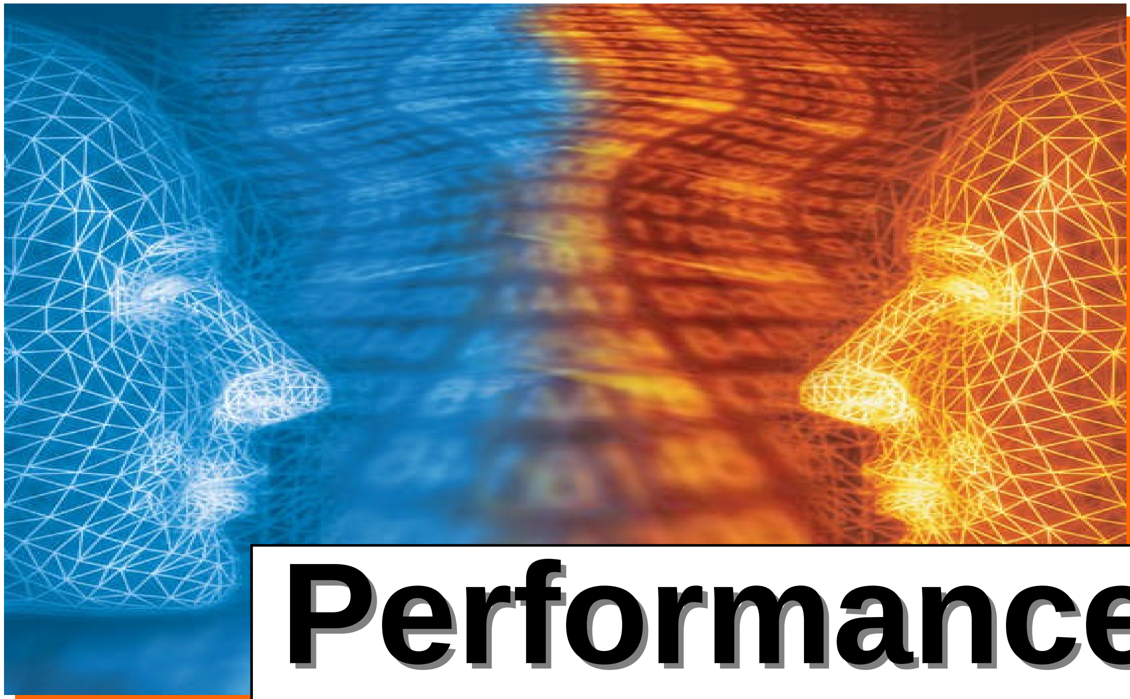

Performance Assessment of NNAs

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Agenda

- Hardware Evaluated
- System tests
  - Baseline R134a
  - "Baseline" NNA
  - NNA with a 580mm IHX
- Test results
  - Capacity
  - Efficiency
- Vehicle fuel consumption
- Next Steps

Experimental Hardware

- Hyundai Accent System – R134a & Fluid H (Plymouth, Michigan)
  - 160 cc internally controlled compressor
  - 16mm IRD condenser
  - TXV (TGK)
  - 45mm plate-fin evaporator
- Ford Mondeo system - R134a, AC-1 & DP-1 (Kerpen, Germany)
  - 160 cc internal controlled compressor
  - 16 mm IRD condenser
  - TXV (Egelhof)
  - 58 mm plate-fin evaporator

System Modifications for Baseline NNA

- Hyundai Accent System (R134a & Fluid H)
  - As demonstrated in Vehicle at 2006 ARSS:
    - Modified 16mm condenser
    - Modified 45mm evaporator
    - Modified TXV (provided by TGK)
    - All new low pressure drop suction line
    - Same compressor
- Ford Mondeo system (R134a, AC-1 & DP-1)
  - Modified TXV
- Same IHX for both: 580mm tube-in-tube

Test matrix

Test	Compressor	Condenser		Evaporator		
	Evolution /rpm	Air flow kg/h	Temp. air in °C	Air flow kg/h	Temp.air in °C	Humidity %
1	2500	2880	45	650	43	40
2	1800	2712	45	650	43	40
3	800	2160	45	650	43	40
4	2500	2880	37	650	35	40
5	1800	2712	37	650	35	40
6	800	2160	37	650	35	40

