Efficiency of Mobile Air Conditioning

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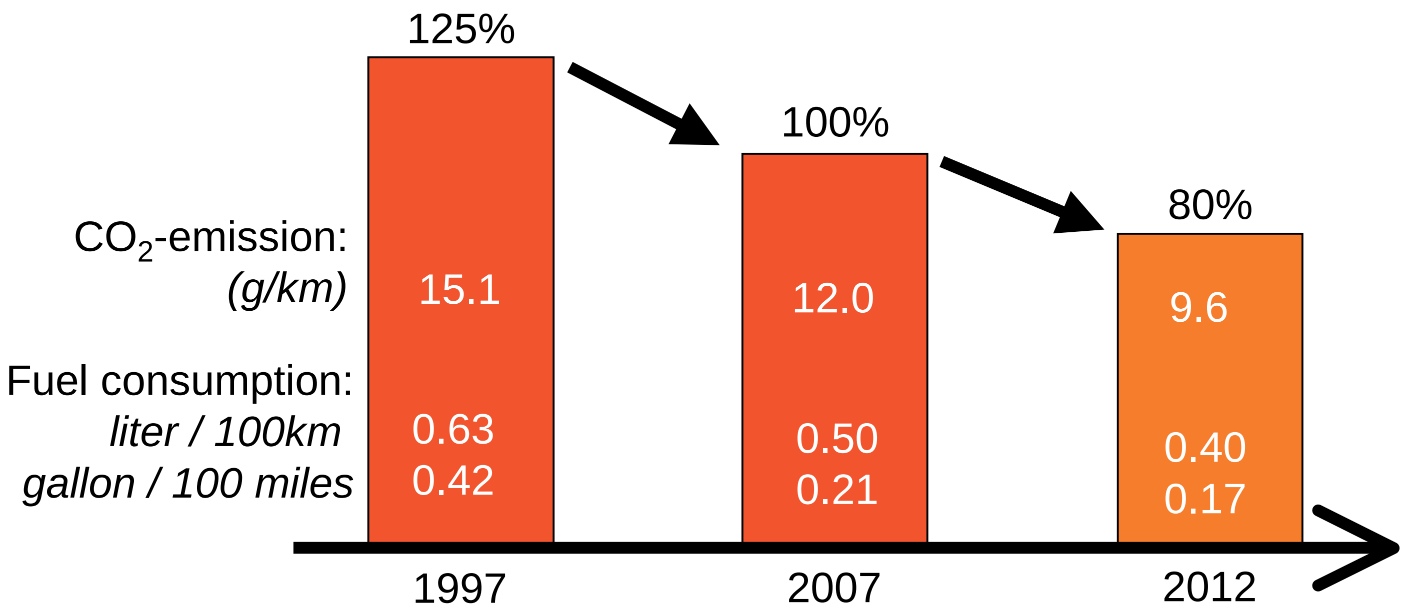
BEHR GmbH & Co. KG

