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Refrigeration and Air Conditioning
High Performance Buildings

Effects of Vapor Injected Compression, Hybrid Evaporator Flow Control, and Other Parameters on Seasonal Energy Efficiency.

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Outline

- Introduction and Motivation
- Calculation Method
- Capacity, COP, and Building Heating Requirement
- Results for different system configurations
- Parametric Studies
- Conclusions and future work

Introduction and Motivation

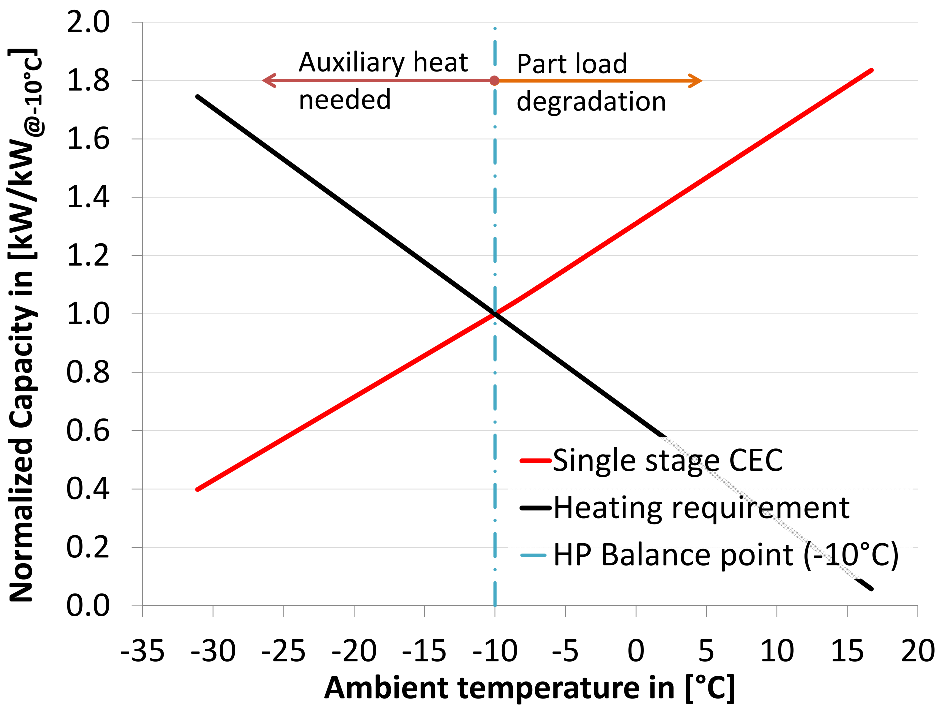
- Known issues of heat pumps are:
  - » Insufficient at low ambient temperature → auxiliary heat
  - » Excess capacity at high ambient temperature → cycling
- Shen et al. (2014) mentions over-capacity as key to good seasonal performance
- Previous presentation (paper #2111):
  - » Vapor injected compression increases low temperature capacity and COP
  - » Hybrid control further increases capacity and COP, especially if airside maldistribution occurs
- No good illustration available/found on the effect of vapor injection onto heating seasonal performance for vapor injected compression, hybrid control, and influence of system parameters
  - » Starting point for this work

Calculation Method

- Based on heating seasonal performance factor calculation (HSPF) of ANSI/AHRI 210/240
- Consideration of auxiliary heat and part load degradation
- Consideration of low temperature cutout
- Inter/extrapolation based on measured temperature instead of test plan temperature
- Addition of Minneapolis TMY3 data (NREL, 2013)
- Design heating requirement set to yield a heat pump balance point of -10°C for baseline single stage system

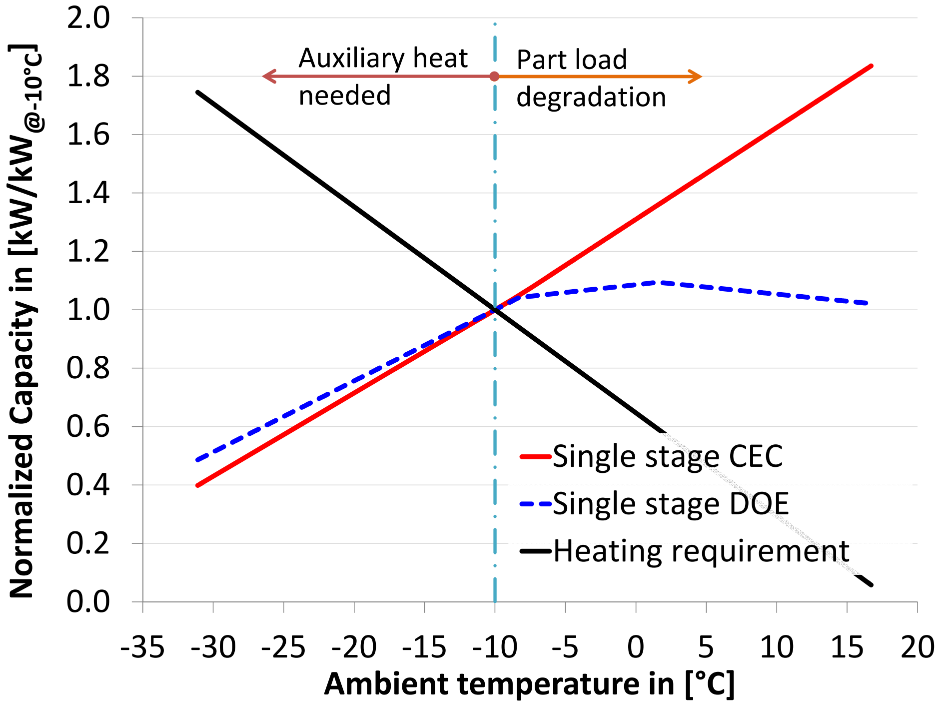
Capacity and Building Heating Requirement

