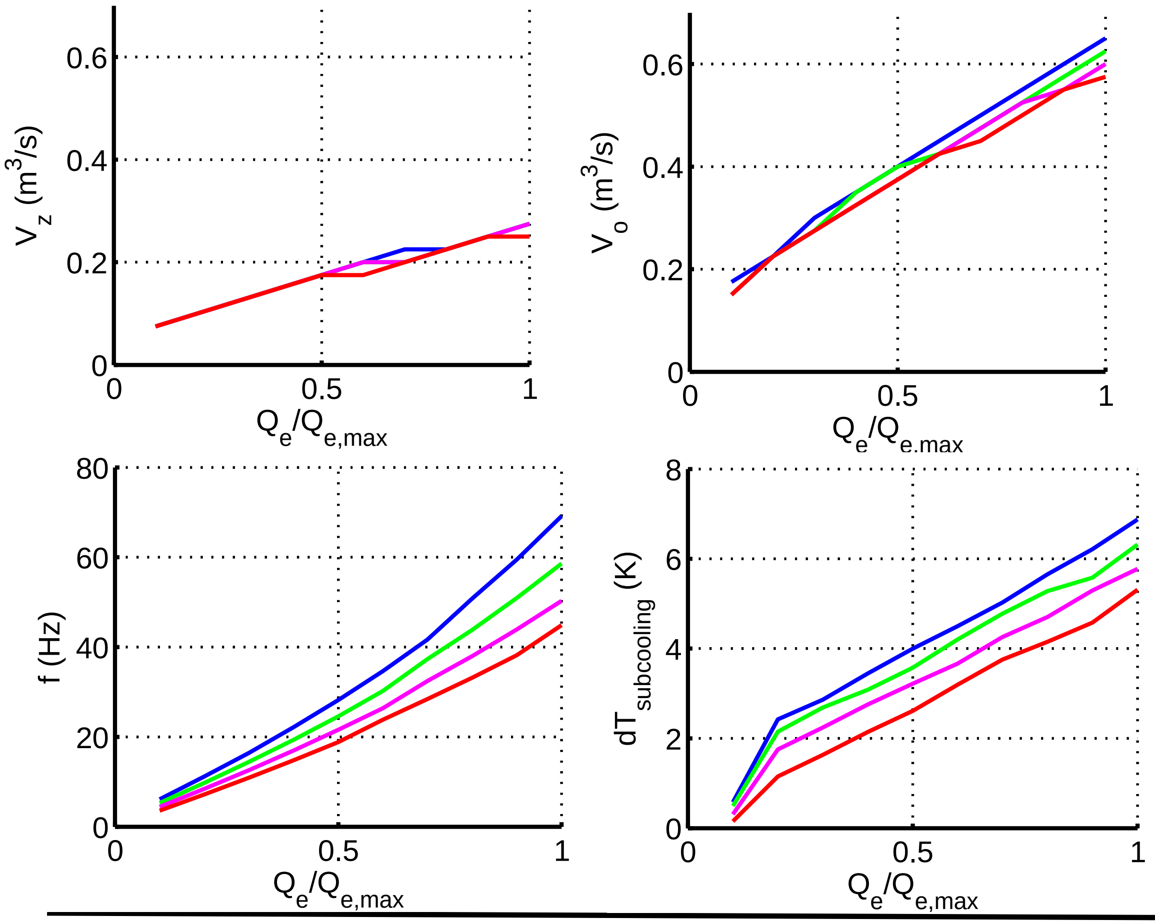


Given: Q_e = 3.2 kW

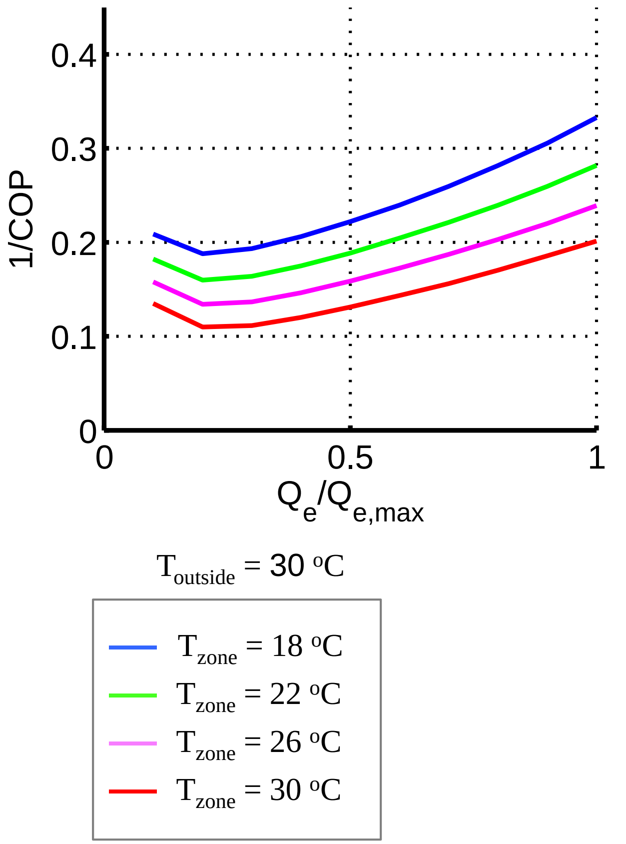
Heat pump static optimization

Optimization results

Optimal parameters

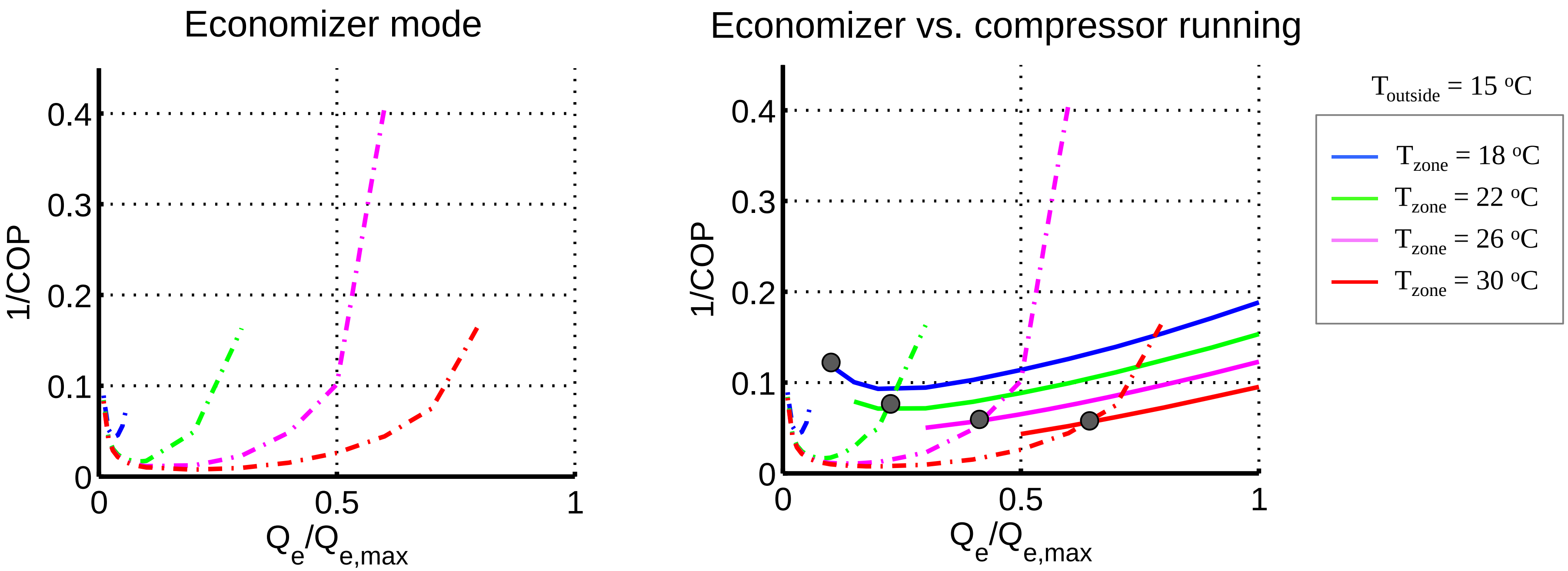