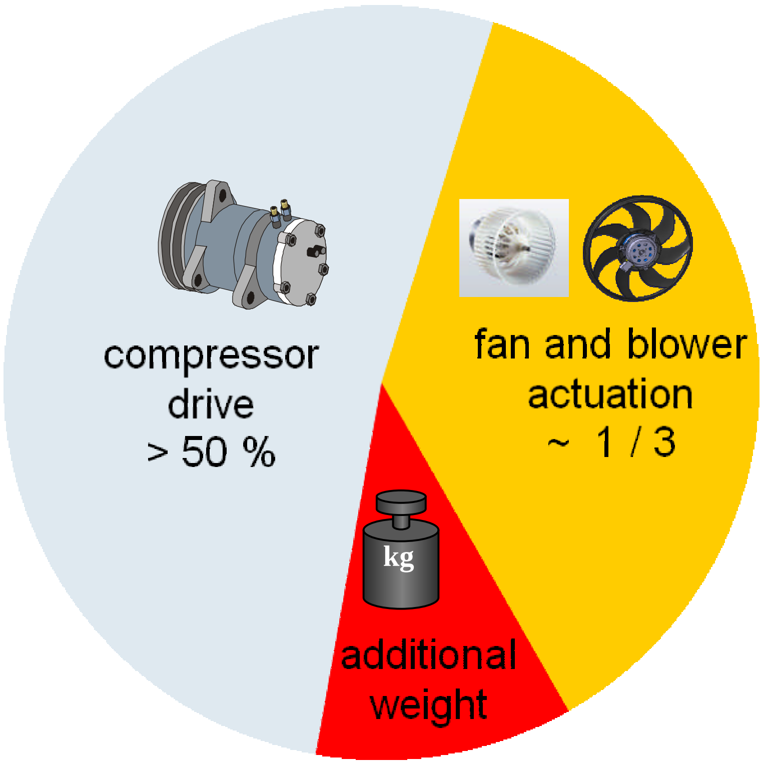
Fuel consumption of MAC



Our target: 0.4 l/100 km or 0.17 gal. / 100 miles

→ Contributors to fuel consumption of MAC ?

Fuel consumption of MAC



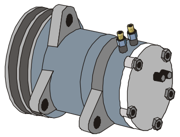
More than 50% of MAC fuel consumption is caused by compressor

→ Annual energy consumption of compressor ?

Energy consumption compressor

annual fuel consumption ~ energy consumption of compressor, that is work of compressor, W

~ power P integrated over time



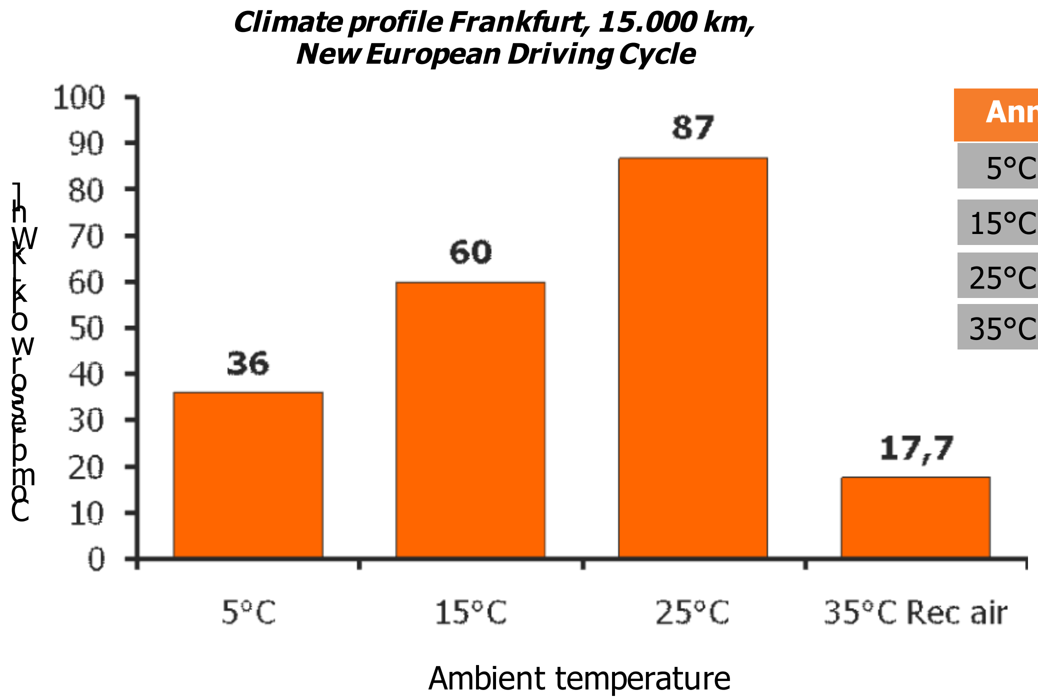
$$W = \int_{year} P_{compressor}(T)dt = \int_{year} \frac{\dot{Q}_{evaporator}(T)}{COP(T)} dt$$

$$\dot{Q}_{evaporator}(T, r.H.) \approx f(\text{climate})$$

Reduction of fuel consumption to	80%	(4/5 = 0.8)
Improvement of COP to	125%	(5/4 = 1.25)