- Single stage, single speed CEC system opposite trend of required



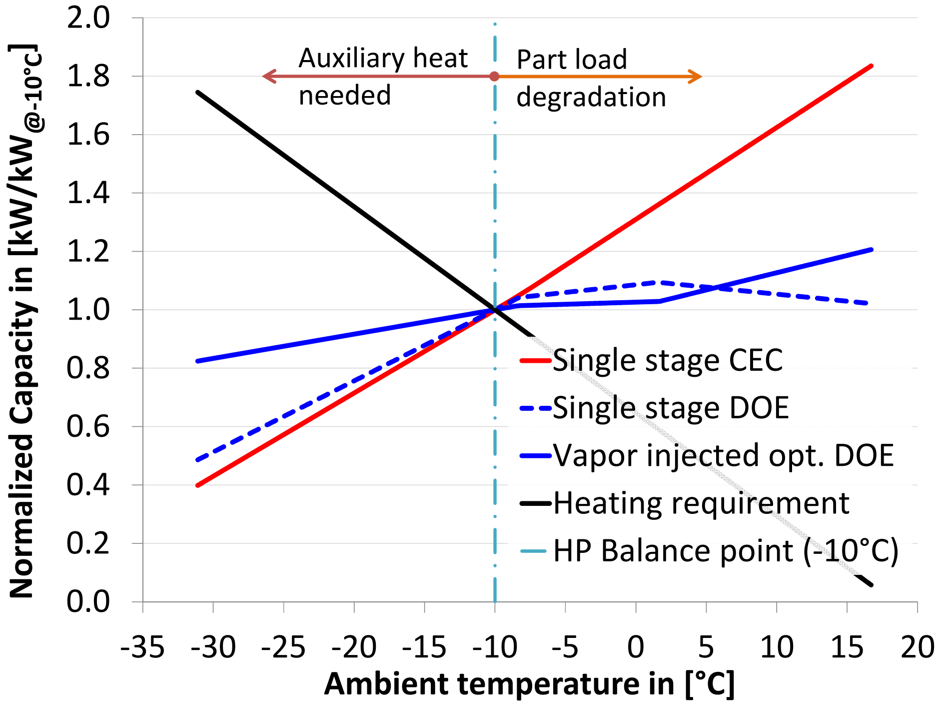
Capacity and Building Heating Requirement

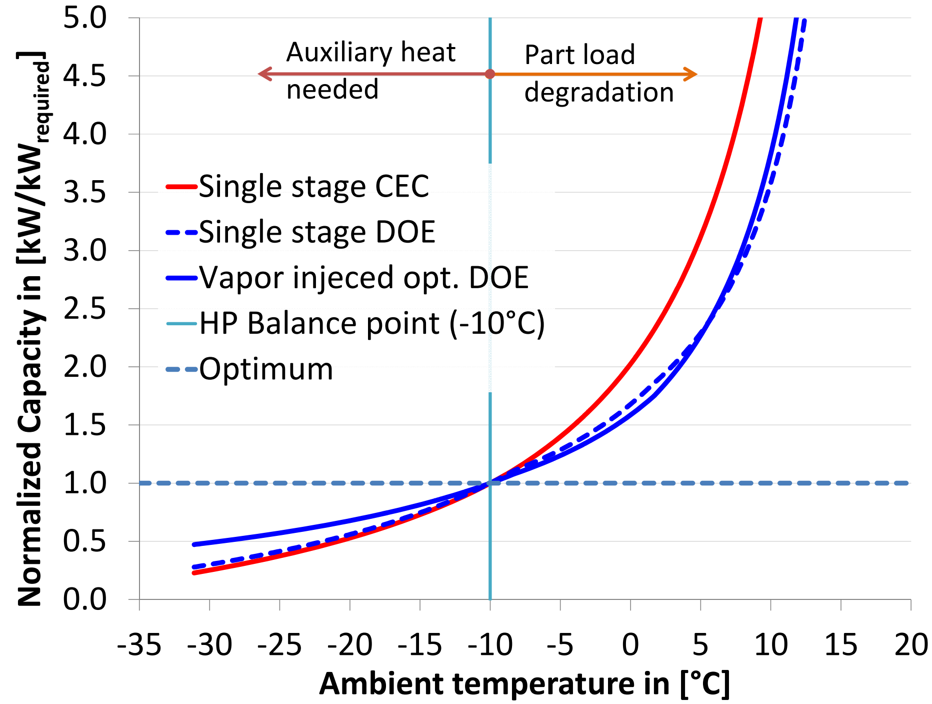
- Single stage, single speed CEC system opposite trend of required
- Single stage, variable speed DOE system reduces overcapacity



Capacity and Building Heating Requirement

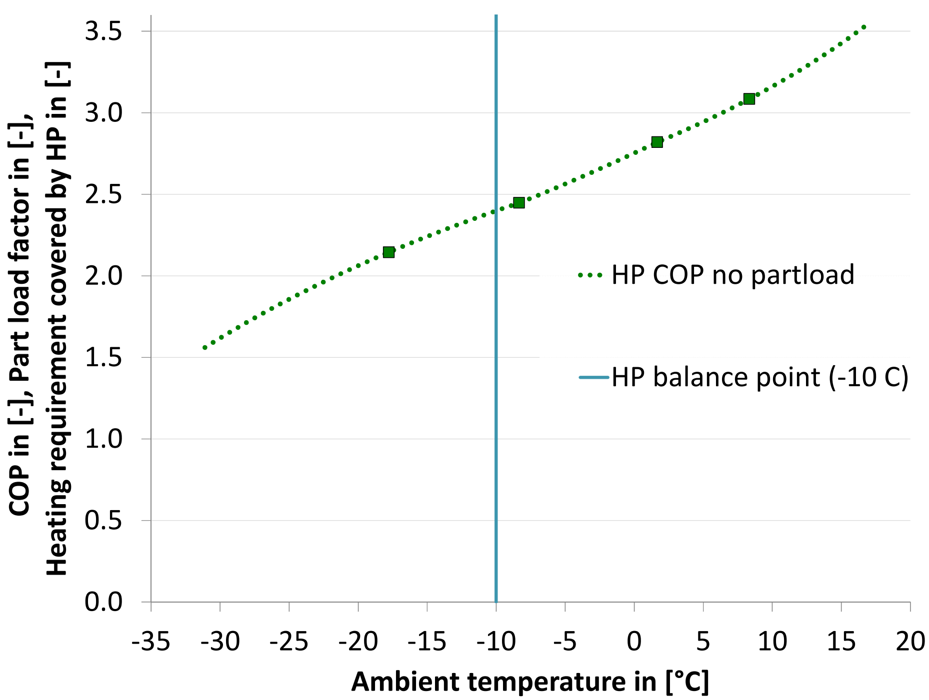
- Single stage, single speed CEC system opposite capacity trend of required
- B0: Single stage, variable speed DOE system reduces high temp. overcapacity
- B1 opt: Single stage, variable speed vapor injected DOE system reduces low temp. undercapacity





