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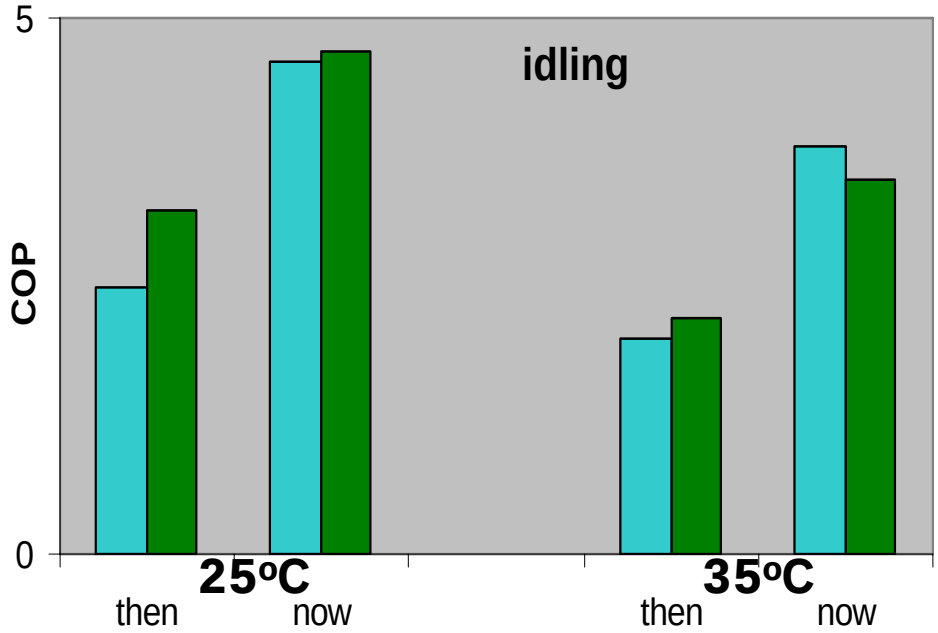
Improvement options for CO_2 and R134a systems

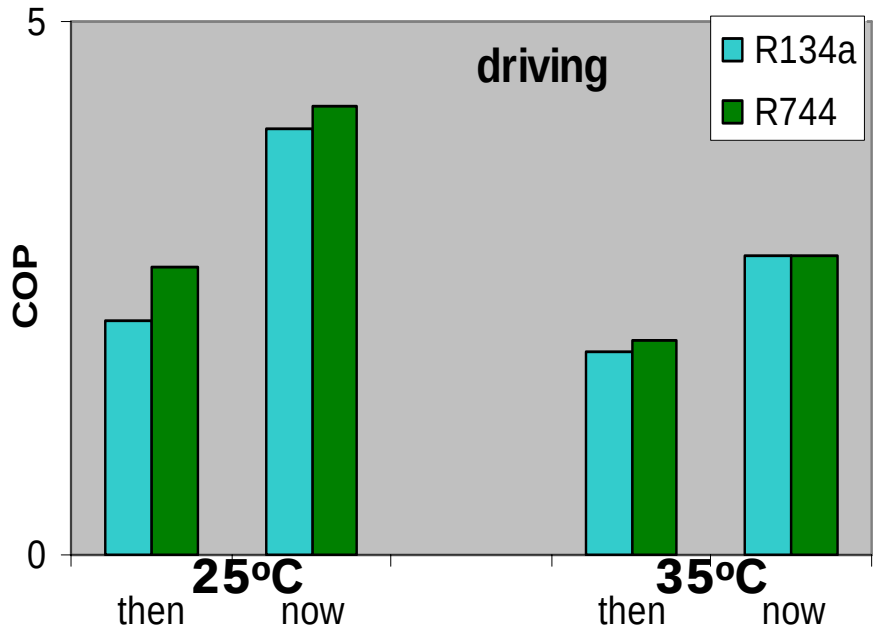
achievements and potentials of efficiency increase

Pega Hrnjak
pega@uiuc.edu
Res. Professor, Co-Director ACRC
University of Illinois, Urbana-Champaign, USA