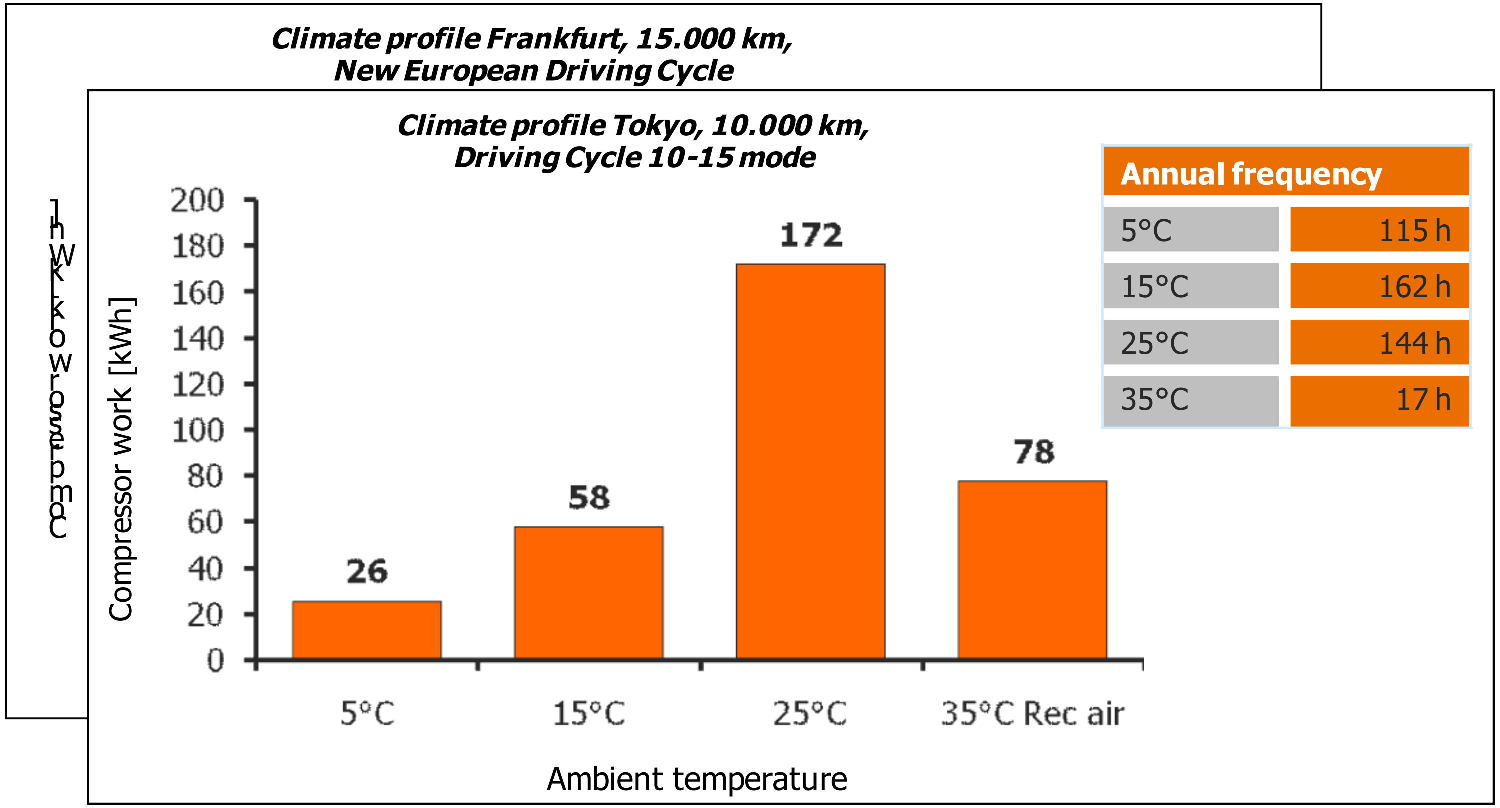
→ Evaluate compressor work for Frankfurt, Tokyo, Los Angeles