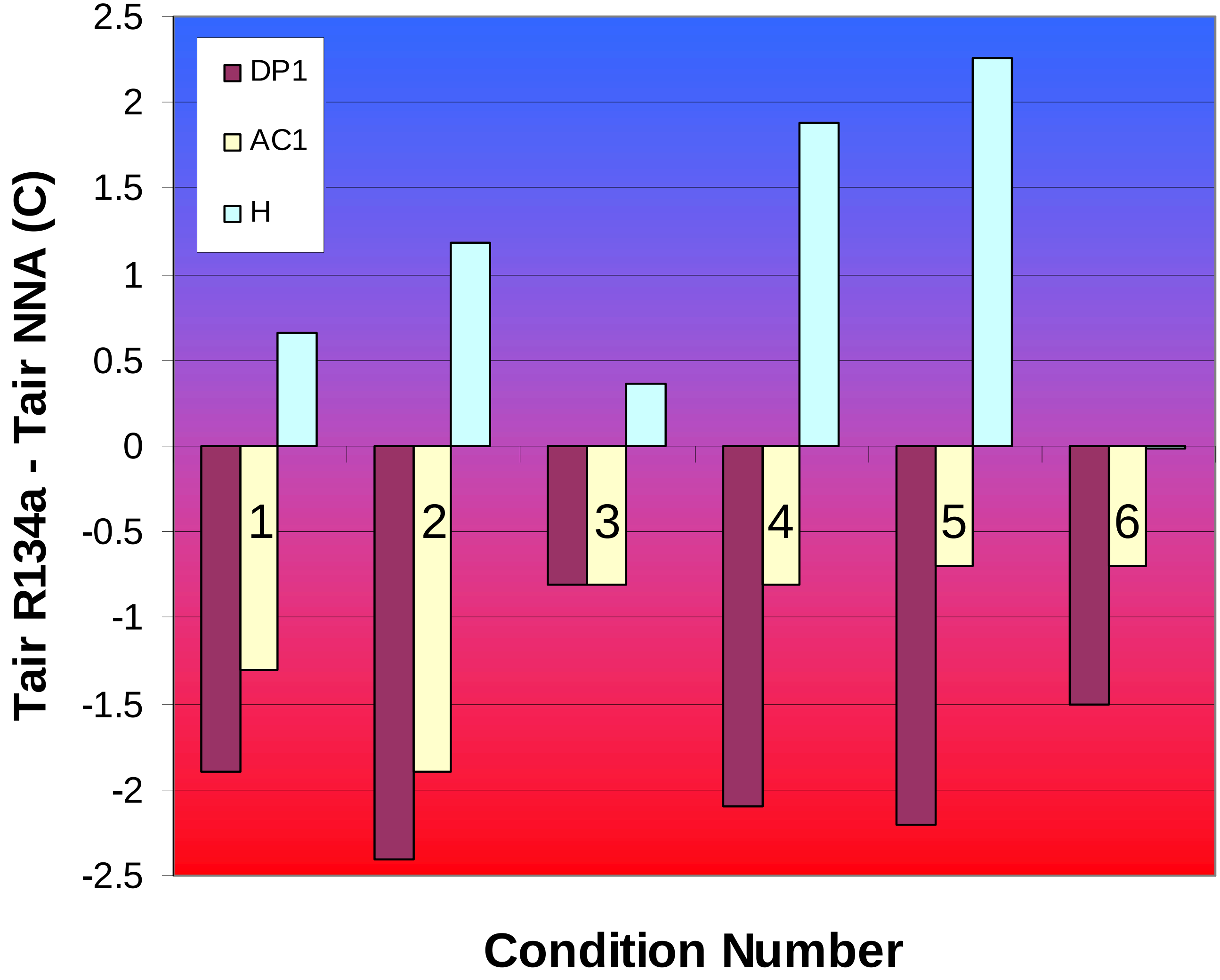
- High load test points
- Test results at low load conditions obtained but due to MCV and flooding data are not comparable