Let's summarize

MAC efficiency over last ten years

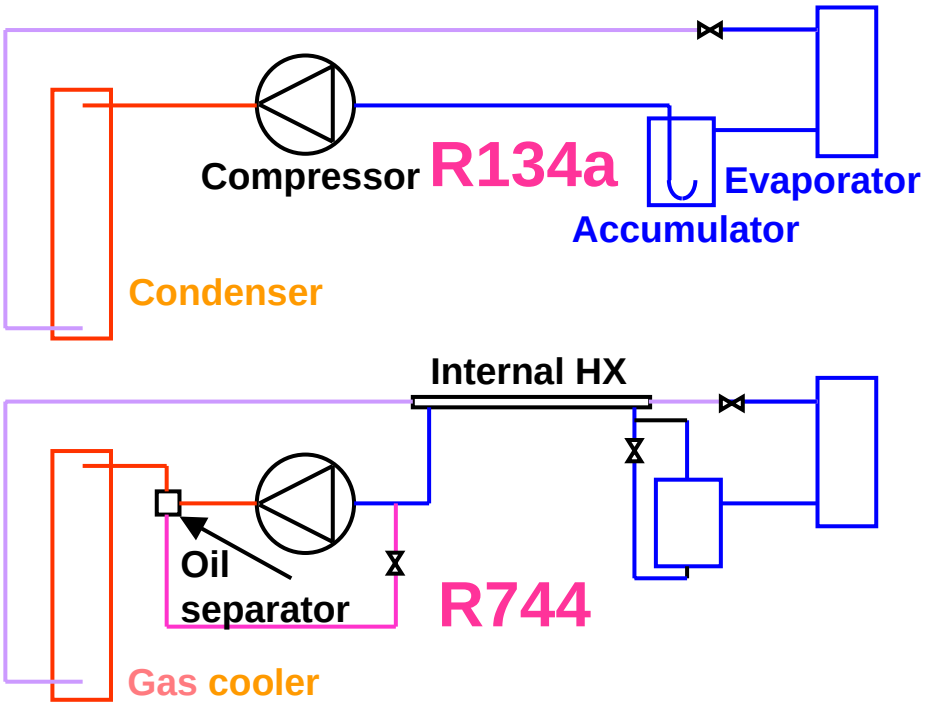


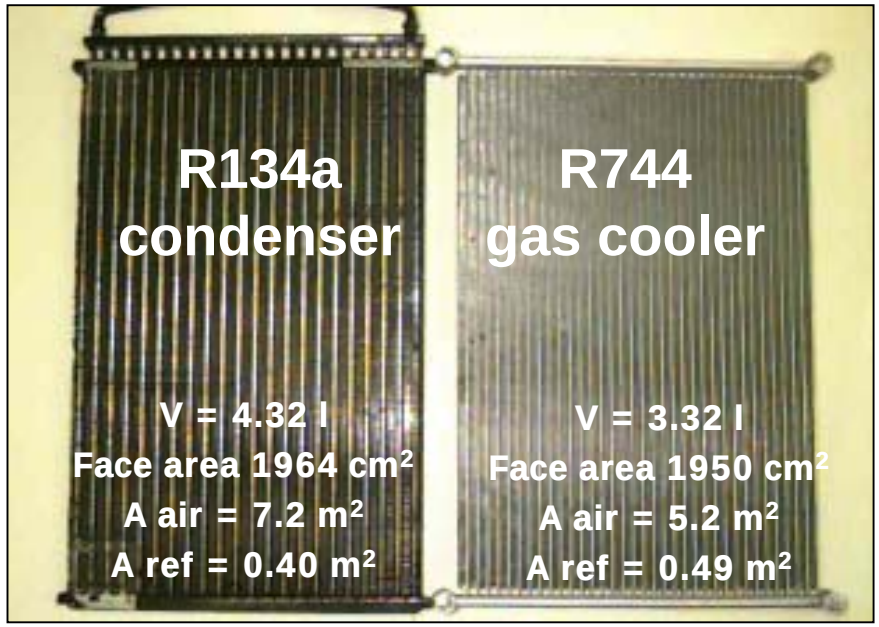


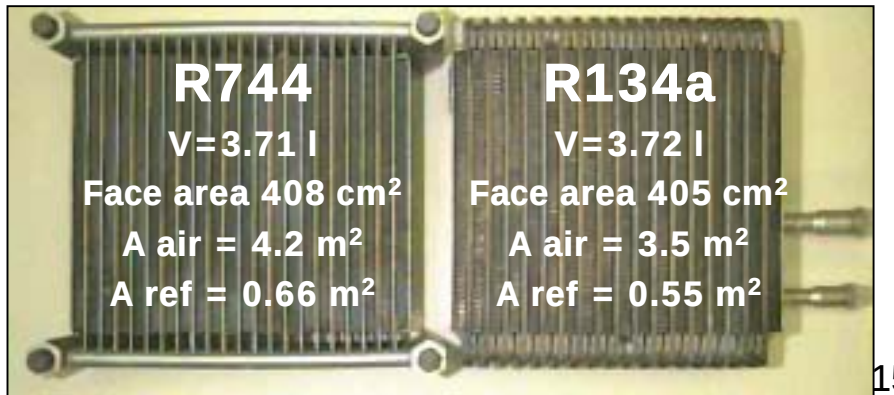
Improvement of efficiency for each system over 10 years at any condition is greater than the difference in system efficiency at any given time.