Energy Consumption Compressor
Annual Profile Frankfurt, Tokyo, Los Angeles

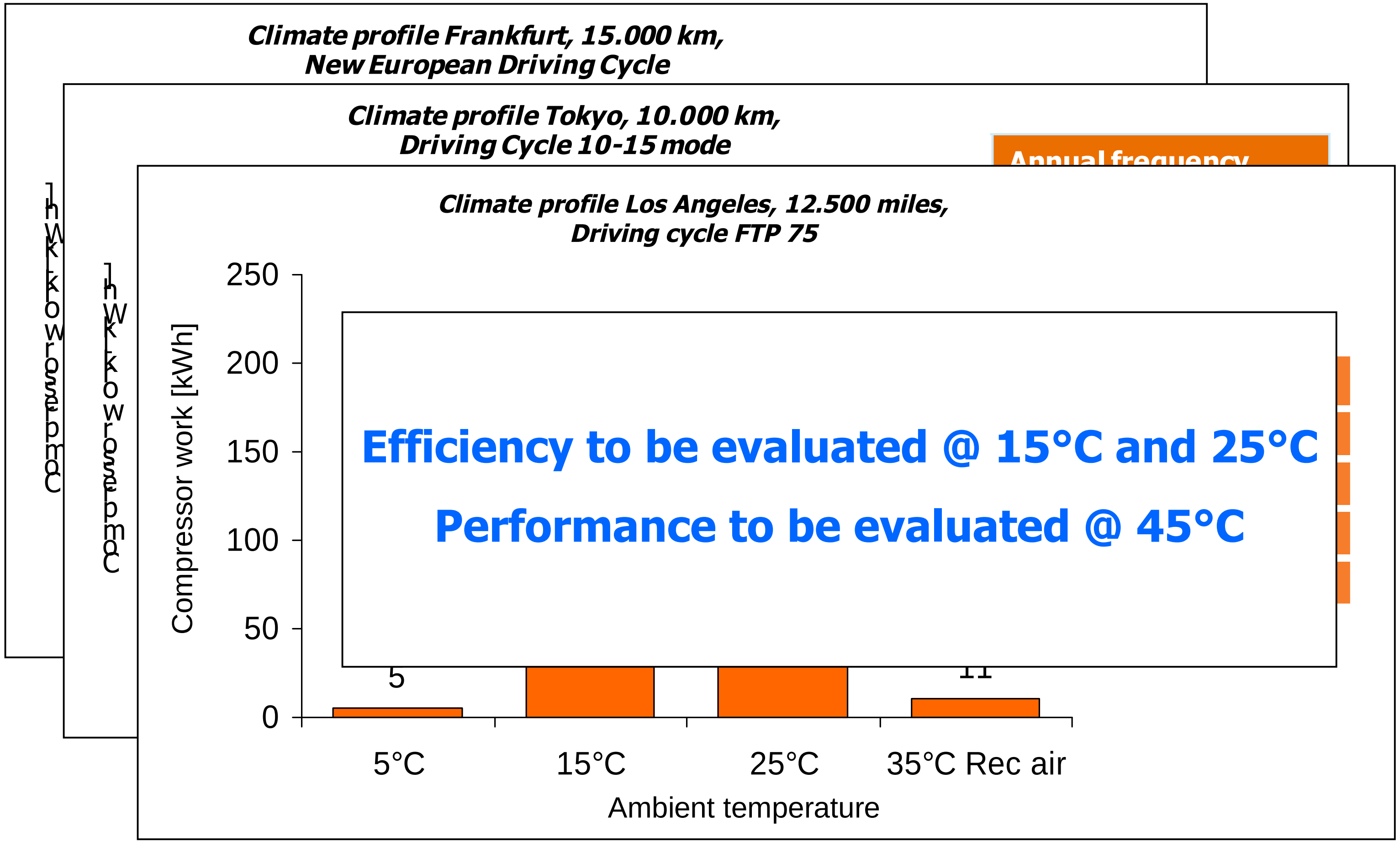


Annual frequency	
5°C	162h
15°C	169h
25°C	73h
35°C	4h

Energy Consumption Compressor
Annual Profile Frankfurt, Tokyo, Los Angeles

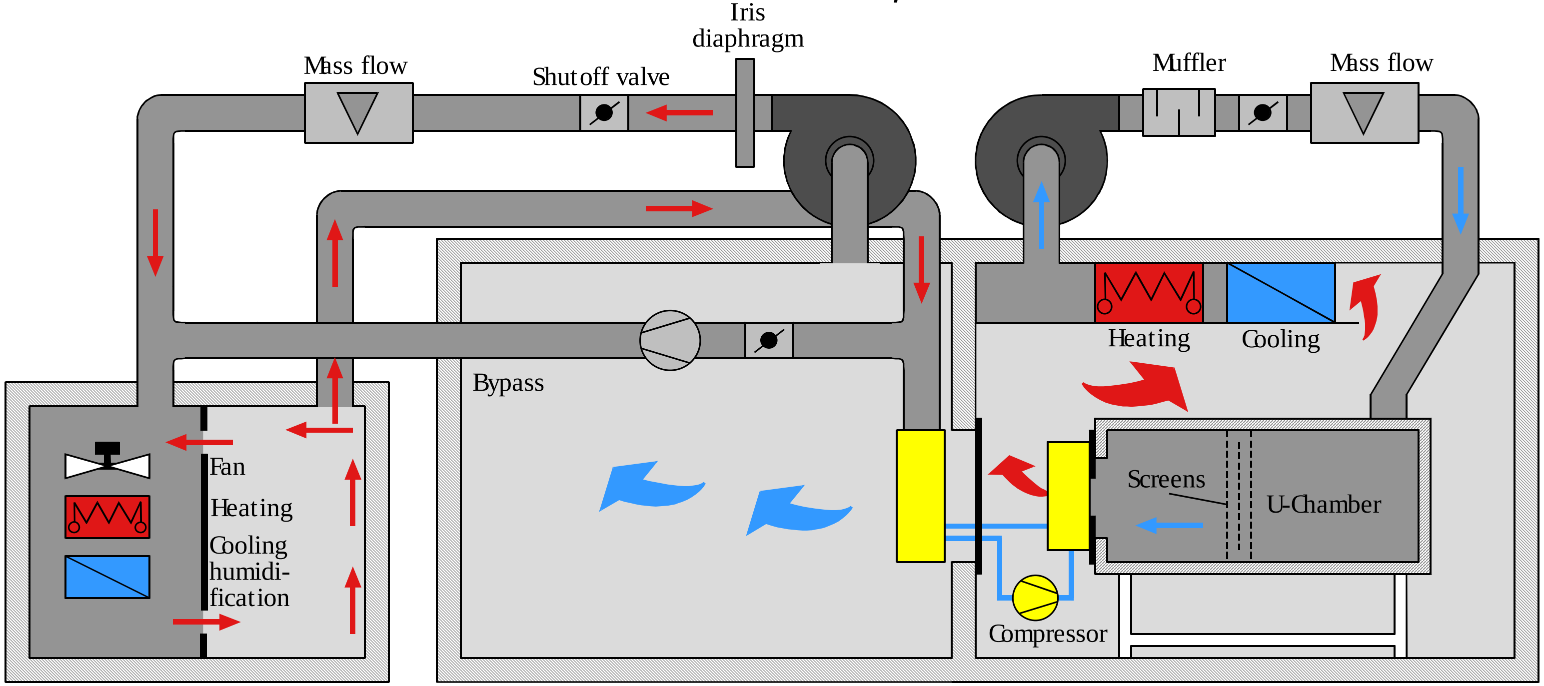


Energy Consumption Compressor
Annual Profile Frankfurt, Tokyo, Los Angeles

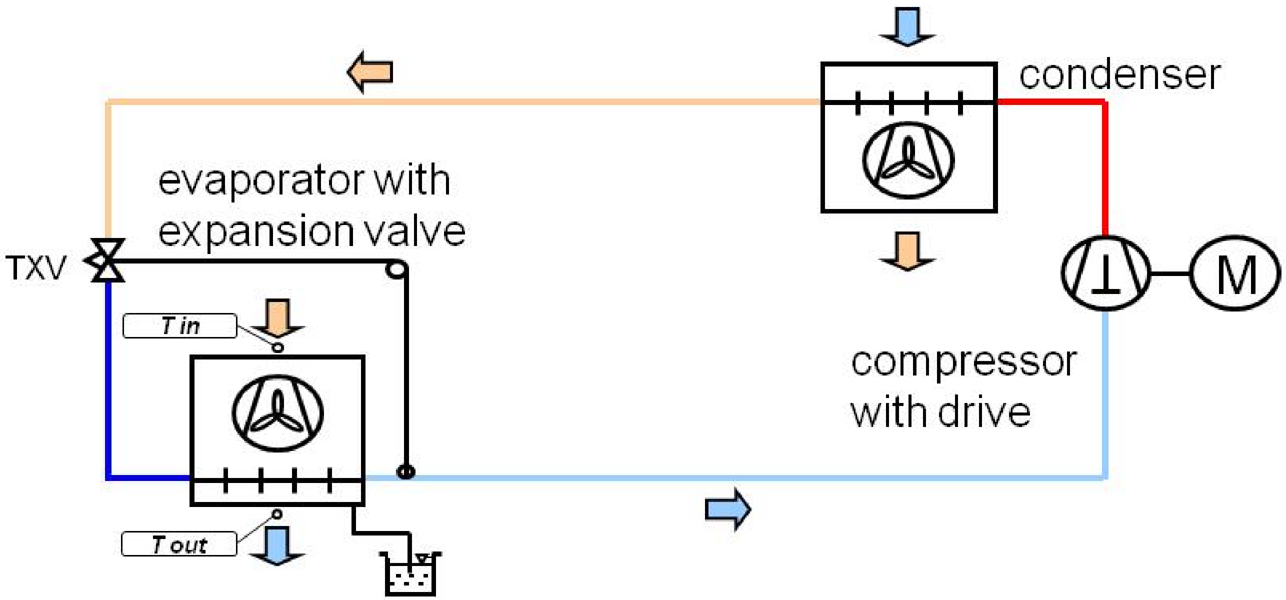


Determination of COP on refrigerant test bench

$$COP = \frac{\dot{Q}_{evaporator}}{P_{compressor}}$$



