Consequences of the Newest Improvements in R-744 Systems

Automotive Alternate Refrigerant Systems Symposium

Scottsdale AZ, July 2003

Jostein Pettersen

Norwegian University of Science and Technology – NTNU

Trondheim – Norway

Petter Nekså

SINTEF Energy Research, Trondheim - Norway

with input and support from:

Audi, BMW, DaimlerChrysler, Denso, LuK, Modine,

Obrist Engineering, Shecco Technology, U of Illinois, Visteon

SAE® NTNU SINTEF

Overview

- Improvements in R-744 system design since SAE AR CRP testing
- Performance of enhanced HFC-134a vs 2002 R-744 system, using SAE AR CRP test matrix
- Comparison of Life Cycle Climate Performance (LCCP) and seasonal energy use
- Some comments
- Conclusion and suggestions

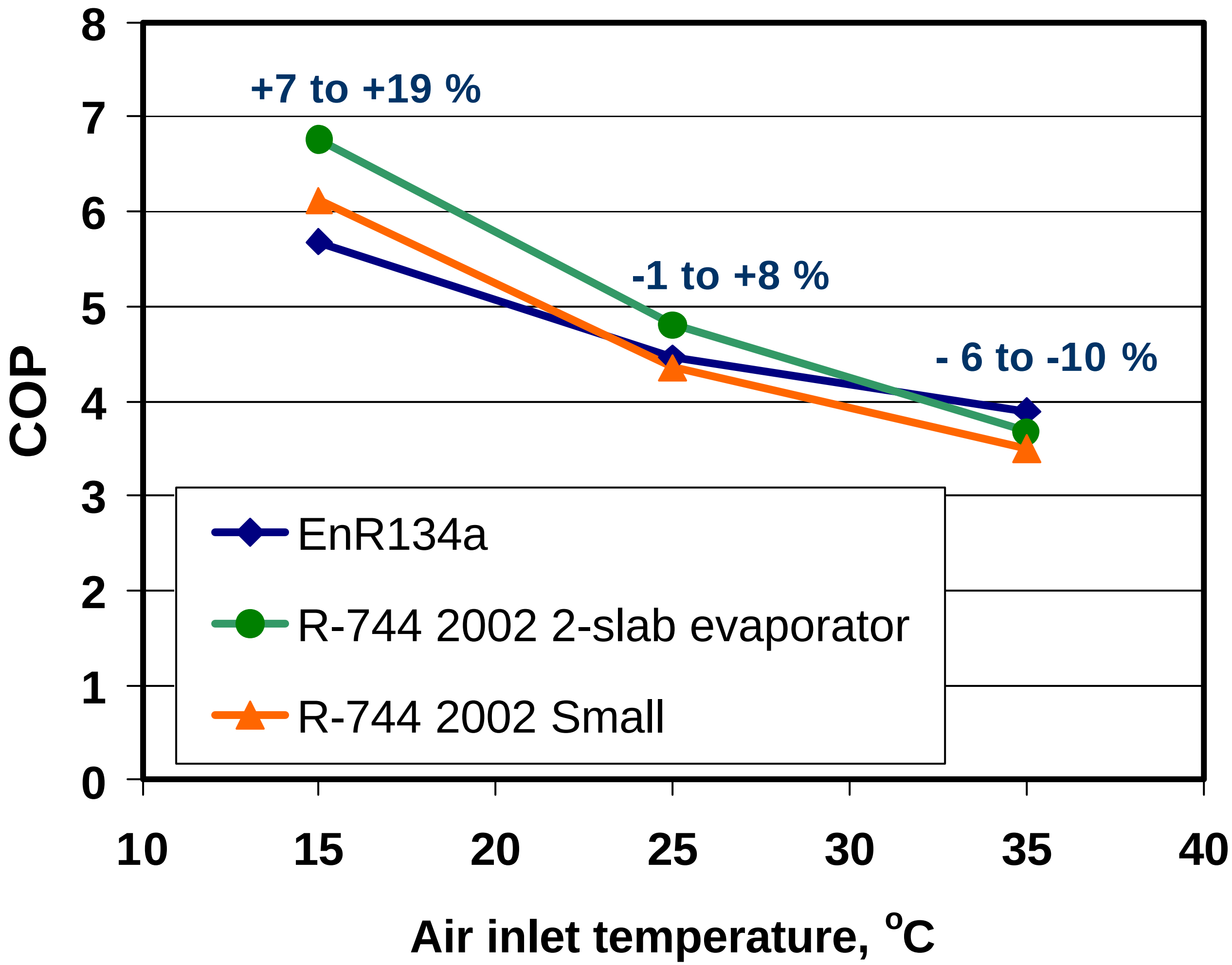
Summary of R-744 system improvements

- Improved COP:
  - More efficient evaporator
  - Reduced gas cooler temperature approach
  - Improved compressor efficiency

- More compact heat exchangers:
  - Evaporator core volume 76 % of enhanced HFC-134a (1-slab R-744)
  - Gas cooler core volume 90 % of enhanced HFC-134a condenser
  - Gas cooler face area 69 % of enhanced HFC-134a condenser

COP data 900 rpm (idling, 20% of the usage)
5°C air from evaporator or equal capacity