Power consumption



Heat pump static optimization

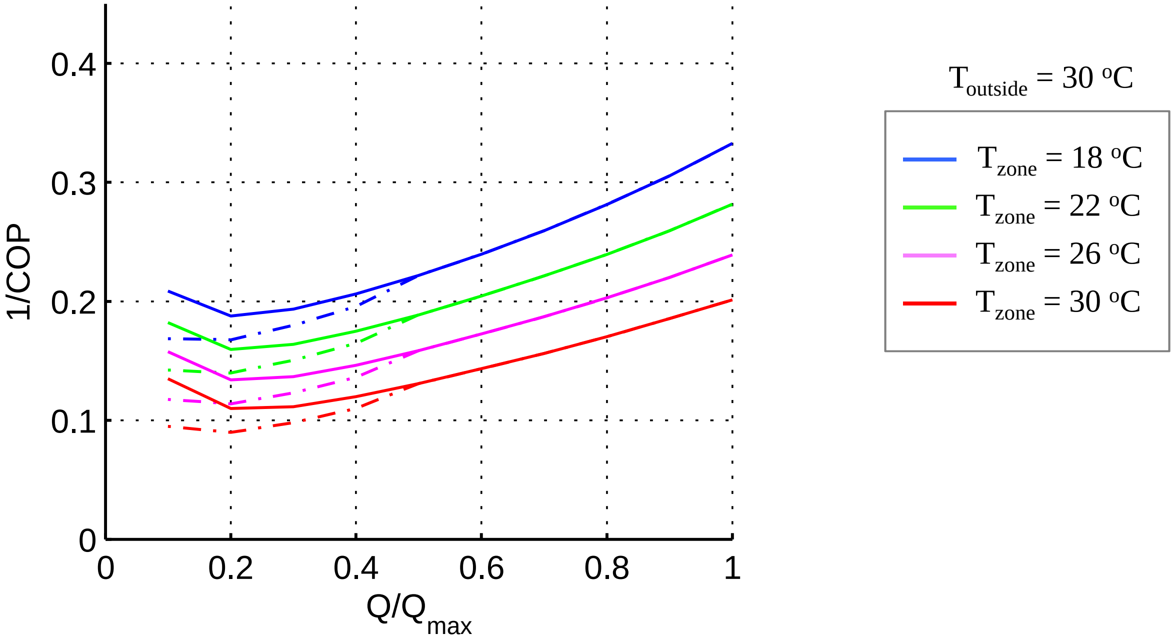
Economizer mode



Heat pump static optimization

Two-compressor heat pump