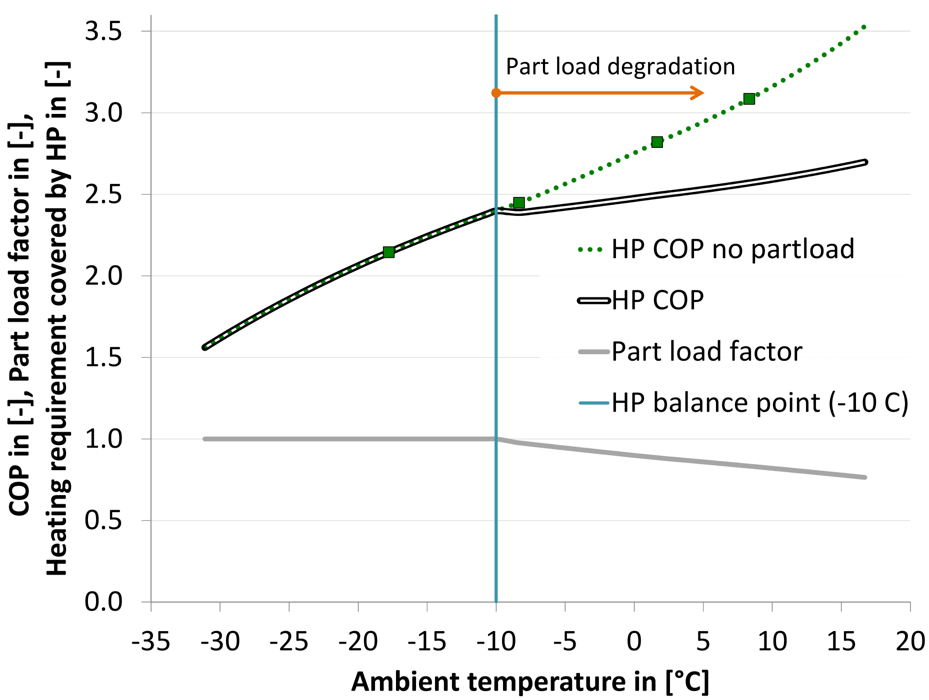
Heating Coefficient of Performance (COP)

- Exemplarily shown for B0: DOE single stage system



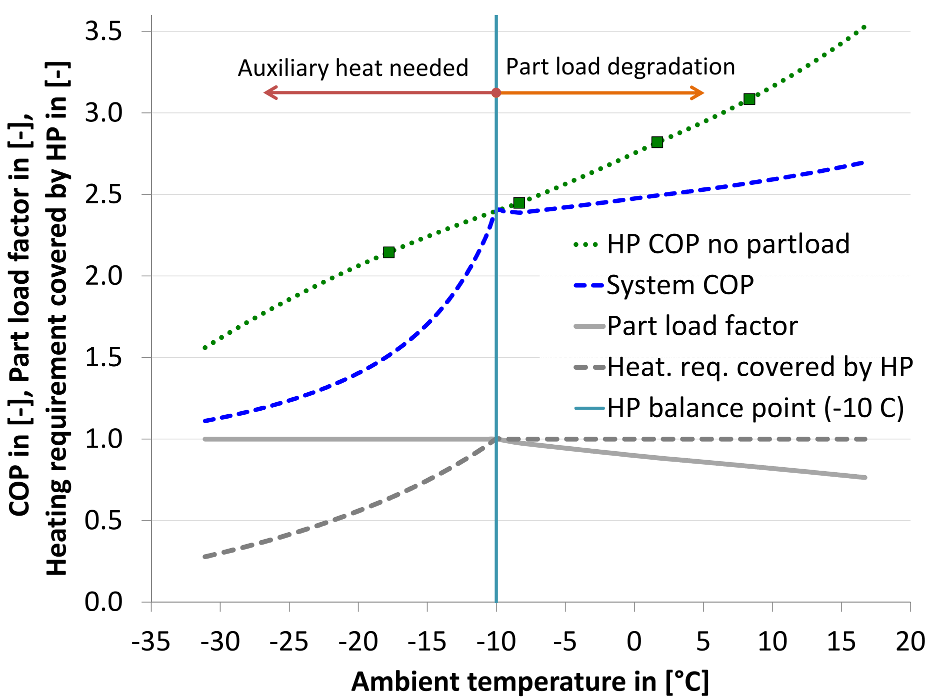
Heating Coefficient of Performance (COP)

- Exemplarily shown for B0: DOE single stage system
- Part load degradation toward building balance point (18.3°C)