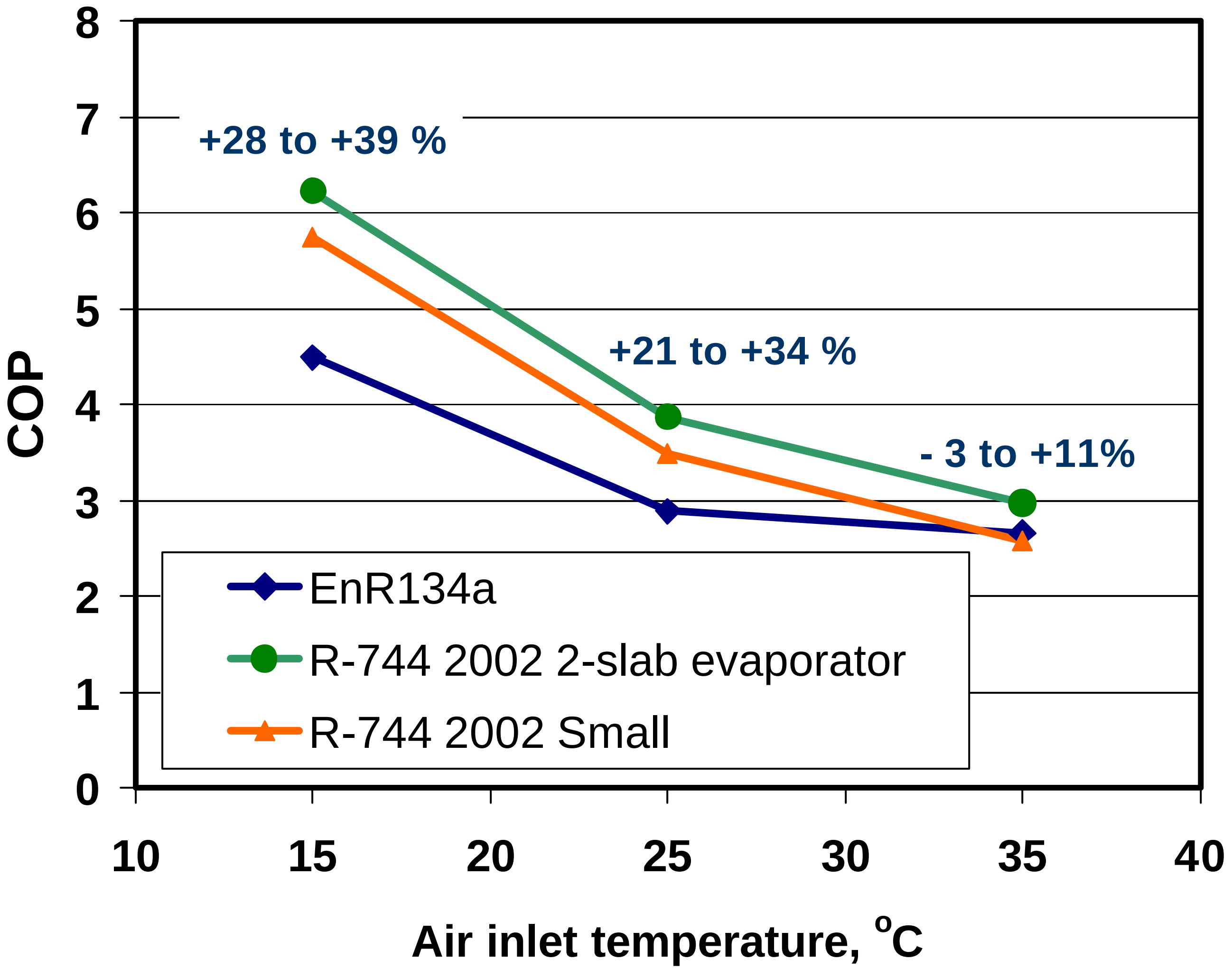
HFC data from SAE AR CRP (2002), R-744 data from Hrnjak (2003)



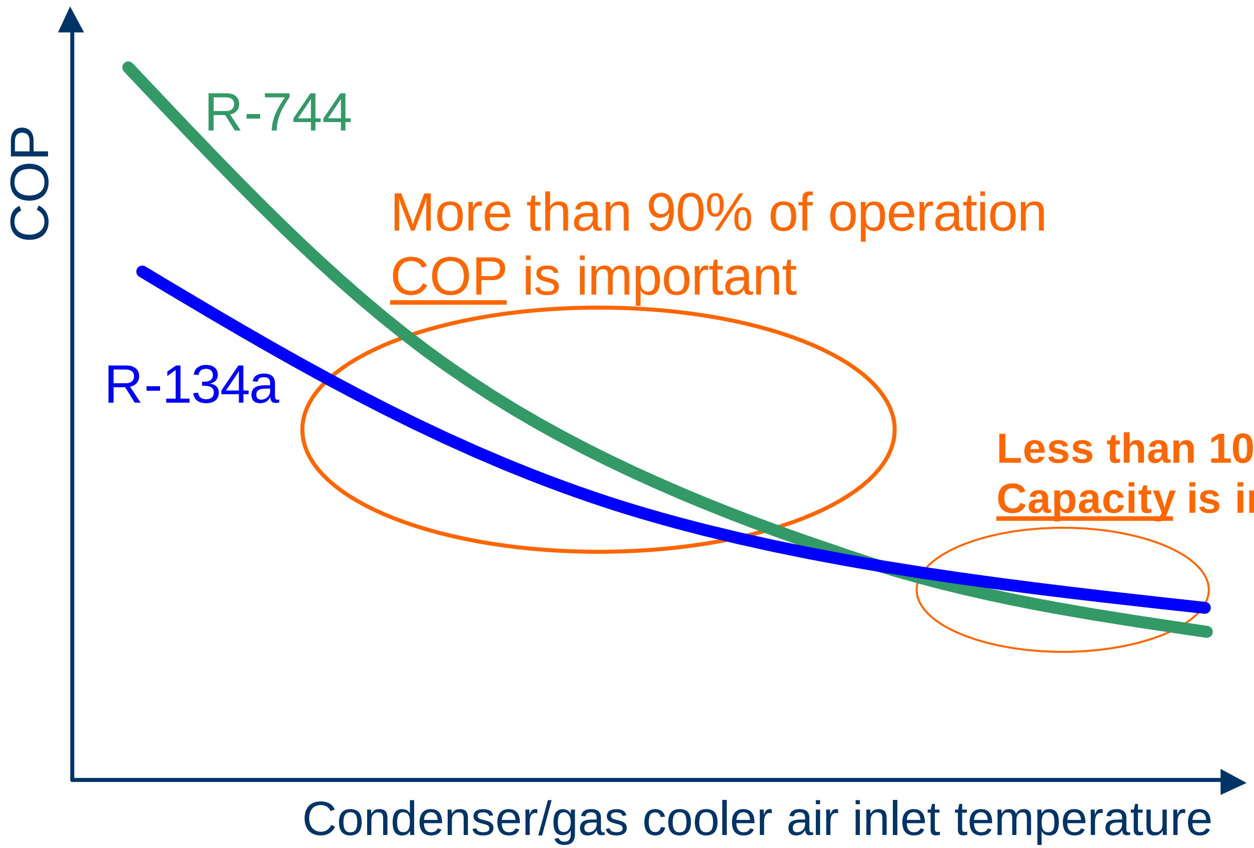
SAE® NTNU SINTEF

COP data 2500 rpm (driving, 80% of the usage) 5°C air from evaporator or equal capacity