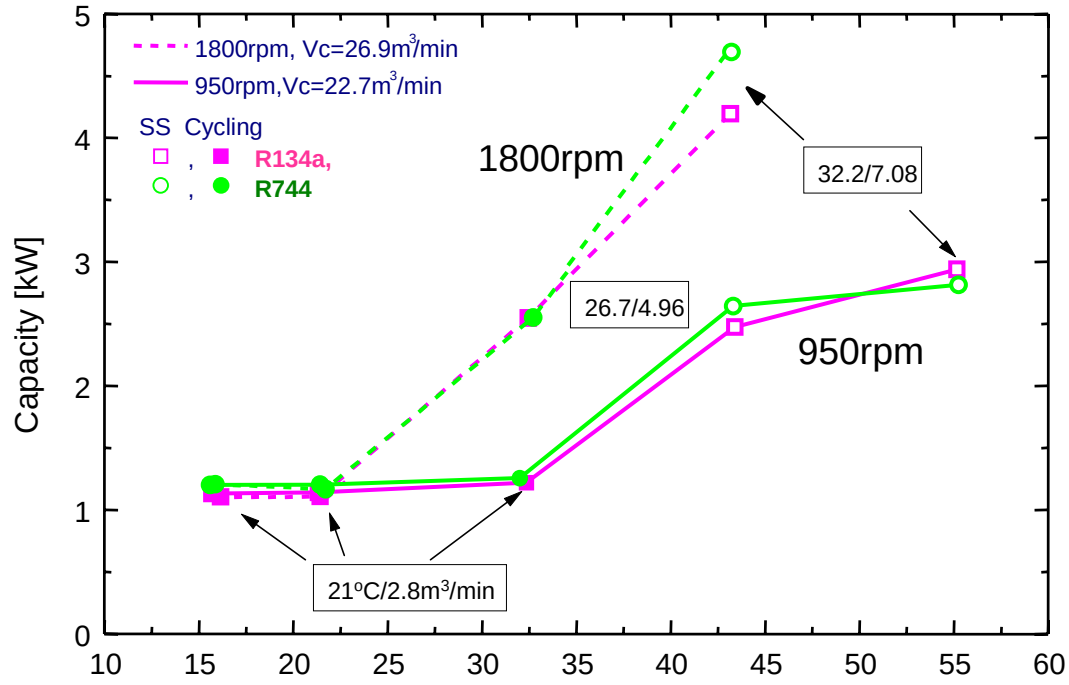
Mobile a/c system 1996

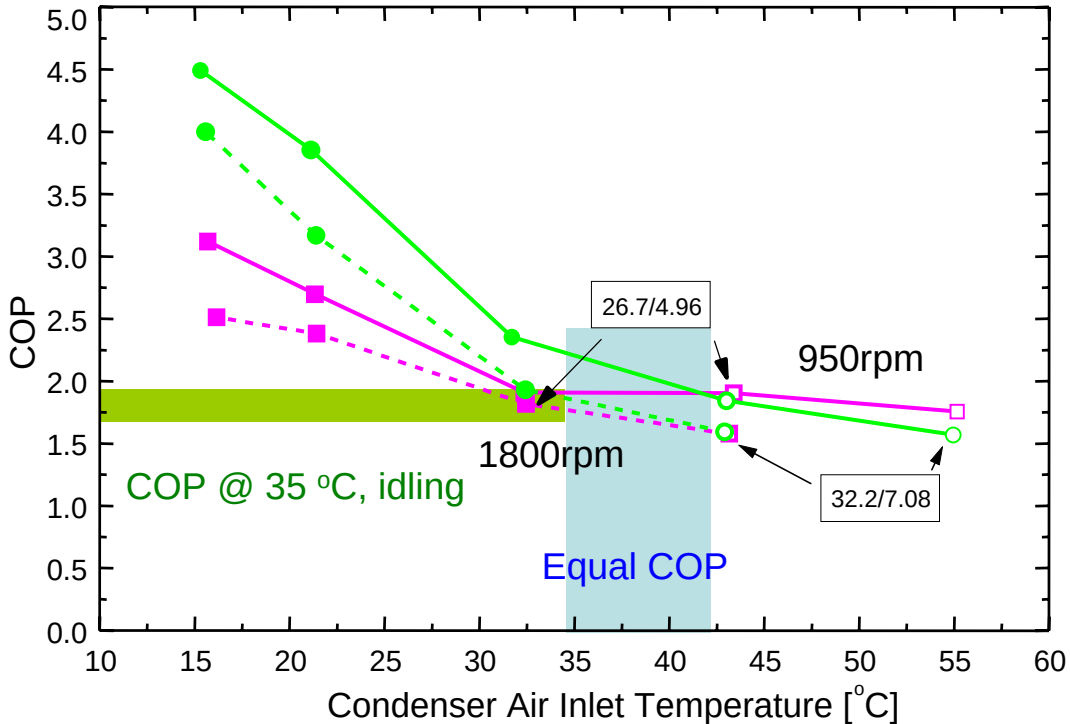
same HX shape, V, DP_{air}, face area, same conditions