Comparison w/o IHX - Baseline

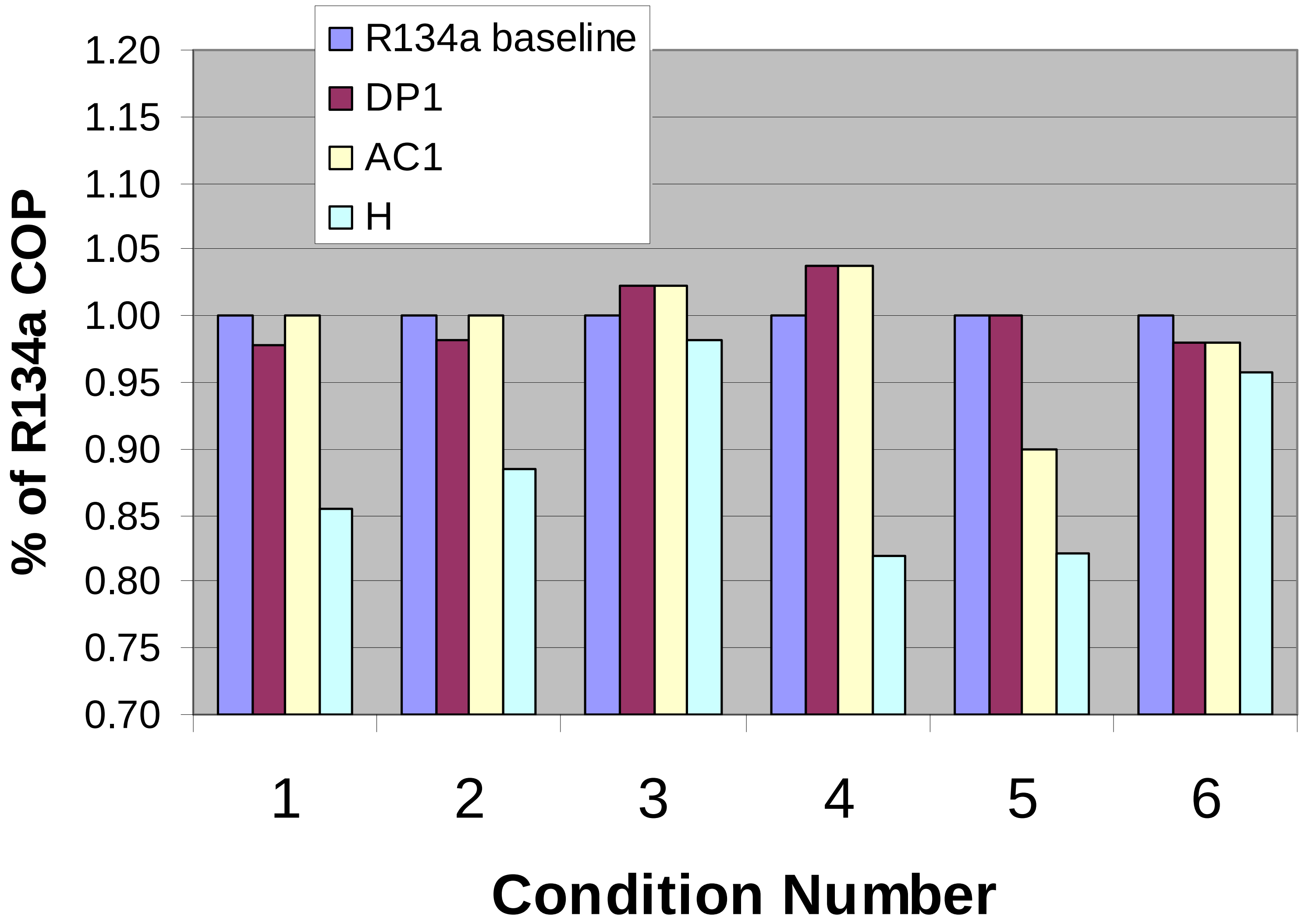
				Visteon, Germany			Visteon, USA	
Test	**Comp.**	**Cond.**	**Evap.**	**R134a**	**DP-1**	**AC-1**	**R134a**	**Fluid H**
	rpm	**°C**	**°C**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**
1	2500	45	43	2,25 @ 18,3°C	2,20 @ 20,2°C	2,25 @ 19,6°C	2.8 @ 15.4°C	2.4 @ 14.7°C
2	1800	45	43	2,75 @ 18,7°C	2,70 @ 21,1°C	2,75 @ 20,6°C	3.4 @ 16.1°C	3.0 @ 15.0°C
3	800	45	43	4,50 @ 23,4°C	4,60 @ 24,2°C	4,60 @ 24,2°C	5.9 @ 19.7°C	5.8 @ 19.3°C
4	2500	37	35	2,60 @ 12,3°C	2,70 @ 14,4°C	2,70 @ 13,1°C	2.7 @ 11.8°C	2.2 @ 9.9°C
5	1800	37	35	3,00 @ 12,3°C	3,00 @ 14,5°C	2,70 @ 13,0°C	3.3 @ 11.5°C	2.7 @ 9.2°C
6	800	37	35	4,90 @ 15,3°C	4,80 @ 16,8°C	4,80 @ 16,0°C	5.8 @ 13.2°C	5.6 @ 13.2°C