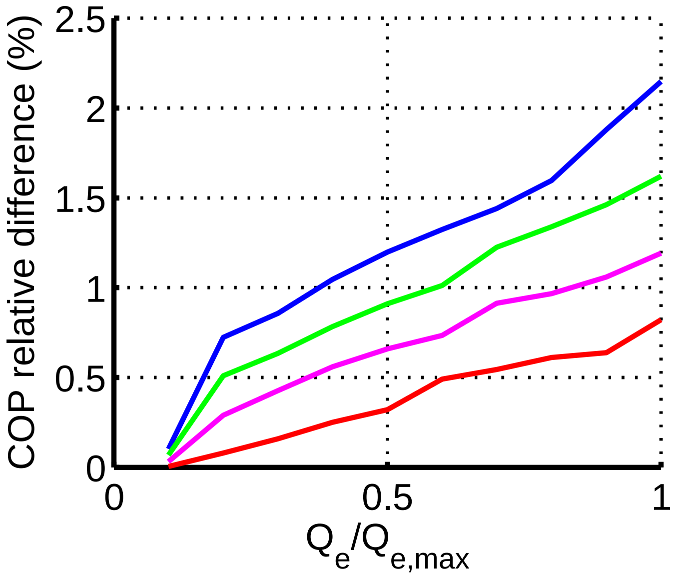
Specific power as a function of part-load ratio for single-compressor machine (solid line) and two-compressor machine with each compressor sized for half Q_{max} (dashed line).