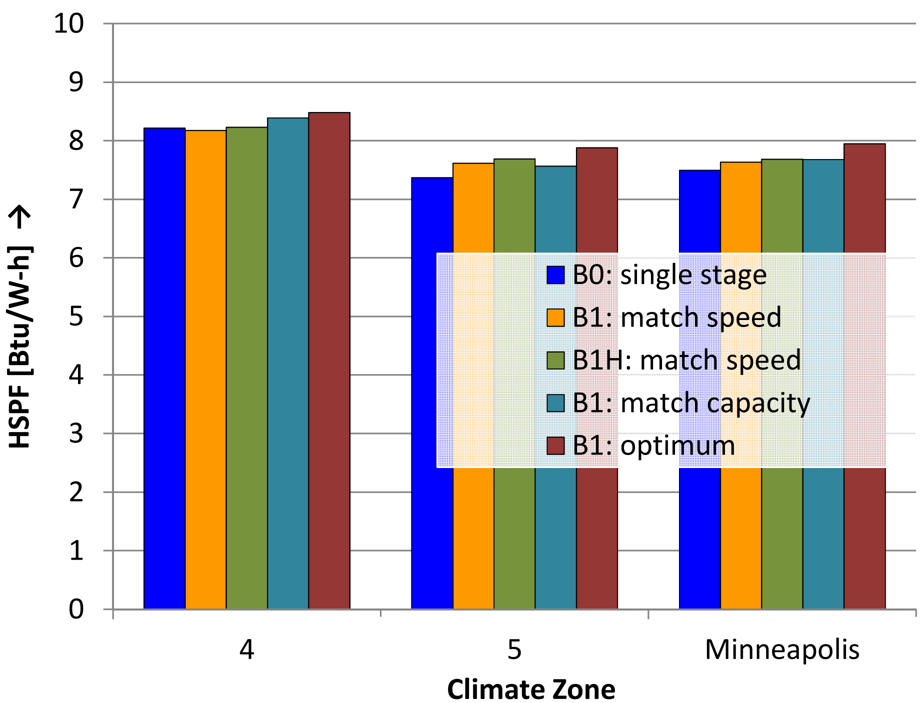
Heating Coefficient of Performance (COP)

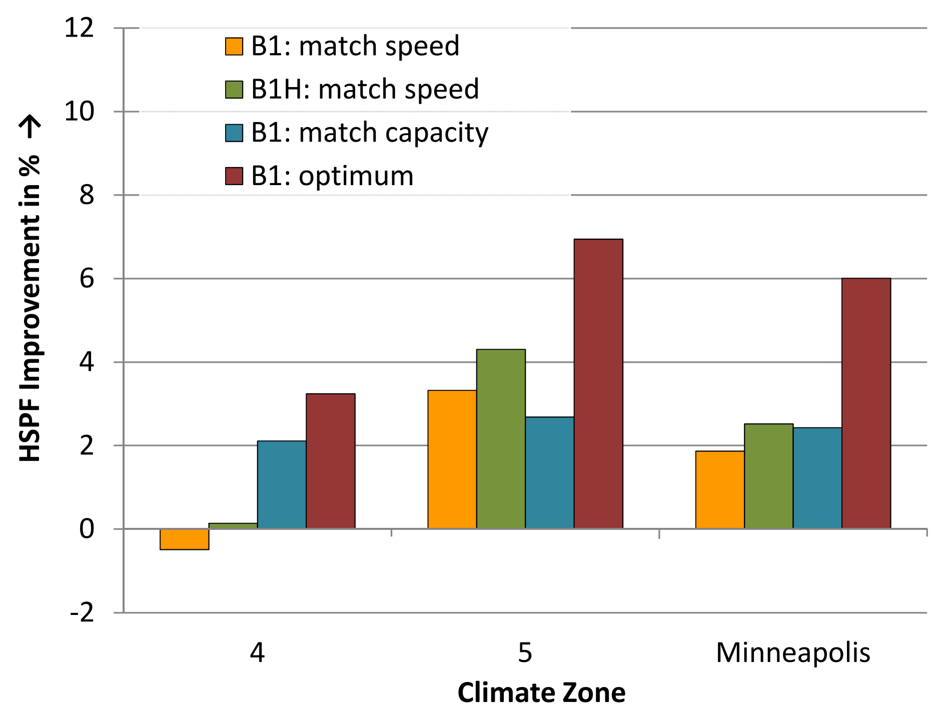
- Exemplarily shown for B0: DOE single stage system
- Part load degradation toward building balance point (18.3°C)
- System COP degraded below HP balance point due to aux. heat



Heating Seasonal Performance Factor (HSPF)

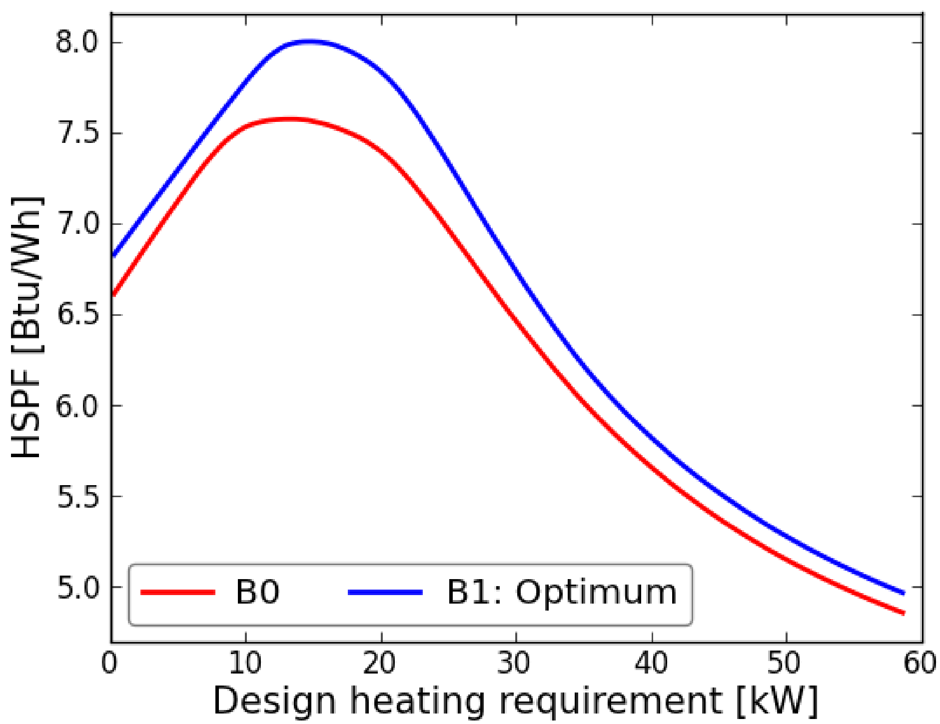
- Vapor injection (VI) benefit depends on compressor speed
  - » B1: match single stage speed,
  - » B1: matched single stage capacity or
  - » combination of both (e.g. B1: optimum)
- Largest HSPF improvement for colder climates (climate zone 5 and Minneapolis)
- Hybrid control increases HSPF by 1% relative to same speed VI case
  - » Increased capacity
    - – Part load degradation for higher ambient temperatures
    - – Reducing compressor speed would further increase benefits
  - » Does not include additional benefits for airside maldistribution (!)