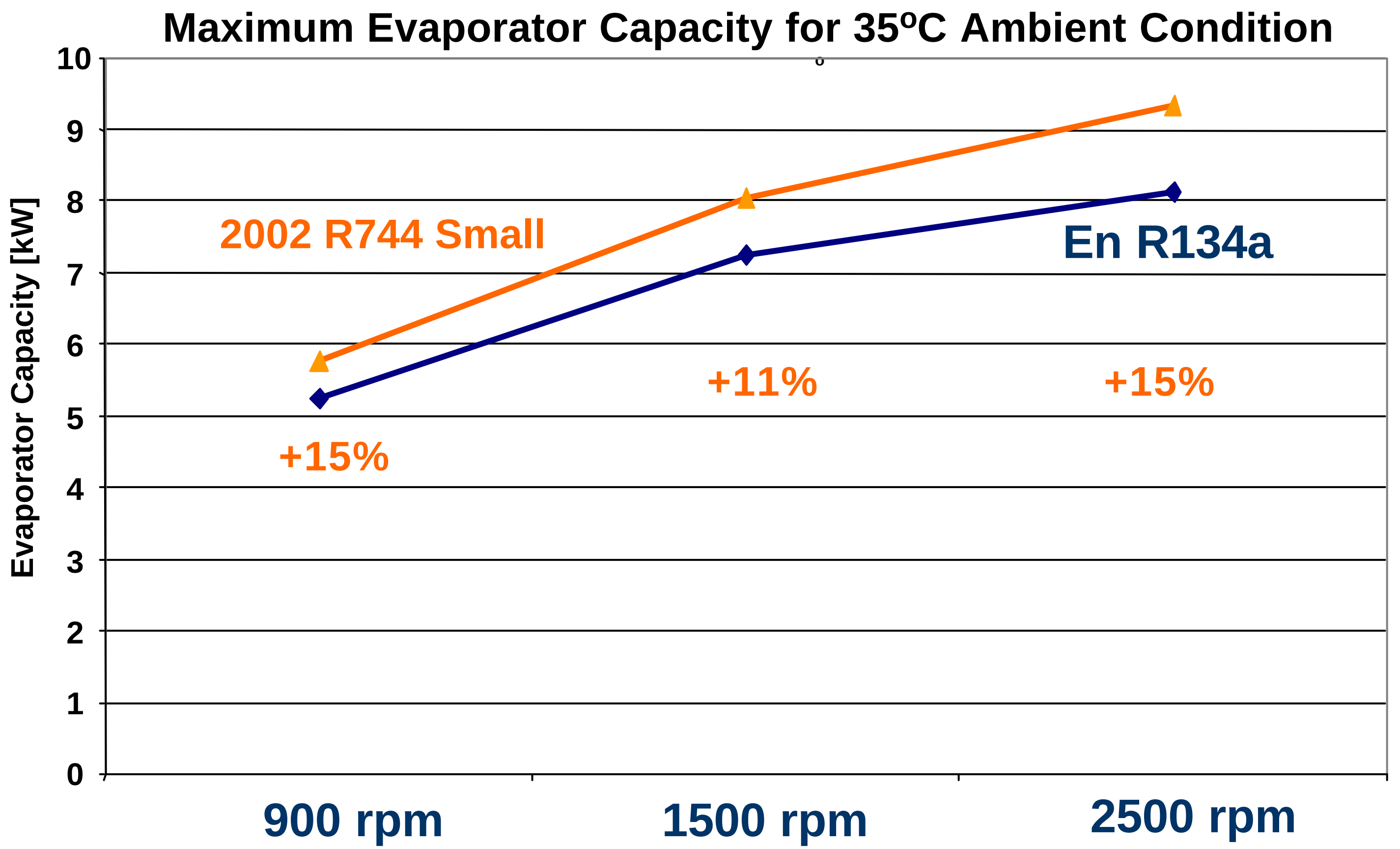
HFC data from SAE AR CRP (2002), R-744 data from Hrnjak (2003)



Typical efficiency at varying condenser/gas cooler air inlet temperature



What if R-744 system is allowed to operate with <u>max capacity</u> at high ambient?



Even with the smaller evaporator, R-744 capacity is superior to En R134a

SAE® NTNU SINTEF

Summary of test results

- R-744 COP is equal or better than R-134a at most relevant temperatures
- Significant improvement in COP at the dominant conditions: Moderate temperature and higher rpm
- Because R-744 gives higher maximum capacity, we achieve faster pulldown at warm ambient