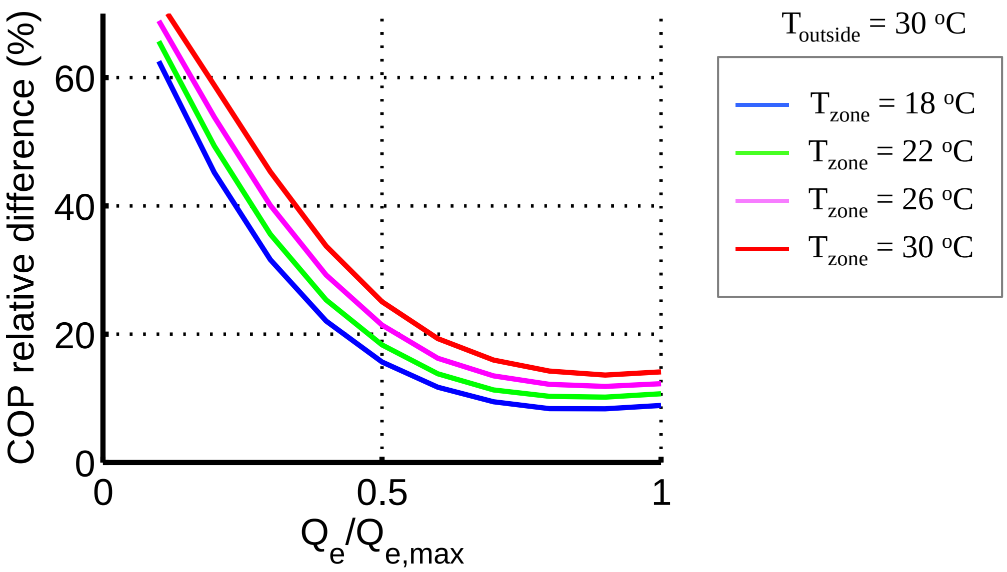
Heat pump static optimization

Optimization relevance example

Difference in COP for optimal versus zero subcooling case



Difference in COP for optimal versus fixed airflow case



$V_z = V_{z,max} = 0.15\ m^3/s$

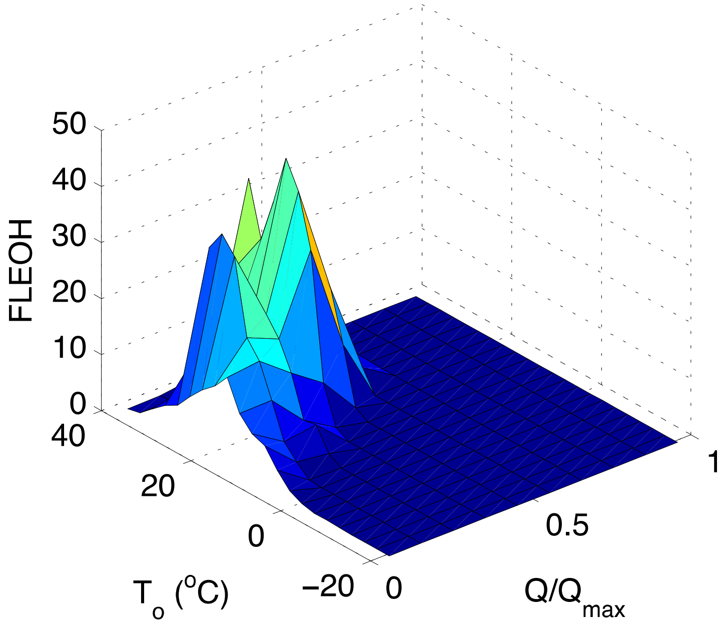
$V_o = V_{o,max} = 0.77\ m^3/s$

$$COP_{relative\_difference} = \frac{COP_{opt\_sub} - COP_{zero\_sub}}{COP_{opt\_sub}} * 100$$

$$COP_{relative\_difference} = \frac{COP_{opt\_airflow} - COP_{fixed\_airflows}}{COP_{opt\_airflow}} * 100$$