- Alternatives with deficits in cooling performance and/or COP
- Evaporator air outlet distribution
  - DP-1 higher (smaller cooling capacity)
  - AC-1 approx. comparable
  - Fluid H lower (higher cooling performance)

Baseline Capacity Comparison



Baseline Efficiency Comparison



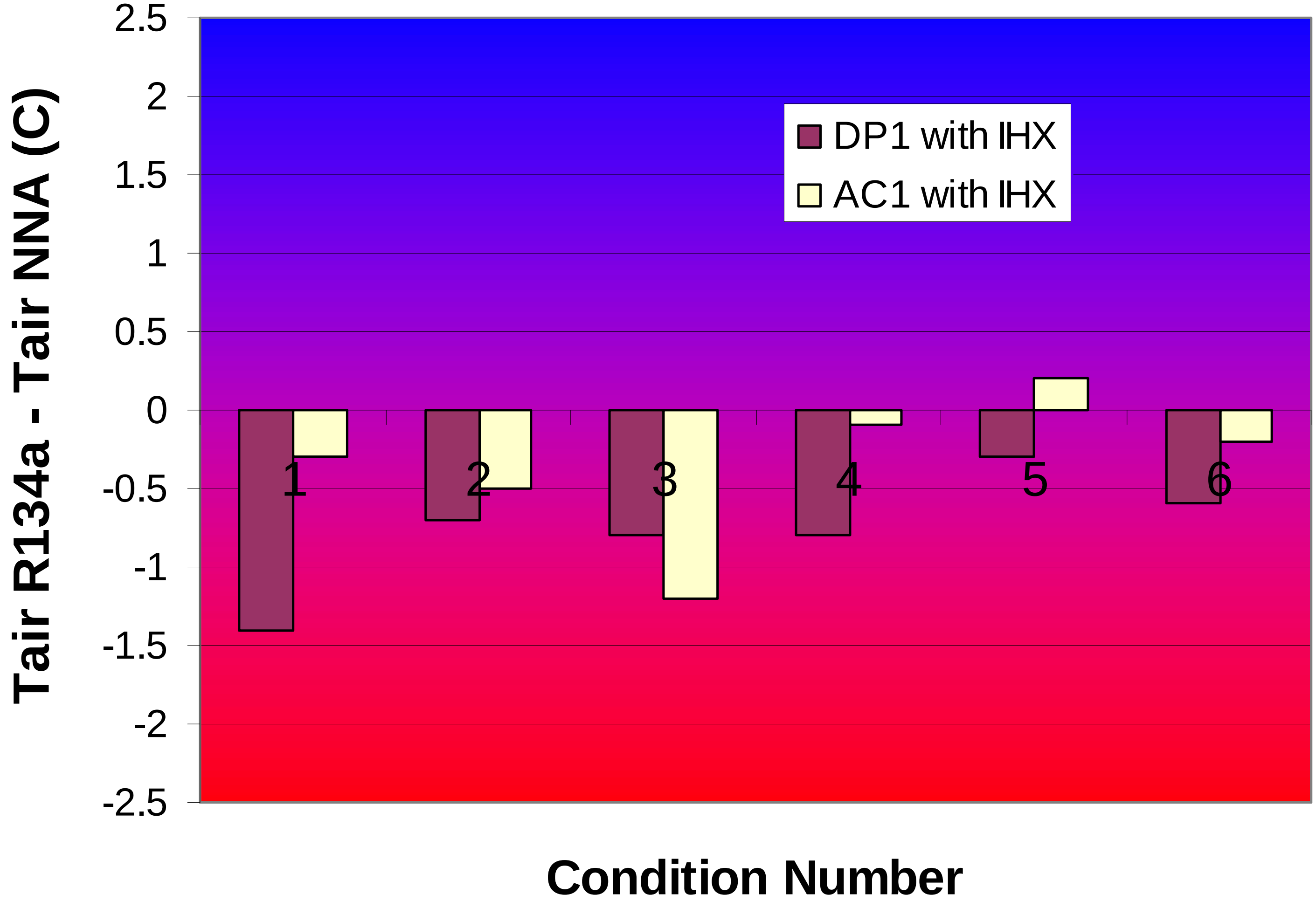
IHX comparison

				Visteon, Germany			Visteon, USA	
Test	**Comp.**	**Cond.**	**Evap.**	**R134a**	**DP-1**	**AC-1**	**R134a**	**Fluid H**
	rpm	**°C**	**°C**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**	**COP @ tair out evap**
1	2500	45	43	2,30 @ 17,1°C	2,20 @ 19,7°C	2,30 @ 18,6°C		2.3 @ 16.4°C