Determination of COP on refrigerant test bench



temperature air in, °C
dew point, °C
mass flow air, kg/s

temperature air out, °C
mass flow condensate, kg/s

$$\frac{\dot{Q}_{evaporator}}{P_{compressor}} = COP$$

number of turns, rpm
torque, Nm

Determination of COP: error and uncertainty worst case uncertainties at 7 kW cooling performance

worst case uncertainty:

±1.0 K temperature air in, °C
±0.3 K dew point, °C
± 2 % mass flow air, kg/s

±1.0 K temperature air out, °C
±0.1 % mass flow condensate, kg/s

$$COP = \frac{6.9\,\text{kW}}{4.7\,\text{kW}} = 1.5$$

±15 rpm number of turns, rpm
±0.50 Nm torque, Nm

max. error $$\frac{\Delta_{COP}}{COP} = \frac{\Delta_{\dot{Q}_{evaporator}}}{\dot{Q}_{evaporator}} + \frac{\Delta_{P_{compressor}}}{P_{compressor}} = 6.8\% + 4.3\% = \pm 11\%$$

mean error $$\frac{\Delta_{COP}}{COP} = \sqrt{\left(\frac{\Delta_{\dot{Q}_{evaporator}}}{\dot{Q}_{evaporator}}\right)^2 + \left(\frac{\Delta_{P_{compressor}}}{P_{compressor}}\right)^2} = \sqrt{1.9\%^2 + 3.9\%^2} = \pm 4.3\%$$

refrigerant side balance with considerable higher error
→ part load ?