Results

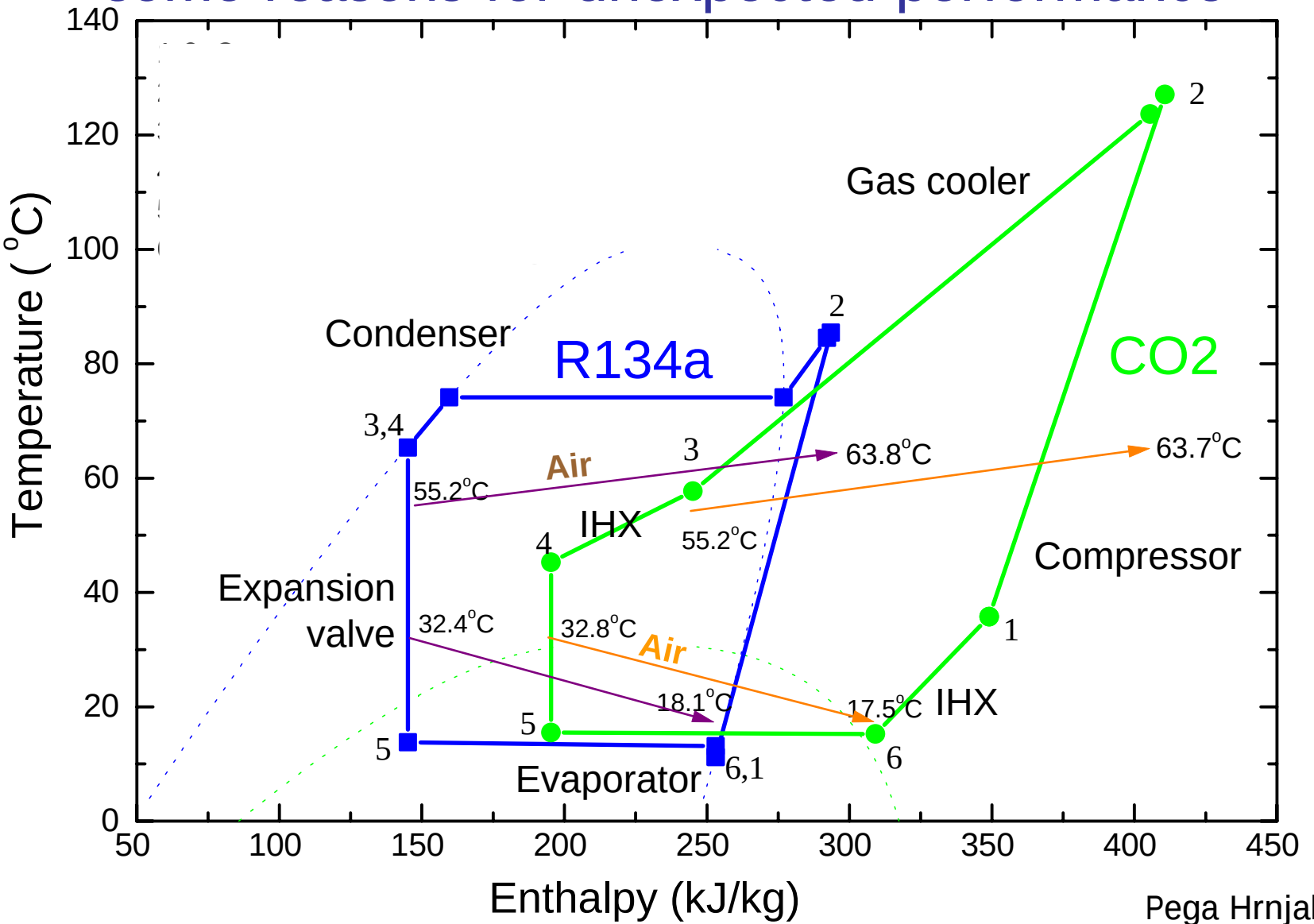
Very similar performance

R134a slightly more efficient at high ambient temperatures

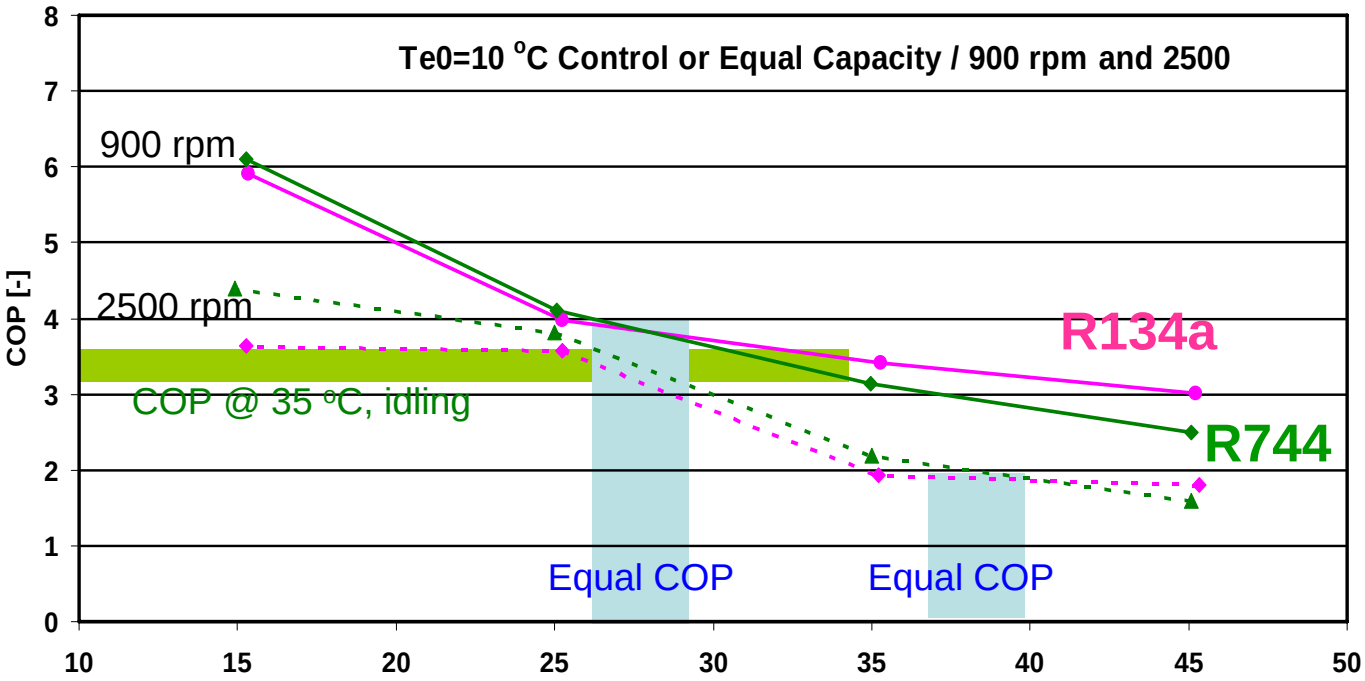
R744 more efficient at medium and lower ambient temperatures