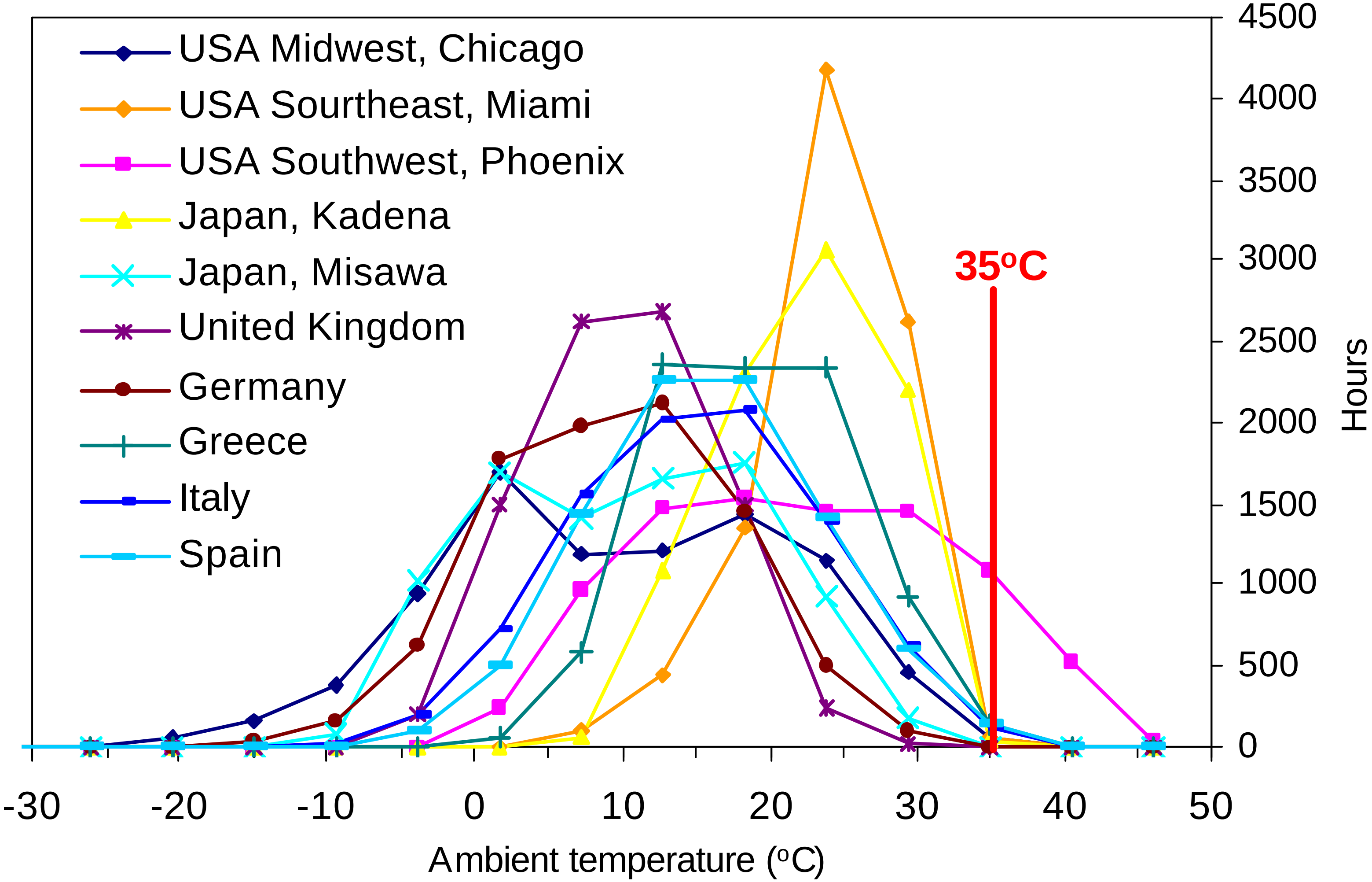
Simplified LCCP analysis – assumptions (1)

- Compressor power from
  - SAE AR CRP data for enhanced HFC-134a (SAE ARCRP, 2002)
  - 2002 R-744 Pilot Project data from Hrnjak (2003) – Small system
- Driving/idle cycle 80/20%. Total hours with AC system on based on climate data and usage profiles from Sand et al. (1997), and Duthie et al. (2003)
- R-744 system 1.6 kg heavier than HFC-134a system
  - Current prototypes show less weight difference than this
  - Fuel use due to transportation of AC system was taken from (AFEAS, 1991)

Simplified LCCP analysis – assumptions (2)

- Direct HFC-134a emission data per vehicle based on:
  - Controlled losses (Schwartz and Harnisch, 2003) of 53 g/yr, plus estimate for uncontrolled losses from Öko-Recherche of 16 g/yr, plus estimate for service losses 10 g/yr: **total 80 g/yr**
  - Achievable total controlled losses of 35 g/yr suggested by Fernqvist (2003), plus uncontrolled and service losses: **total 60 g/yr**
  - End-of-life recovery 80%
- Production of HFC-134a gives emissions of 77 kg CO_2-equivalents per kg HFC (Campbell and McCulloch, 1998)

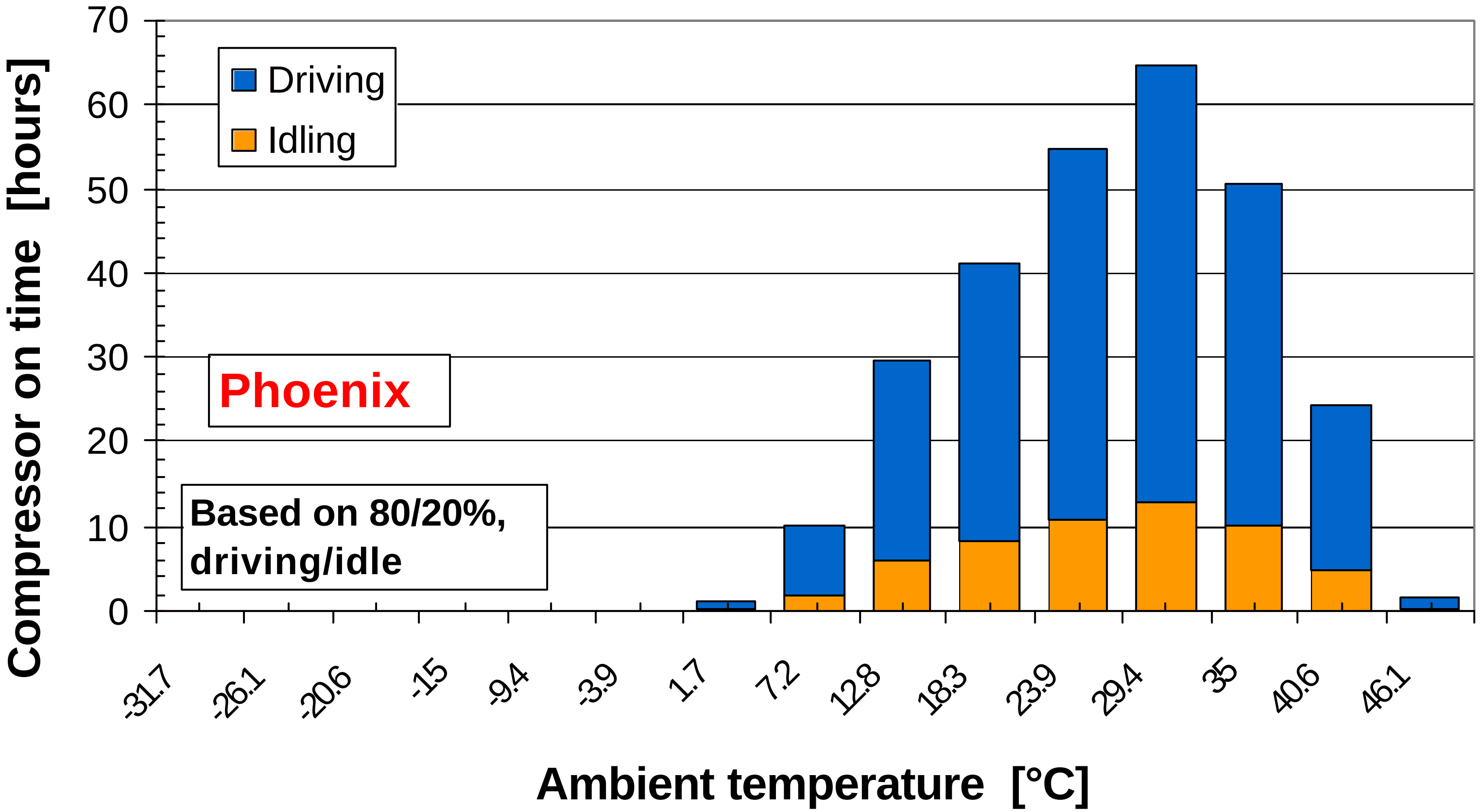
Temperature bin data (Sand et al. 1997)