2	1800	45	43	2,85 @ 17,5°C	2,70 @ 19,4°C	2,80 @ 19,2°C		2.8 @ 17.4°C
3	800	45	43	4,50 @ 24,3°C	4,40 @ 24,2°C	4,45 @ 24,6°C		5.1 @ 21.4°C
4	2500	37	35	2,75 @ 10,8°C	2,50 @ 13,1°C	2,78 @ 12,4°C		2.1 @ 11.8°C
5	1800	37	35	2,91 @ 10,3°C	2,80 @ 12,6°C	3,02 @ 12,1°C		2.5 @ 11.1°C
6	800	37	35	4,90 @ 15,6°C	4,70 @ 15,9°C	4,90 @ 15,5°C		4.6 @ 14.5°C

- R134a data **with** IHX (following graphs are for R134a baseline)
- AC-1 with IHX comparable with R134a w/o IHX
- Evaporator air out distribution at high load comparable

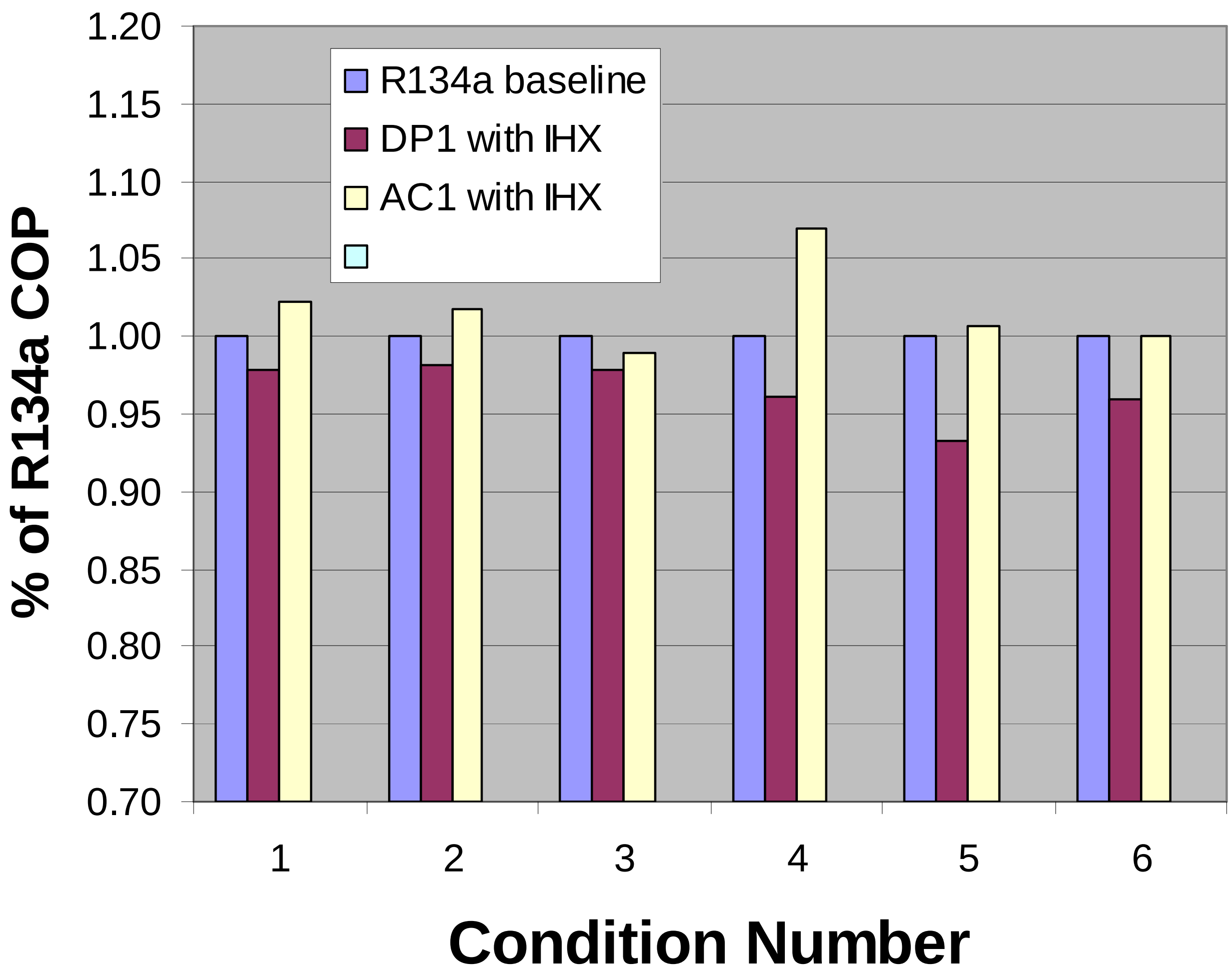
IHX Capacity Comparison to Baseline R134a