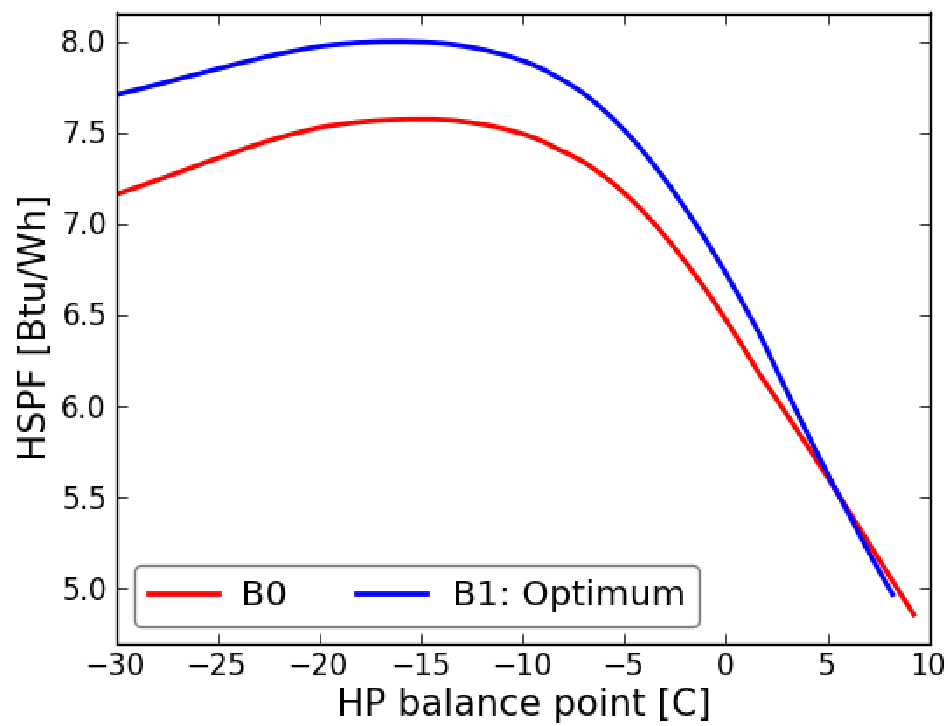




Parametric Studies: Design Heating Requirement and Balance Point

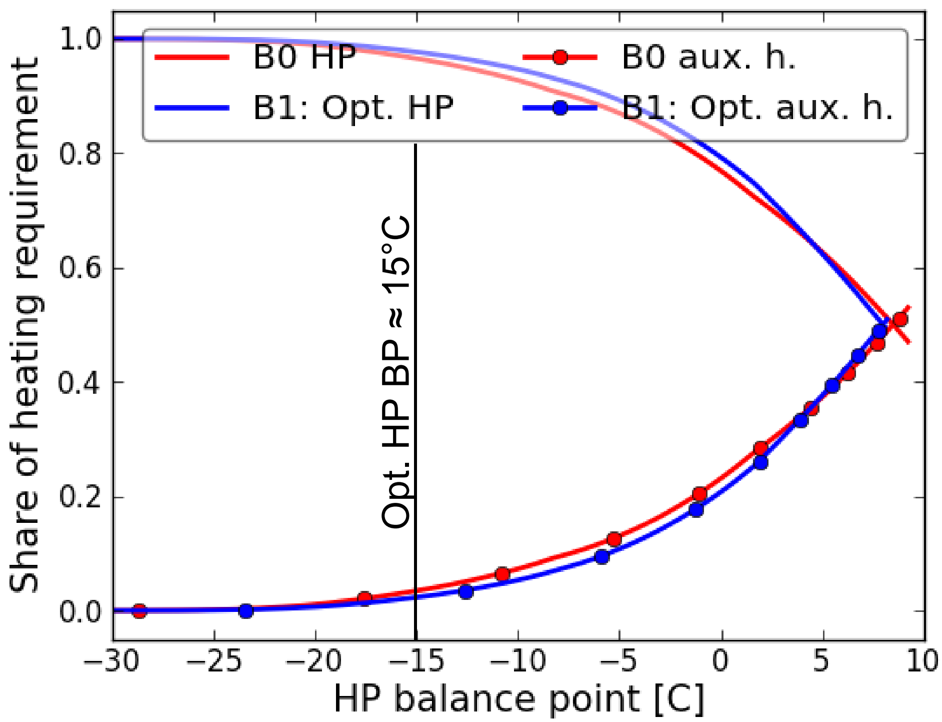
- All subsequent parametric studies for Minneapolis temperature data
- Change of design heating requirement @ -10°C amb. temp.
  - » Optimum value ≈ 15 kW
- Heat pump (HP) balance point more intuitive measure
  - » Optimum for both configurations ≈ 15°C