Cycle comparison

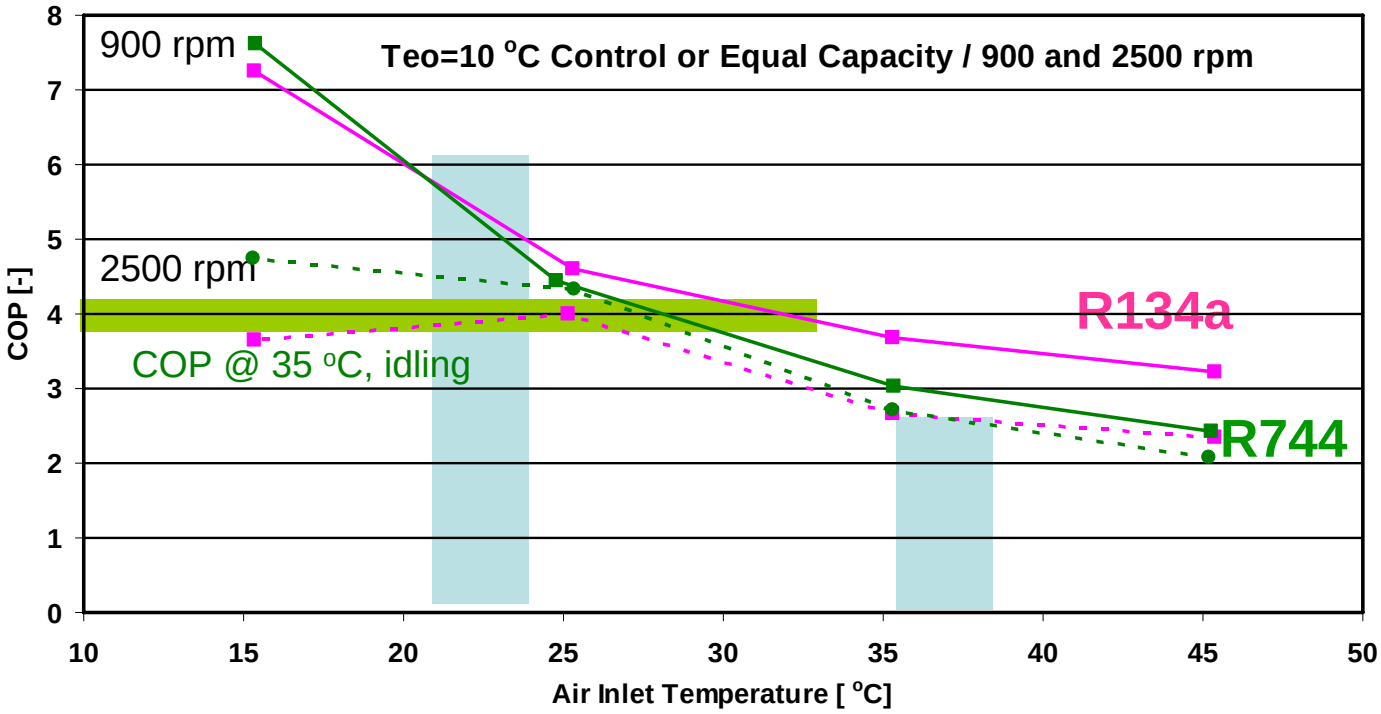
some reasons for unexpected performance



SAE AR CRP