Temperatures above 35ºC hardly ever occurs

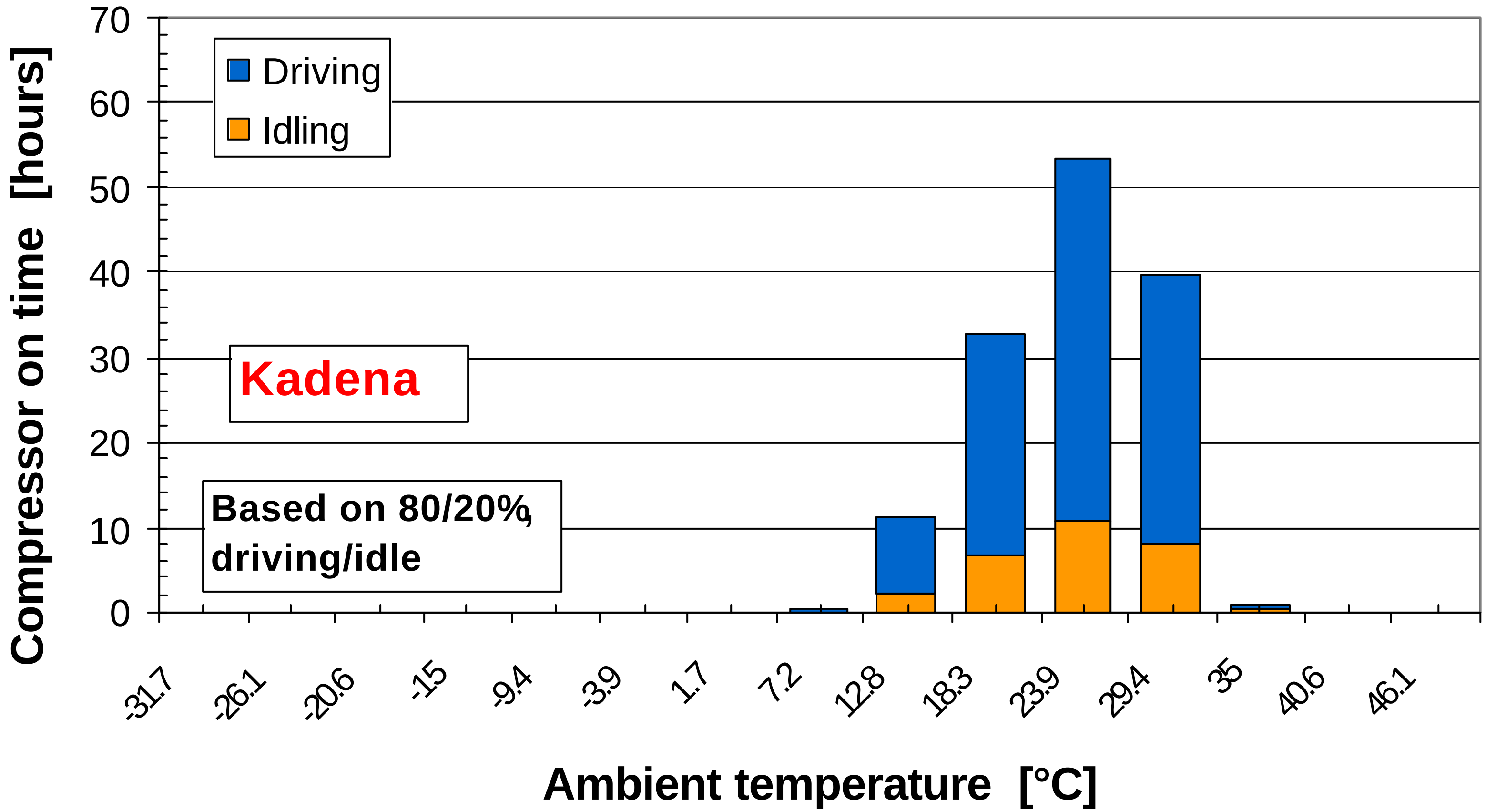
AC system usage profile (Phoenix)