Heat pump static optimization

Optimization relevance example



Cooling loads for a building
with thermal storage (inherent in mass)*

Annual energy savings		
Optimized versus zero subcooling	$(E_{zero\_sc} - E_{optimized})/E_{zero\_sc}$	**0.4 %**
Optimized versus non-optimized	$(E_{non\text{-}optimized} - E_{optimized})/E_{non\text{-}optimized}$	**49.6 %**
Dual versus single compressor	$(E_{single} - E_{dual})/E_{single}$	**11.9 %**
Variable versus two-speed heat pump	$(E_{two\text{-}speed} - E_{variable})/E_{two\text{-}speed}$	**34.5 %**

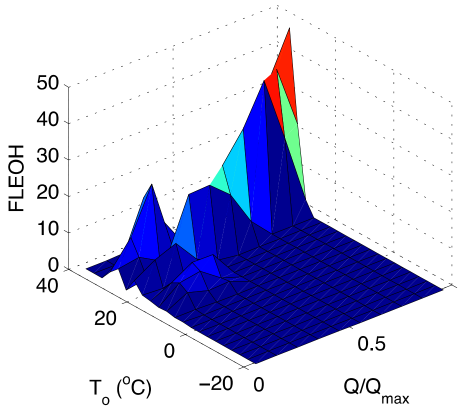
* Sensible cooling loads used are the results of the study done by Armstrong et al. (2009) for a typical office building in Chicago.

Heat pump static optimization

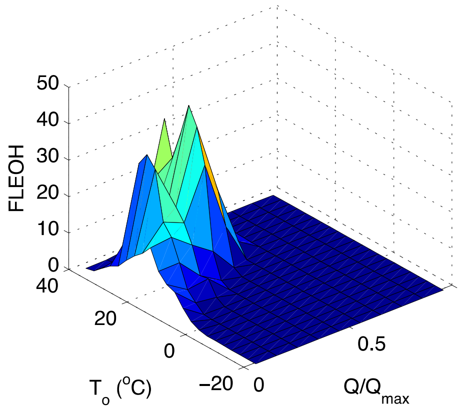
Heat pump sizing example

Building cooling loads*

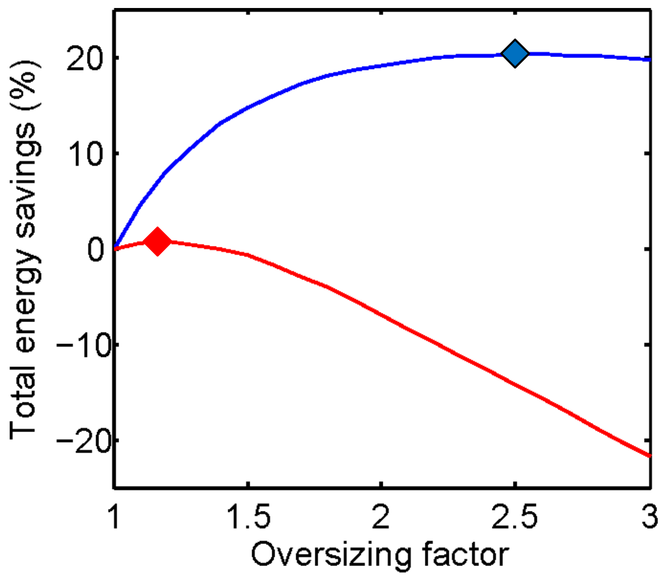
Case A: Without a thermal storage



Case B: With a thermal storage



Heat pump optimal sizing for Case A (blue diamond) and Case B (red diamond)