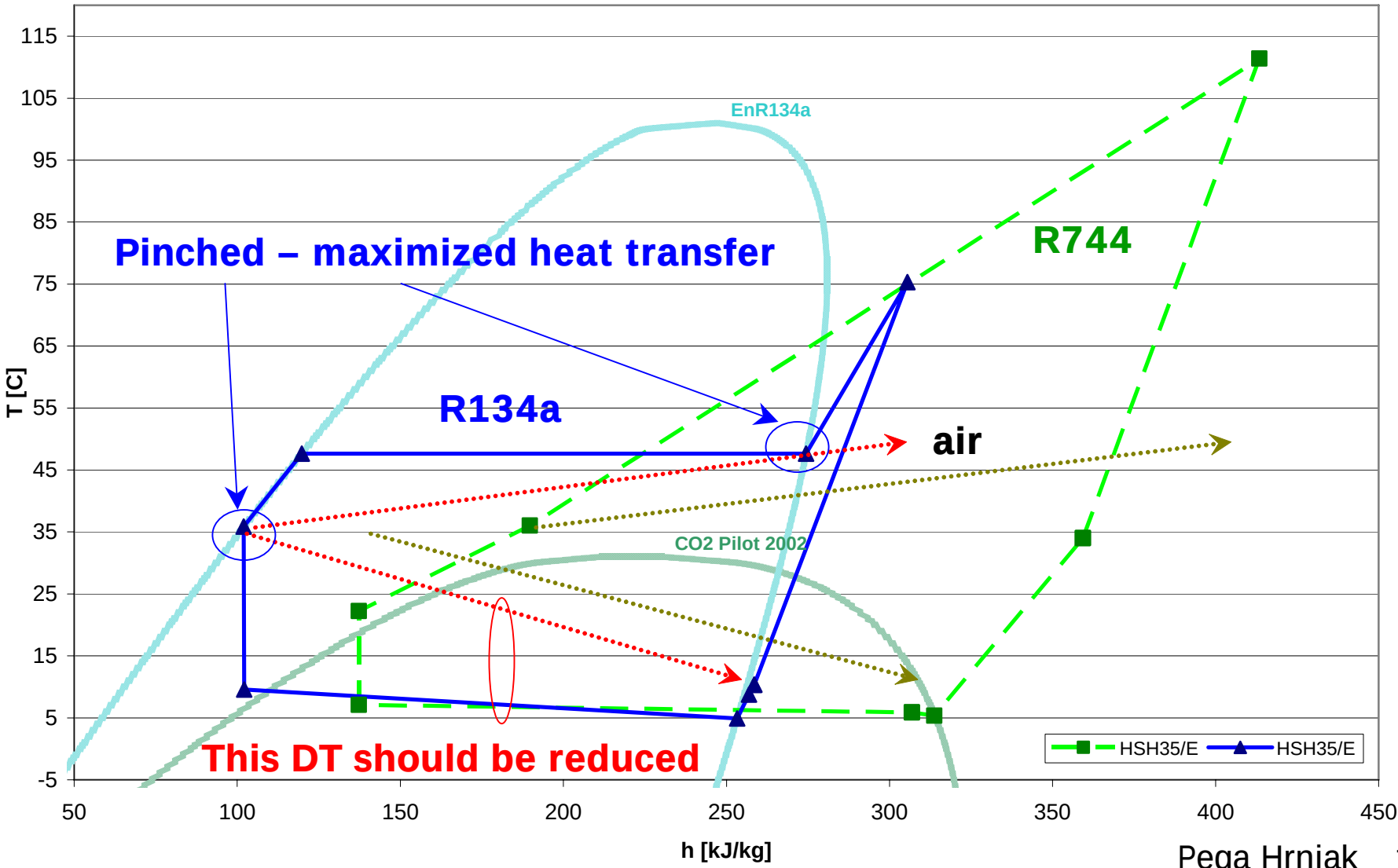
2000



2002

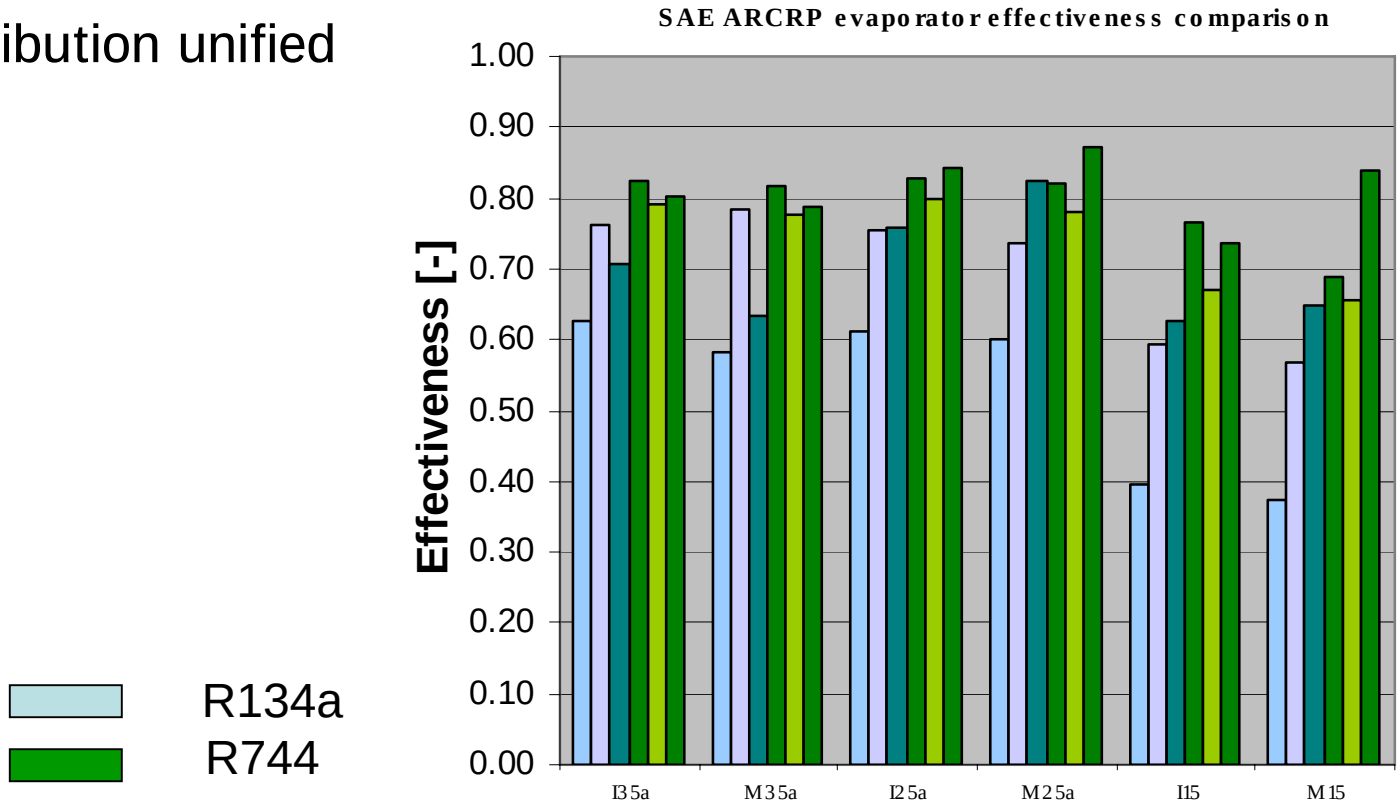
2004

Improved systems indicate:



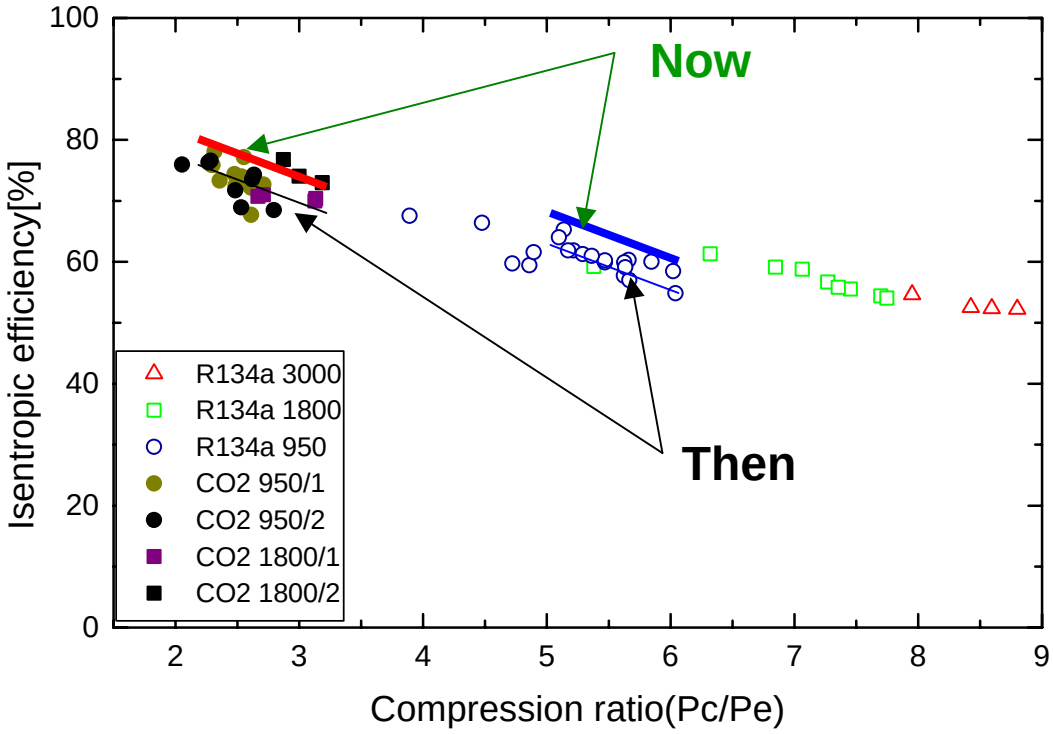
Every element was improved

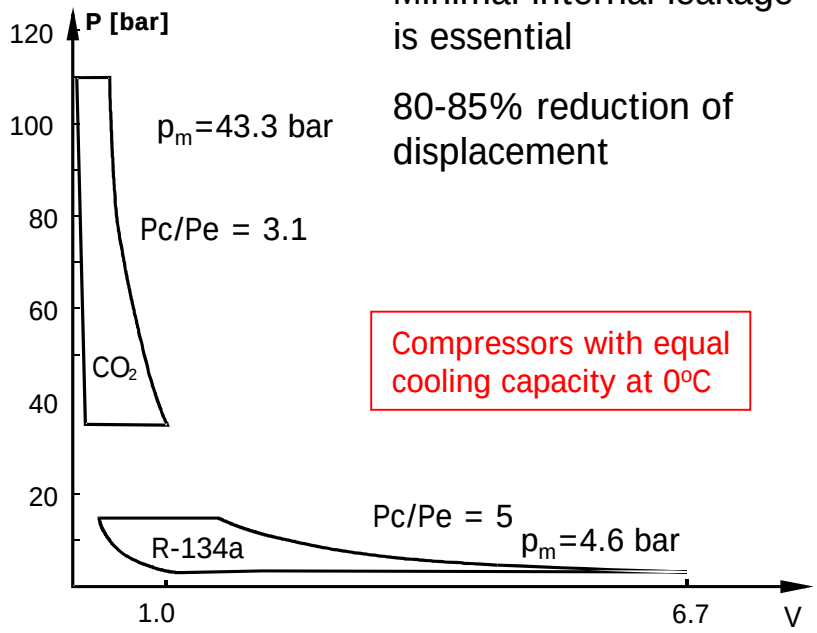
- Evaporators
  - from drawn cup to microchannel
  - improved air side heat transfer and condensate management
  - distribution unified



Compressors

Lower pressure ratio gives higher efficiency





High mean effective pressure (p_m) reduces importance of valve pressure losses

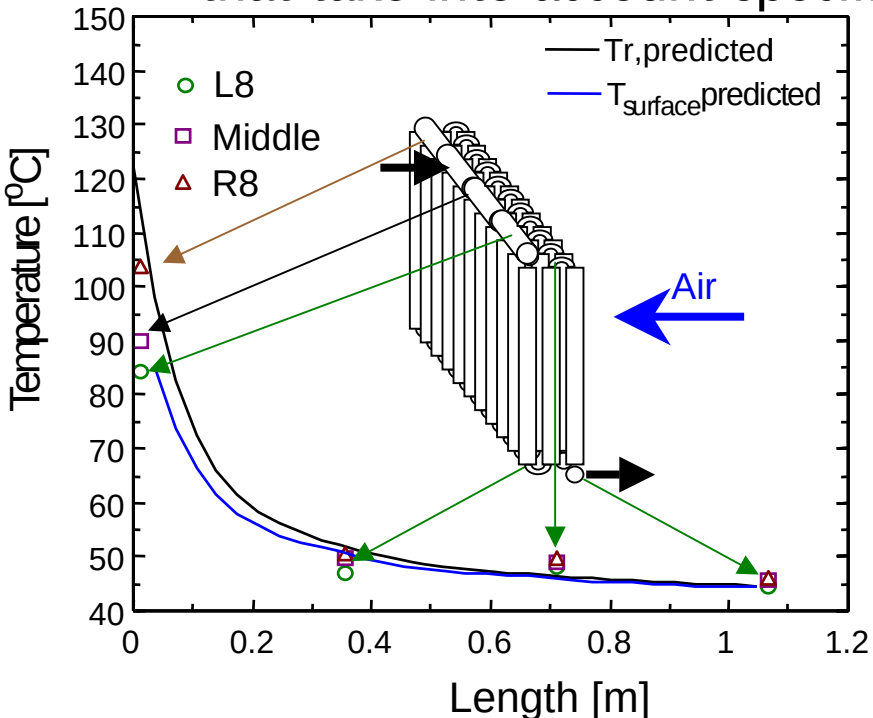
Minimal internal leakage is essential

80-85% reduction of displacement

Compressors with equal cooling capacity at 0°C

Heat rejecting coils

- Condensers
  - Significantly improved by air side enhancements
- Gas coolers
  - Approaching DT=0.5°C vs. typically significantly higher in condensers (5-7°C) and LMTD (15-25°C)
  - Major improvements by counterflow design and other details that take into account specifics of R744