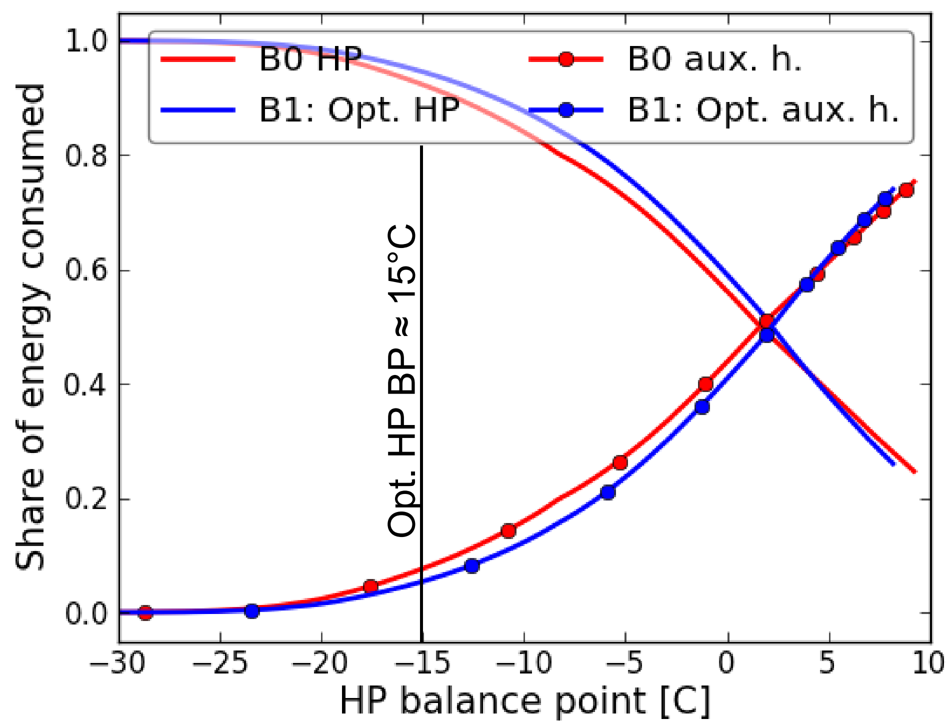




Parametric Studies: Share of Heating Requirement and Energy Consumed

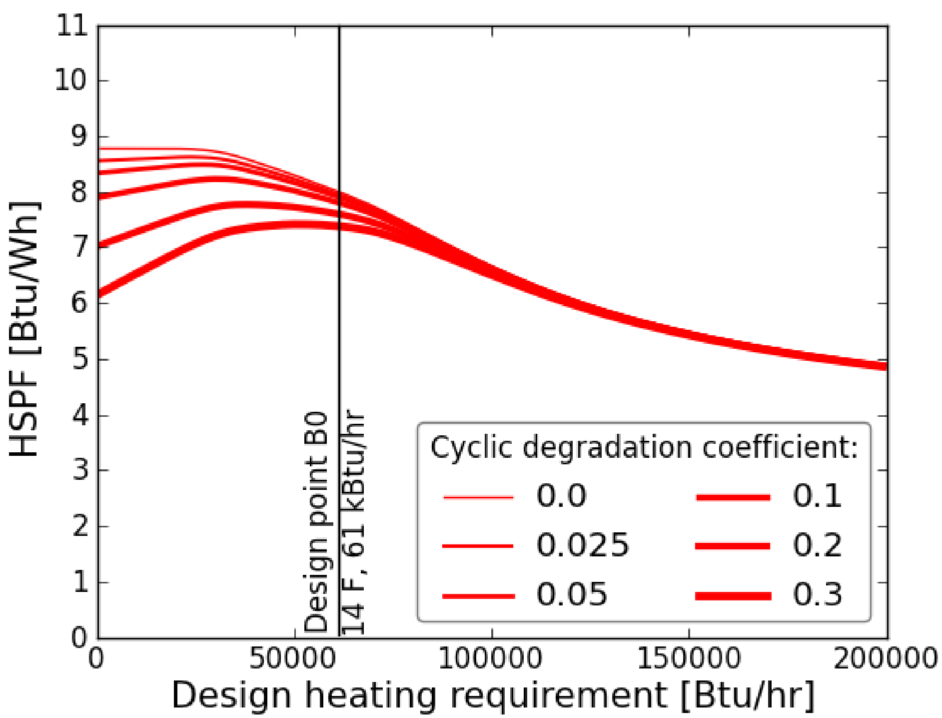
- Optimum HP balance point for both configurations ≈ 15°C
  - » Some coverage of annual heating requirement by aux. heat
  - » Approx. 10% of consumed energy for B0
  - » Tradeoff: Part load losses ↔ Auxiliary heat