Total AC operating hours - 278 of 410



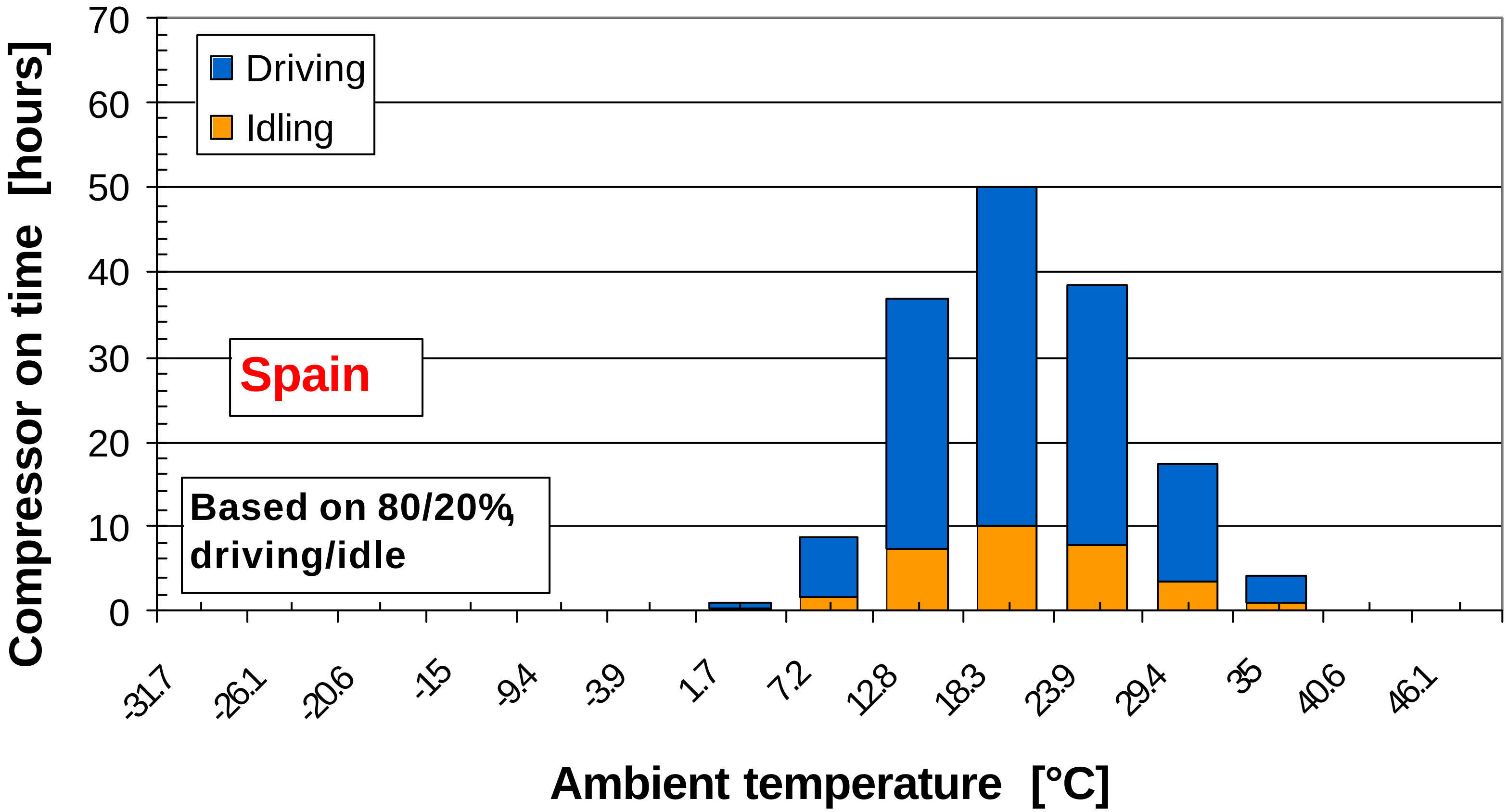
AC system usage profile (Kadena - Japan)

Total AC operating hours – 138 of 160



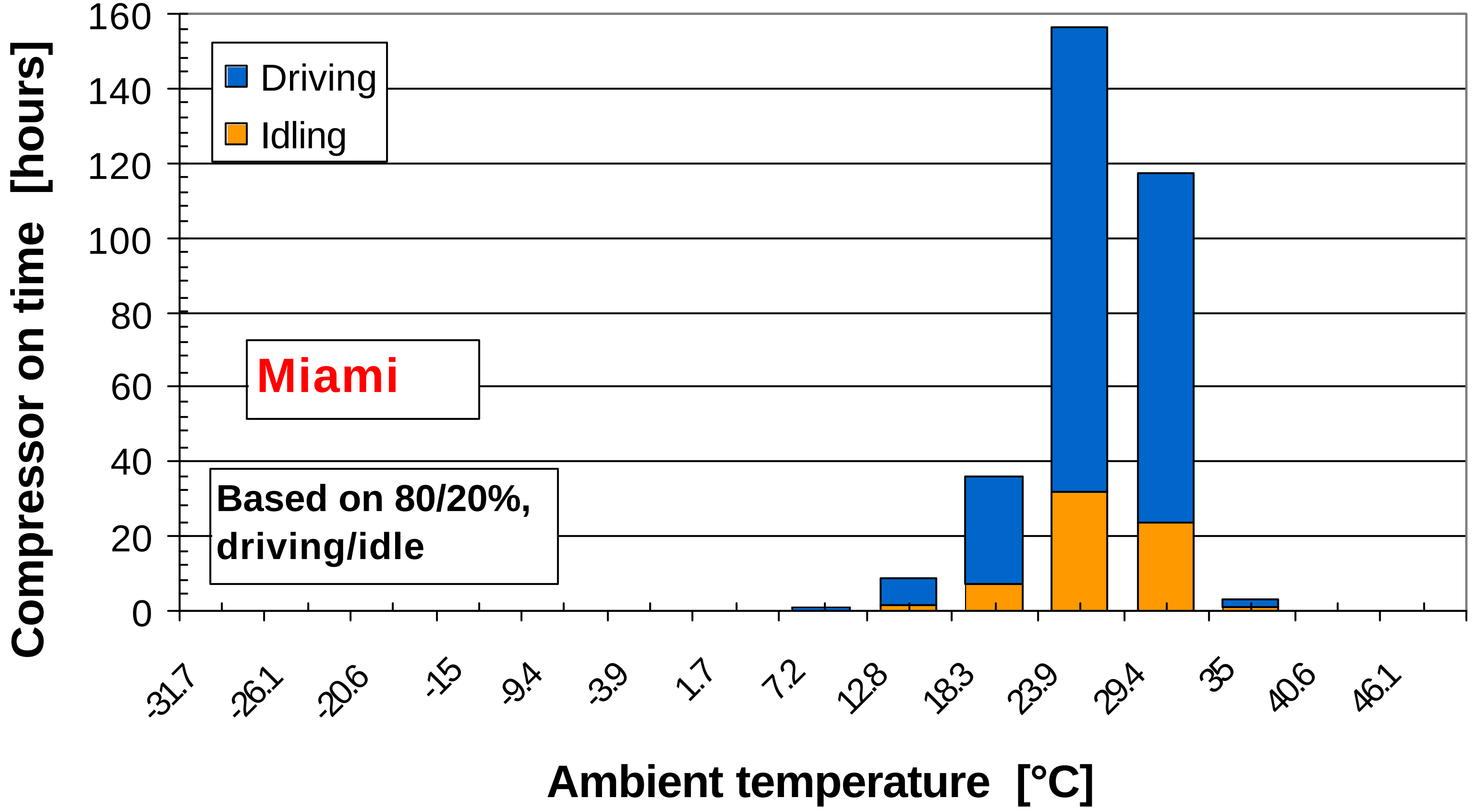
AC system usage profile (Spain)