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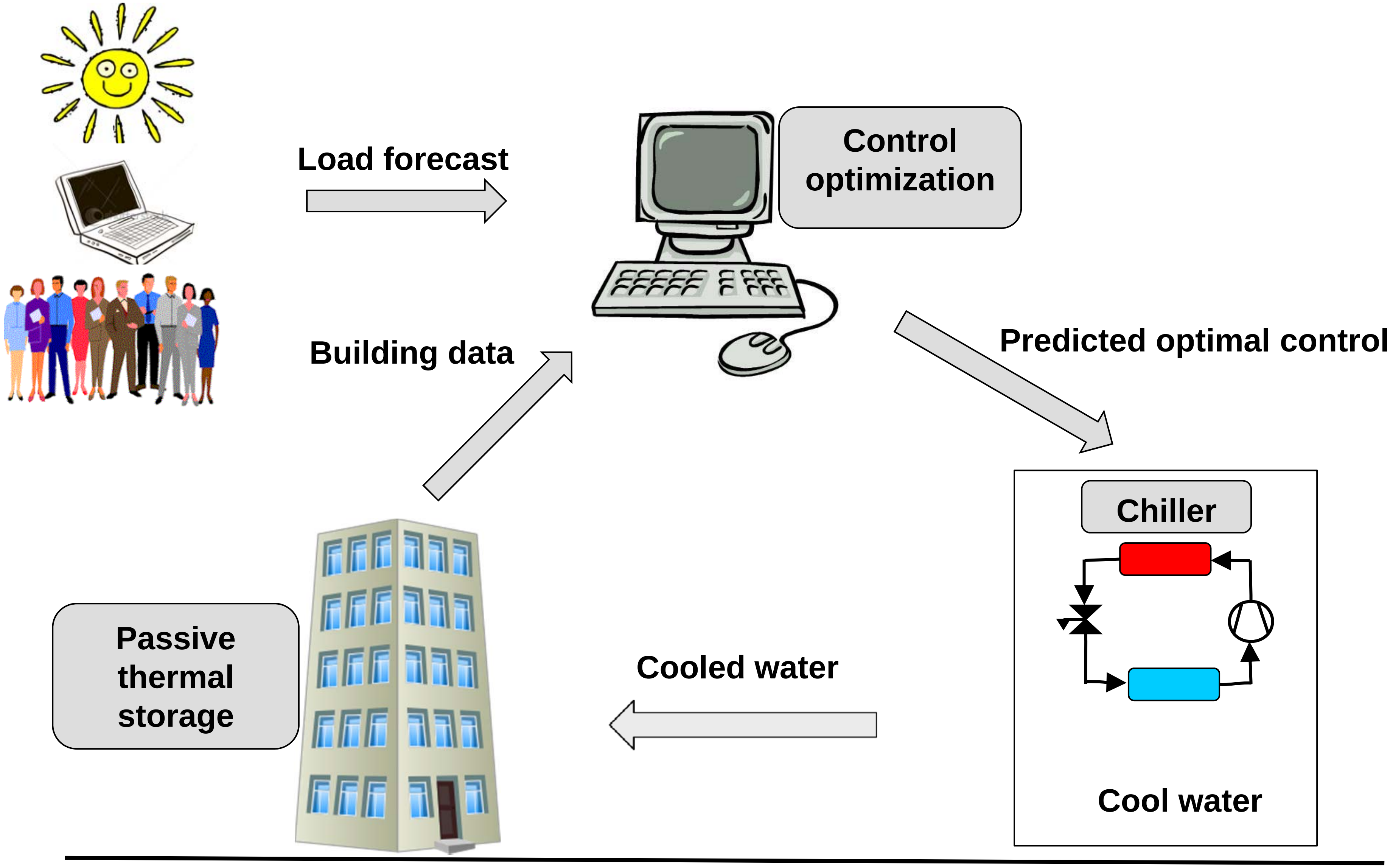
Building level implementation



Load forecast

Control optimization

Building data

Predicted optimal control

Chiller

Passive thermal storage

Cooled water

Cool water

Thank you

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