Potential for further size reduction

Engineers currently agree

- R134a system is less expensive (in mass production)
- R134a is more efficient at higher ambient temperatures, R744 at lower
- Current R744 systems provide more capacity in the same HX size and smaller compressor displacement
- R744 is better for heat pumping
- Cycle improvements seems to be les costly in R134a than in R744 (to reach ideal Evans-Perkins cycle COP)
- Thermophysical properties are generally better for R744. But, air side resistance dominates

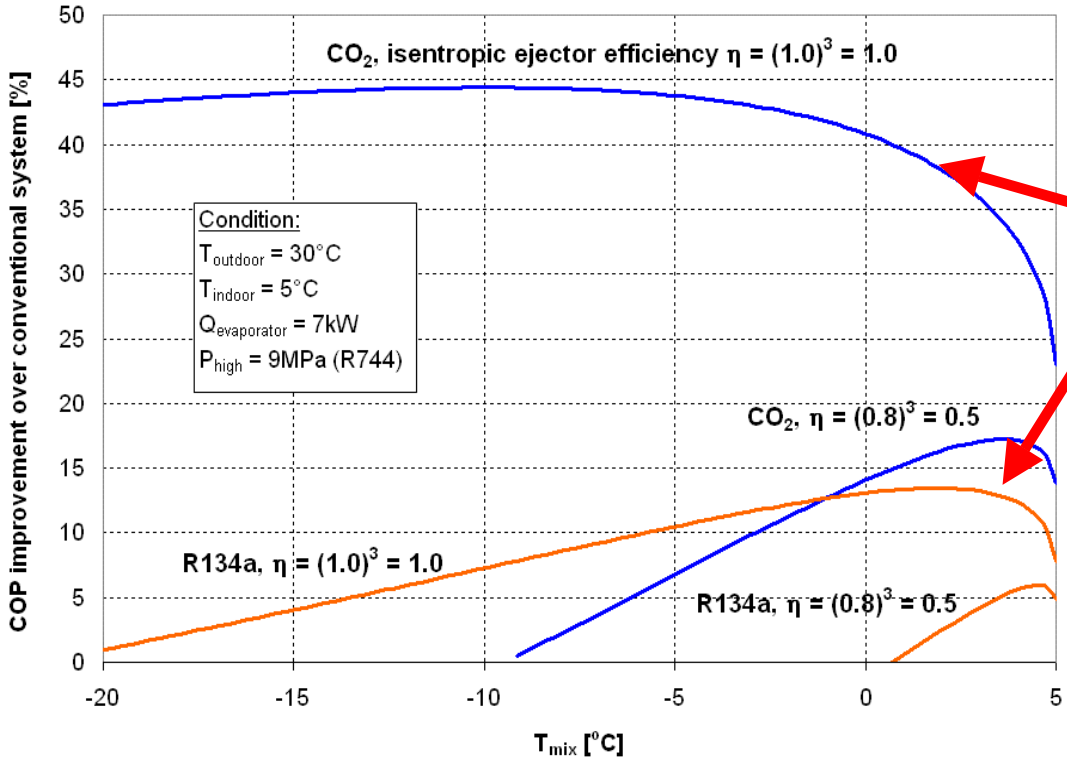
Open questions

- Which operating condition is more important
- Can R744 system be lighter that R134a?

  (pressures are higher but sensitivity to pressure drop is lesser)
- Will 134a system always be less costly than 744 system?

Known potential improvements

- R134a
  - add Internal Heat Exchanger
  - improve components:
    - Evaporator and condenser
    - Compressor
- R744
  - add work recovery
    (much greater potential than in R134a):
    - expanders
    - ejectors
  - Other ways of subcooling
  - Improve components



Ejector

Max. COP improvement 44% (CO_2) vs. 13% (R134a).
Ejector is much more beneficial to CO_2 systems!
However, key is to build highly efficient ejectors.

- A major supplier reported at 2005 SAE meeting 40% improvement! (have not specified baseline)

- We achieved in our lab 11% COP and 8% capacity simultaneously – over the system with internal heat exchanger (reported yesterday).
- Working further!

To conclude

- R744 appeared to be lost cause based on cycle analysis despite superior thermophysical properties
- Challenge created great technological push and R744 is accepted to be at least comparable
- Some technologies developed for R744 transferred to R134a
- Despite R&D investment companies that invested in R744 development are healthy
- Competition pushed development in R134a (IMAC example)

Goal already achieved!

- **Efficiency of both systems almost doubled in last ten years!**
- **Energy saving greater than total R&D spending?**

What to expect soon?

- R134a will improve COP significantly: 20 – 40%
  (IMAC and other drivers)
  - Internal Heat Exchanger (lower potential than in R744)
  - Better components
  - Work recovery? (lower potential than in R744)
- R744 potentials are real
  - Work recovery (10-45%), achieved 16%
  - Improved components
- R744
  - Gas cooler will push toward smaller size and shape easier to fit