Total AC operating hours – 157 of 250



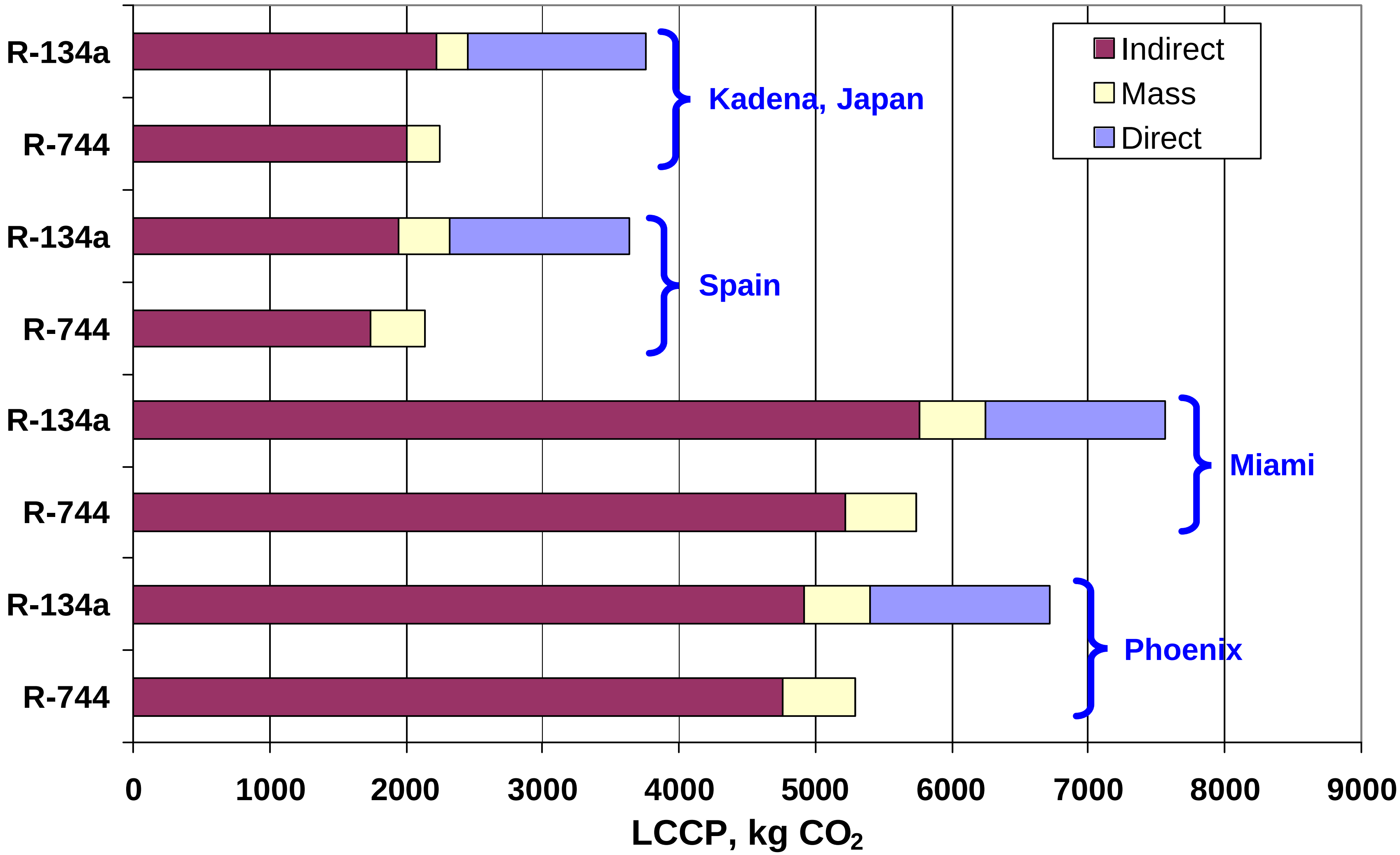
AC system usage profile (Miami)