Fittings for Fluid H IHX had too high of a pressure drop resulting in performance degradation



IHX Efficiency Comparison

Fittings for Fluid H IHX had too high of a pressure drop resulting in performance degradation



AC1 and DP1/R134a Summary (1)

- 160 cm^3 internal controlled compressor
  - Volumetric and isentropic efficiency comparable with R134a
  - Refrigerant mass flow up to 10% higher than R134a
  - Pressure ratio of AC-1 marginal smaller / DP-1 comparable
  - Compressor outlet temperature of AC-1/DP-1 smaller than R134a
- 16mm IRD condenser
  - High pressure level smaller than for R134a (AC-1/DP-1)
  - Temperature difference refrigerant condenser out and air condenser in (ambient) smaller than R134a/ambient temp.
  - Temp.-glide: AC-1/DP-1: 6-7 K (glide + Δp)
    R134a: 0,5 - 2 K (Δp)
  - Subcooling at 25°C and lower is near/or 0K (DP-1 marginal higher)
- IHX
  - Required to meet R134a performance
  - IHX increases refrigerant evaporator temperature glide
  - Tuning at low load conditions

AC1 and DP1/R134a Summary (2)

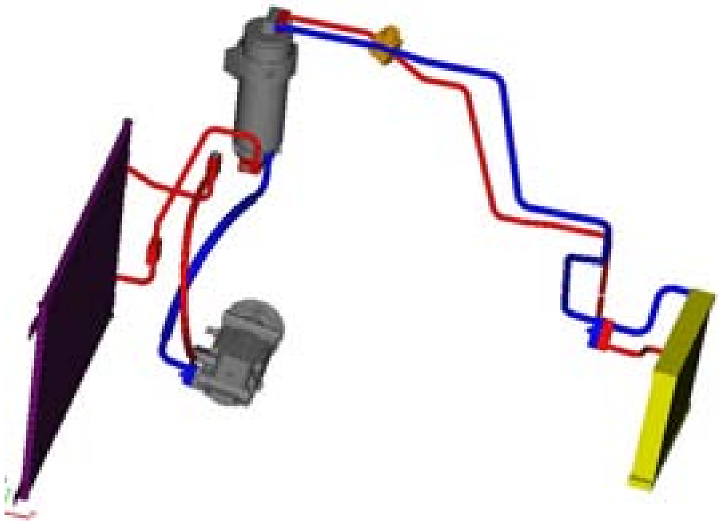
- 58 mm plate & fin evaporator
  - Temp.glide: R134a: 2 to 6 K (Δp)
    AC-1: -2 to 3K / DP-1: -1 to 4K (glide + Δp)
  - AC-1/DP-1 is sometimes colder (high load) or warmer (medium/low load) at the evaporator outlet
  - Temp.-glide (AC-1) will increase at low load conditions (up to -5K)
  - Refrigerant evaporator inlet temperature is approx. 0°C or negative @ low load conditions - Icing (compressor cycling)
- System
  - AC-1/DP-1 require approximately 5-10% more charge
  - High load conditions: system works very well
  - Low load more detailed work required (system and components)
  - AC-1 has a higher performance than DP-1
  - Improving of DP-1 required “more detailed work”