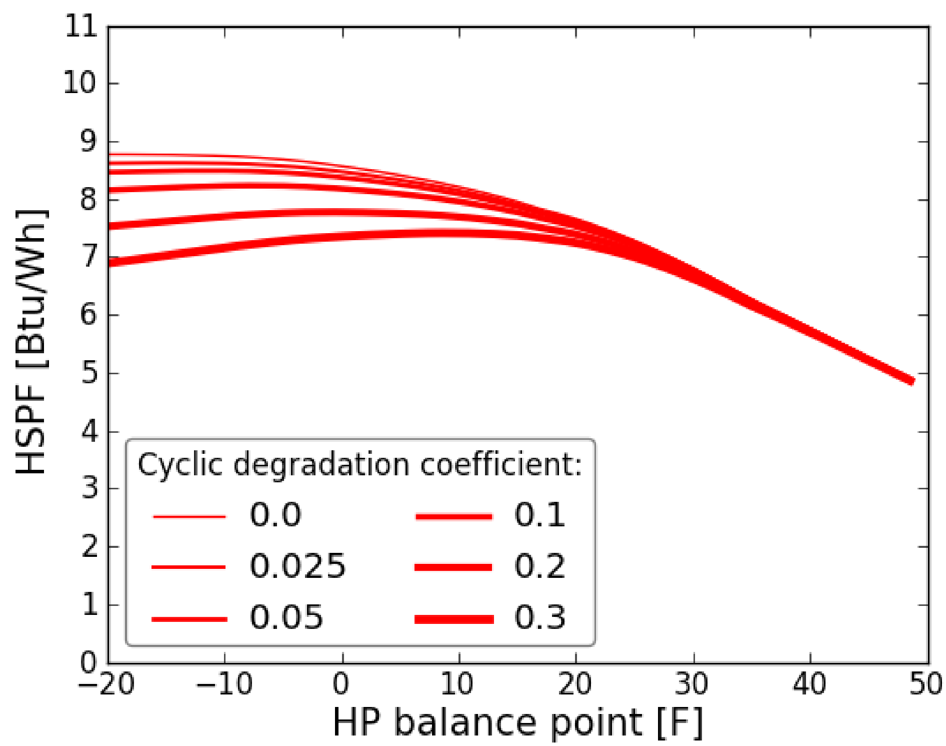




Parametric Studies: Part Load Losses – Cyclic Degradation Coefficient

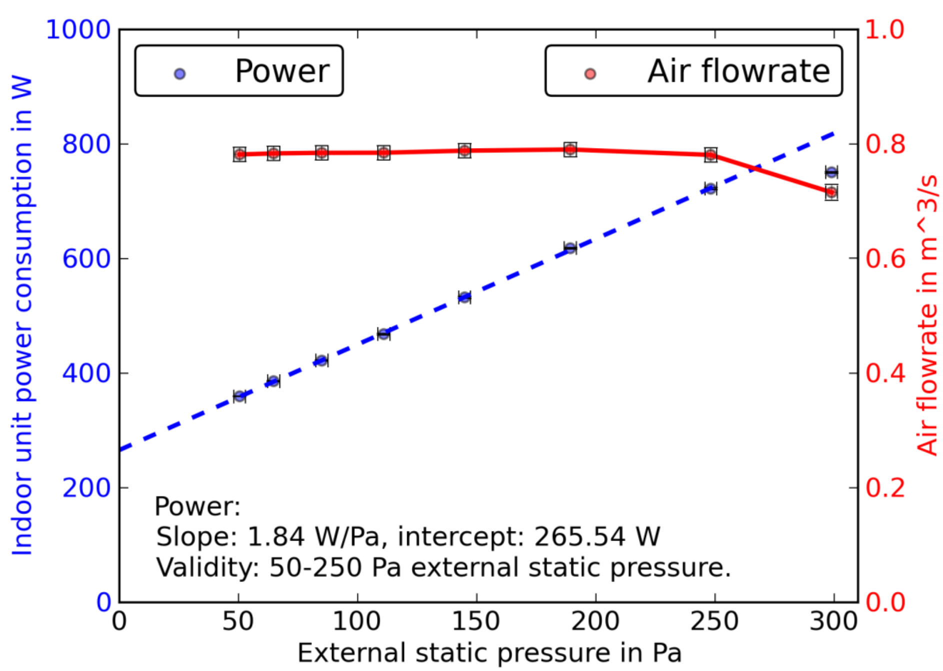
- Cyclic degradation coefficient
  - » Estimate part load degradation due to cycling
  - » Shift of opt. design heating requirement to lower temperatures
  - » Shift of optimum HP balance point to lower temperatures

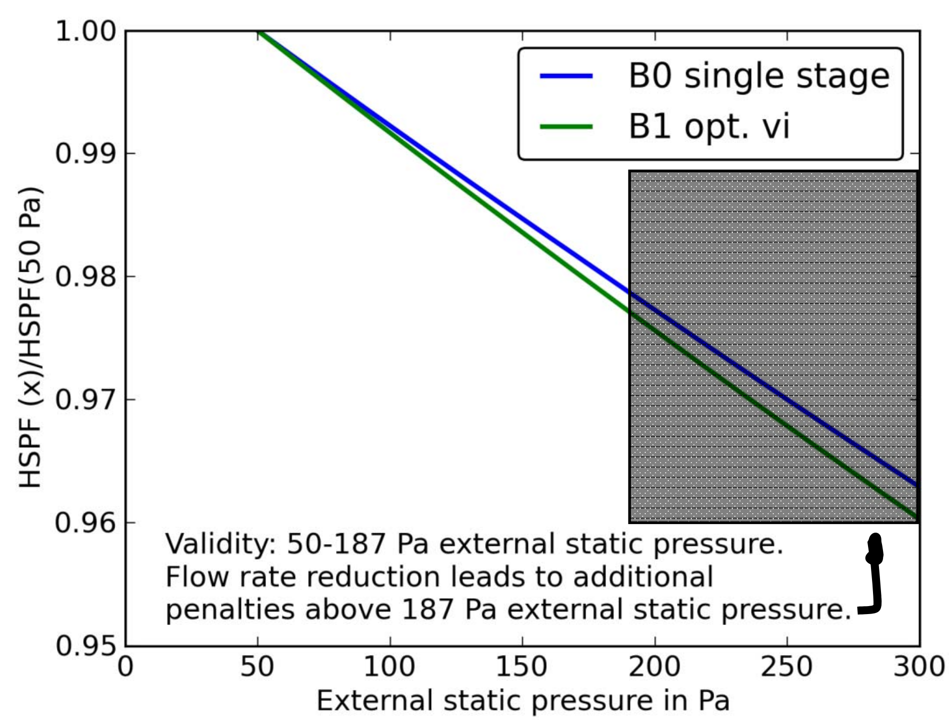




Parametric Studies:
Influence of External Static Pressure (Indoor Fan Coil)