Total AC operating hours – 322 of 410



LCCP Comparison

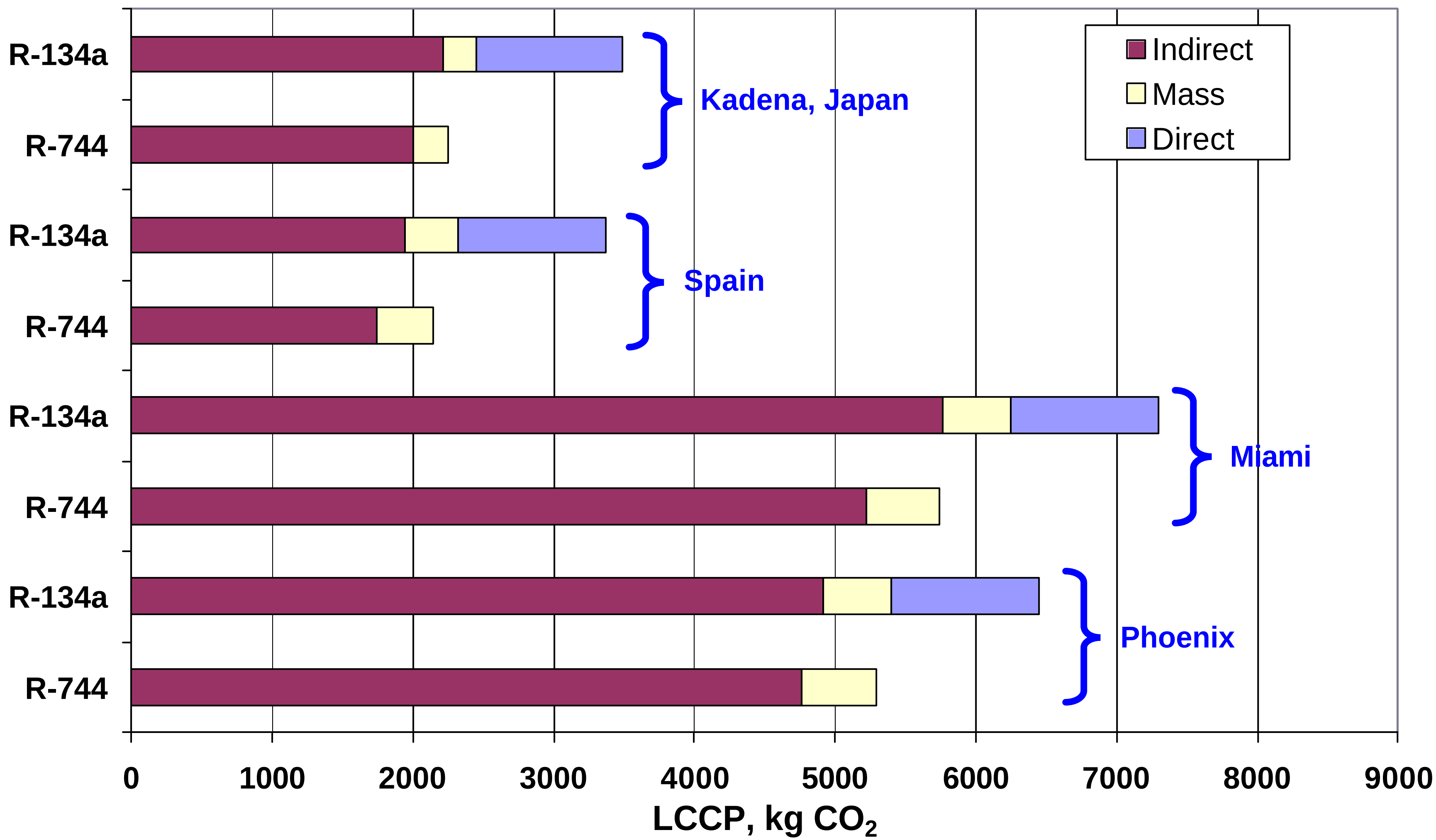
R134a leakage: 80 g/year



SAE NTNU SINTEF

LCCP Comparison

R134a leakage: 60 g/year



SAE NTNU SINTEF

LCCP and energy use: Summary and comments

- Results based on small 2002 R-744 system show
  - 20 to 40 % reduction in LCCP
  - About 10 % reduction in energy (fuel) use in Spain, Japan, Miami
  - About 3 % reduction in energy (fuel) use in Phoenix
- Energy use would be even lower with the ”full-size” R-744 evaporator
- Heat pump operation not included in analysis
- HFC-134a system has better COP only at conditions that seldom occurs. These conditions do not matter for energy (fuel) use

These good results were achieved even though conditions were difficult for R-744

- Very good baseline in SAE Enhanced HFC-134a system:
  - Extremely high COP
  - Large heat exchanger sizes
  - Condenser with high air flow rate and low refrigerant-side pressure drop
- Limited focus of test program:
  - Focus on very high ambient temperature conditions
  - Focus on COP data at high ambient, instead of seasonal comparison of energy use
  - No test points above 2500 rpm
- Unfortunate R-744 compressor sizing:
  - Large displacement giving significant part-load losses

Conclusion

- The test data have reconfirmed that COP is no argument against R-744
- Fuel use of R-744 system is significantly lower than with HFC-134a, even in the warm climates considered here
- LCCP is reduced by 20 - 40% compared to HFC-134a system

- From now on, R-744 should not imitate HFC-134a. Instead, we should develop and compare based on merits of each system

- Let's get started!

References

AFEAS 1991. Energy and Global Warming Impacts of CFC Alternative Technologies, December 1991

Fernqvist, H., 2003. Fuel efficient leak tight HFC-134a systems through design and quality improvements, presented at *MAC Summit*, Brussels, Belgium, February 10-11 2003

Hrnjak, P., 2003. Design and performance of improved R744 System Based on 2002 technology, presented at *SAE Automotive Alternate Refrigerant Systems Symposium*, Scottsdale, Arizona, July 15-17 2003.

Campbell N.J. and A. McCulloch, 1998. The Climate Change Implications of Manufacturing Refrigerants --- A Calculation of Production Energy Contents of Some Common Refrigerants, *Transactions of the Institution of Chemical Engineers*, Vol. 76, Part B, August 1998.

Duthie, G.S., Harte, S. and Jajasheela, 2002. European Average Mobile A/C Customer Usage Model, Visteon Climate Control Group. presented at *SAE Automotive Alternate Refrigerant Systems Symposium*, Scottsdale, Arizona, July 2002.

Memory, S., and Vetter, F., 2003. Automotive AC/HP Systems Using R744 (CO_2), Sixth *Vehicle Thermal Management Systems Conference* (VTMS6), Brighton, UK, May 18-21.

SAE ARCRP, 2002. Alternate Refrigerant Coperative Research Project, Update Report November 2002 http://www.sae.org/technicalcommittees/nov-2002-overview.pdf

Sand, J. R., Fischer, S. K., and Baxter, V. D., 1997. Energy and global warming impacts of HFC refrigerants and emerging technologies, AFEAS/DOE report

Schwartz, W., and Harnisch, J., 2003. Establishing the leakage rates of mobile air conditioners, final report (B4-3040/2002/337136/MAR/C1) prepared by Öko-Recherche and Ecofys for the European Commission (DG Environment), 17 April 2003