Fluid H/R134a Summary

- 160 cm^3 internal controlled compressor
  - Lower pressure ratio
  - Significantly lower discharge temperatures
- 16mm IRD condenser
  - Operates at slightly lower pressure
  - Greater subcool due to circuitry
- IHX
  - Additional fittings required to install IHX ruined performance (Δp)
- 45mm plate-fin evaporator
  - Improved temperature distribution vs R134a
- Low pressure drop suction line
  - Fluid H pressure drop 50-60% that of R134a

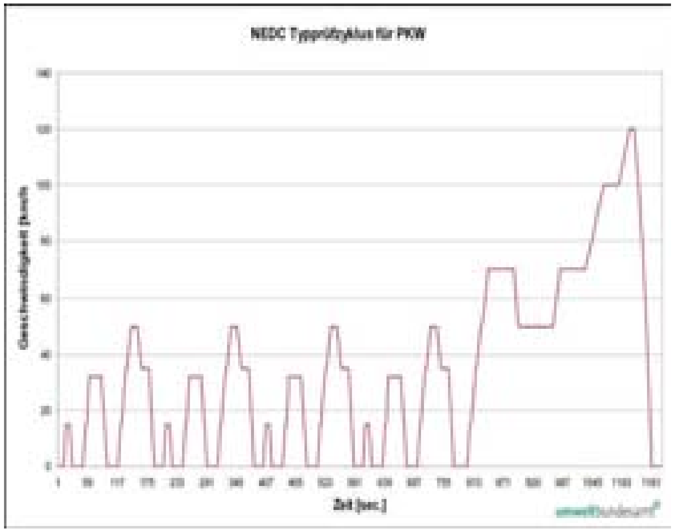
Fuel consumption measurements

- Toyota Yaris/Vitz, MY 2006
- B-class vehicle for Asian and European market
- Specification
  - Engine: 3 cylinders, 1,0 l, 51 kW
  - Test vehicle with 15.000 km
- AC System for R134a/AC1
  - TXV System, adapted for Ref AC1
  - Compressor, 90cc; externally controlled
- AC System for R744
  - standard system architecture with combined accumulator and internal heat exchanger
  - 20 cc compressor, externally controlled
  - Orifice Tube with bypass