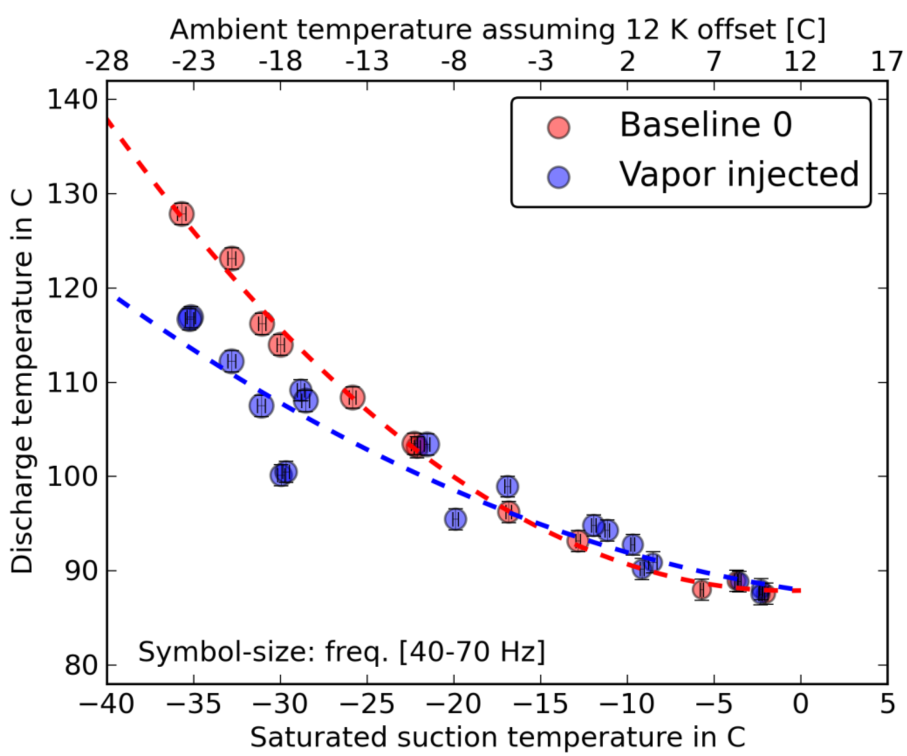
- External static known to negatively affect se asonal cooling performance
- Fan curve of actual test setup constant flow rate
- Include increased fan power consumption in HSPF
- Relatively small penalty even for higher external static pressures
- 187 Pa average external static of field study (Proctor, 2011)

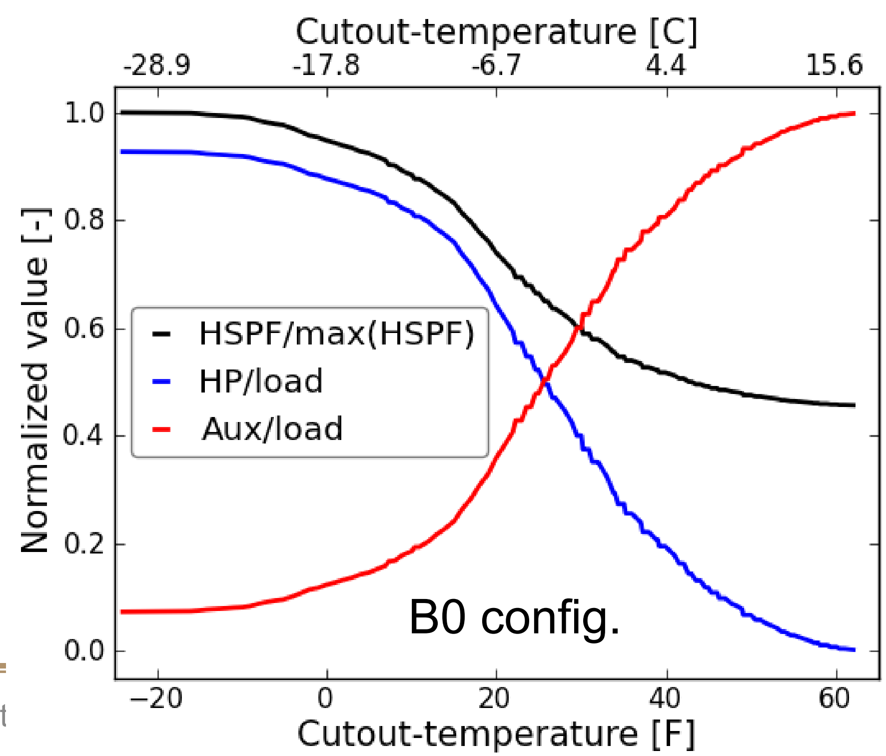




Parametric Studies:
Influence of Cutout Temperature

- Discharge temperature/ambient temperature:
  - » Assumed offset of 12 K, max discharge temperature of 135°C
  - » No cutout for vapor injected system
  - » -27°C cutout for baseline system – approx. 1 % HSPF penalty (baseline)





Conclusions and Future Work

- Low ambient temperature capacity most important factor for a high HSPF.
  - » Part load degradation sets upper limit
  - » Compressors with extremely wide frequency range (e.g. 10-100 Hz) should be investigated to overcome the above issue
  - » Benefit of vapor injected system result of increase in low ambient temperature capacity
- Low ambient temperature cutout no serious concern for the HSPF of the tested system - even for cold climates
- External static pressures as observed in practice do not lead to a large degradation of seasonal heating performance

References

Proctor, J., Chitwood, R., and Wilcox, B. A., 2011, *Efficiency Characteristics and Opportunities for New California Homes*, Proctor Engineering Group, Ltd.

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NREL, 2013, *National Solar Radiation Data Base - 1991- 2005 Update: Typical Meteorological Year 3 - List of Sites in Alphabetical Order by State and Site Name, location 726580, Minneapolis-St Paul Int'l Arp*, downloaded 09/22/2013 from http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html.

→ additional references cited in manuscript