Determination of COP: error and uncertainty worst case vs. improved uncertainties

Cooling performance	7 kW	1.4 kW
Max. error	± 11%	± 33%
Mean error	± 4.3%	± 20%

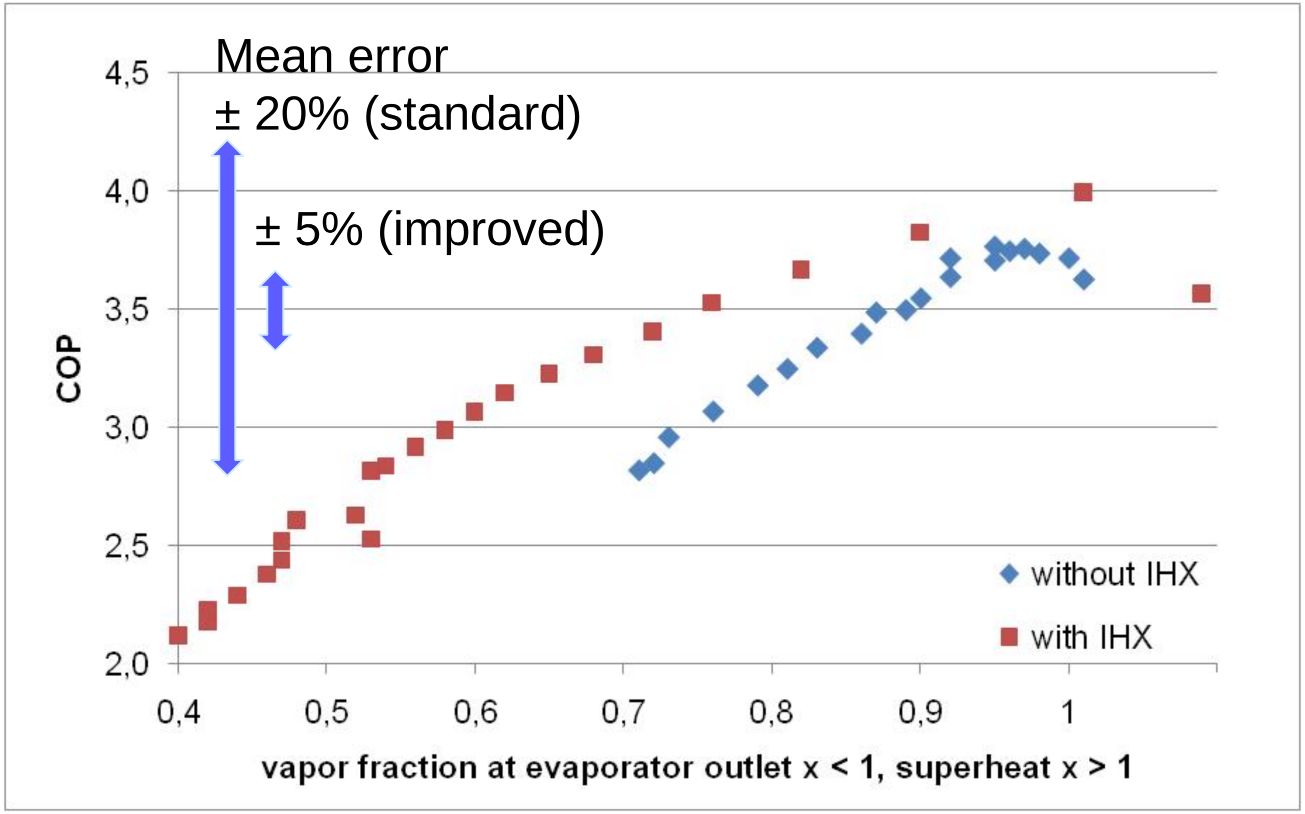
error at part load too big

→ improved equipment:

Cooling performance	7 kW	1.4 kW
Mean error		< ± 5%

Is < ± 5% enough ?
→ discuss example of COP improvements at part load

Example of uncertainty of COP @ 1.4 kW

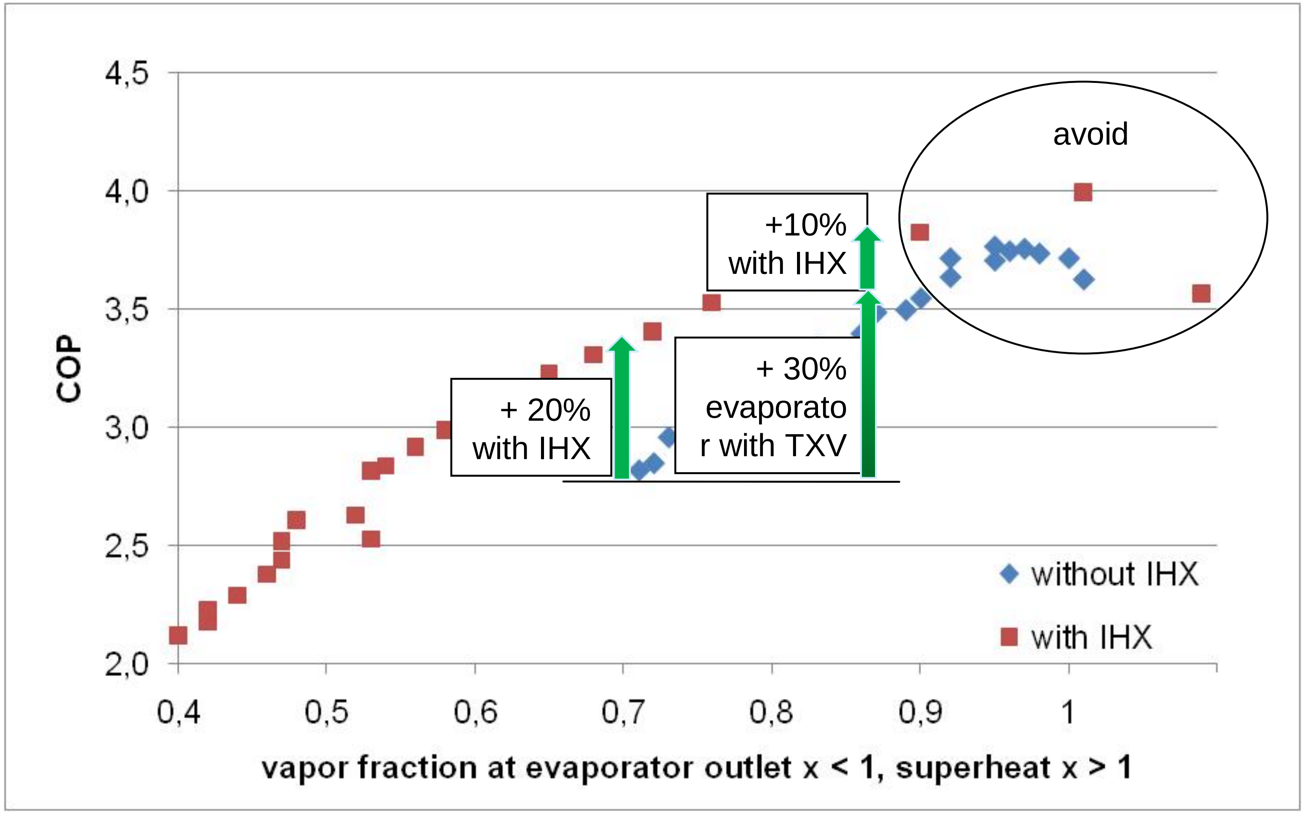


70 -90% vapor mass fraction (quality) can be typical @ part load (superheat @ full load)

→ Mean error small enough to distinguish effects

further improvement possible

Discussion of COP improvement @ 1.4 kW



70 - 90% vapor mass fraction (quality) can be typical @ part load (superheat @ full load)

25% COP improvement (→ 20% fuel reduction) possible

Conclusions

- Compressor is mostly operated in part load. Most energy is consumed there.
- Low mean errors are necessary to accurately determine COP in part load, which is important for LCCP determination
- Contribution of IHX to COP improvement can be significant
- COP improvement with IHX decreases dramatically with more efficient evaporator-TXV baseline (higher vapor quality)
- COP improvement of 25% possible, that is 20% fuel reduction