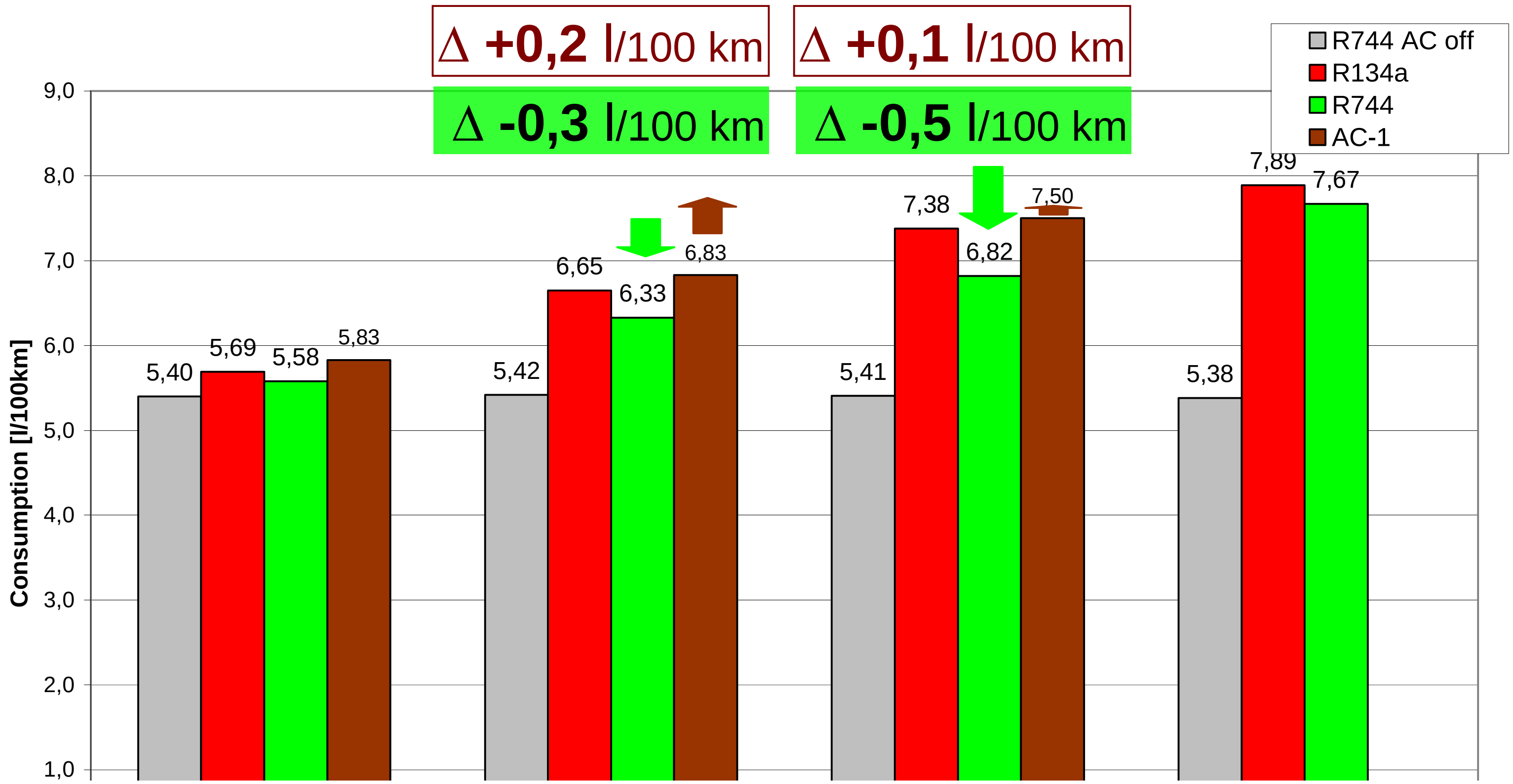
Test Results: Fuel Consumption

- Evaluation based on NEDC procedure
- Test runs with AC off at different ambient conditions
  - Preconditioning to heat up the engine
  - Temperature soak
  - 3 NEDC cycles for each test session
  - Manual control adapted to each condition
  - All systems controlled to same performance
- 30 runs of NEDC cycles and 10 pull down runs to validate the measurements



	NEDC 10°C	NEDC 25°C	NEDC 35°C	NEDC 45°C
Blower	Step 1	Step 3	Step 4	Step 4
AC-Settings	Full cold	Full cold	Full cold	Full cold
Air-Settings	Panel Fresh	Panel Fresh	Panel Recirc	Panel Recirc
Sun Load (W/m^2)	-	500	750	1000
Soak (Ave. Breath)	10°C	25°C	50°C	65°C

Fuel consumption: NEDC



⇒ Increased fuel consumption with “Drop-in“ AC1 vs R134a
(+0,2 and +0,1 ℓ/100 km @ 25°C and 35°C)

⇒ Significant reduction in fuel consumption with R744 vs R134a
(-0,3 and -0.5 ℓ/100 km @ 25°C and 35°C)

Next Activities

- Zeotropic refrigerants
  - Condenser optimization (performance more sensitive to front-end airflow)
  - Evaporator and IHX designed for glide
  - Robust control strategy for high/low load conditions to maximize performance with protection against icing
- Azeotropic refrigerants
  - Increase understanding of capacity/efficiency/cost tradeoffs
  - Investigate ease of adoption of R134a technologies
- All refrigerants
  - Optimization of TXV or external controlled valve
  - COP optimization

Conclusions

- Overall, AC1 with IHX is closest to matching R134a performance
- Fluid H with modified (no IHX) baseline hardware has the highest capacity but lowest COP (at the higher capacity)
- Fluid H IHX testing required additional fluid transport fittings resulting in excessive pressure drop and performance degradation
- More work needed to further understand the tradeoffs between cost/COP/capacity of the systems
- With enough engineering resources, any of the fluids will be able to match R134a *baseline* performance

Acknowledgements

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