R-1234yf Validation & A/C System energy efficiency improvements

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Summary

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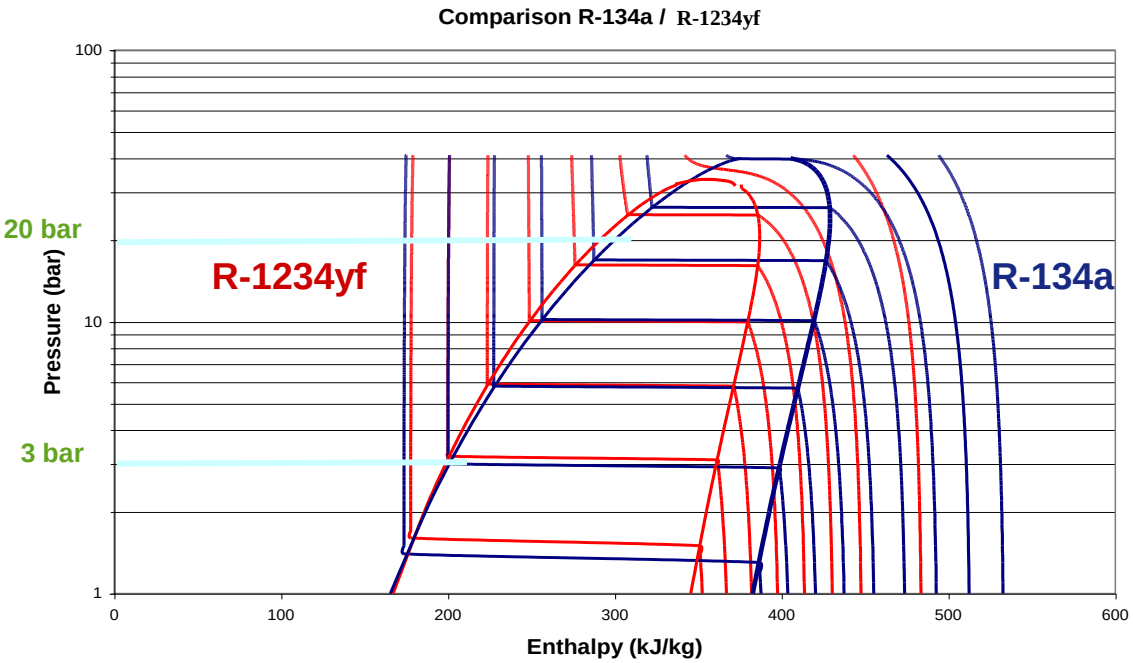
2. Test conditions for energy efficiency evaluation
3. Evaporator & TXV choice impact
4. Low and high efficiency IHX impacts
5. Compressor downsizing potential
6. Test results on car in Wind tunnel
7. Conclusions for mechanical A/C systems
8. Next steps with up-coming Thermal System needs

R-1234yf & Thermo cycle basics



	HFC134a	HFO1234yf
	CH_2FCF_3 	$CH_2=CFCF_3$ 
GWP	1300	4
ODP	0	0
Flammable	Non-Flammable	Low-Flammable
NOEL	50,000ppm	>50,000ppm

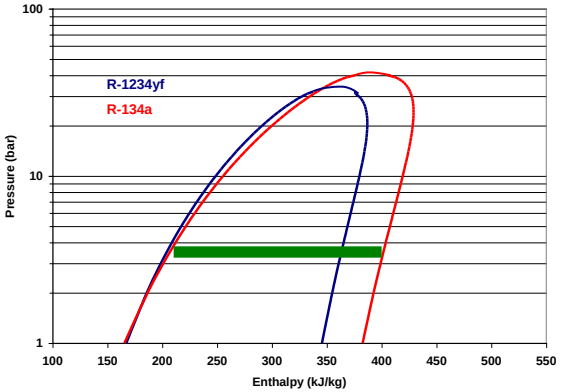
	Enthalpy difference (kJ/kg)	Density (kg/m3)
R-1234yf	161	17
R-134a	198,6	14,4
Difference (%)	**-23%**	**15%**

For an evaporating temperature of 0°C:

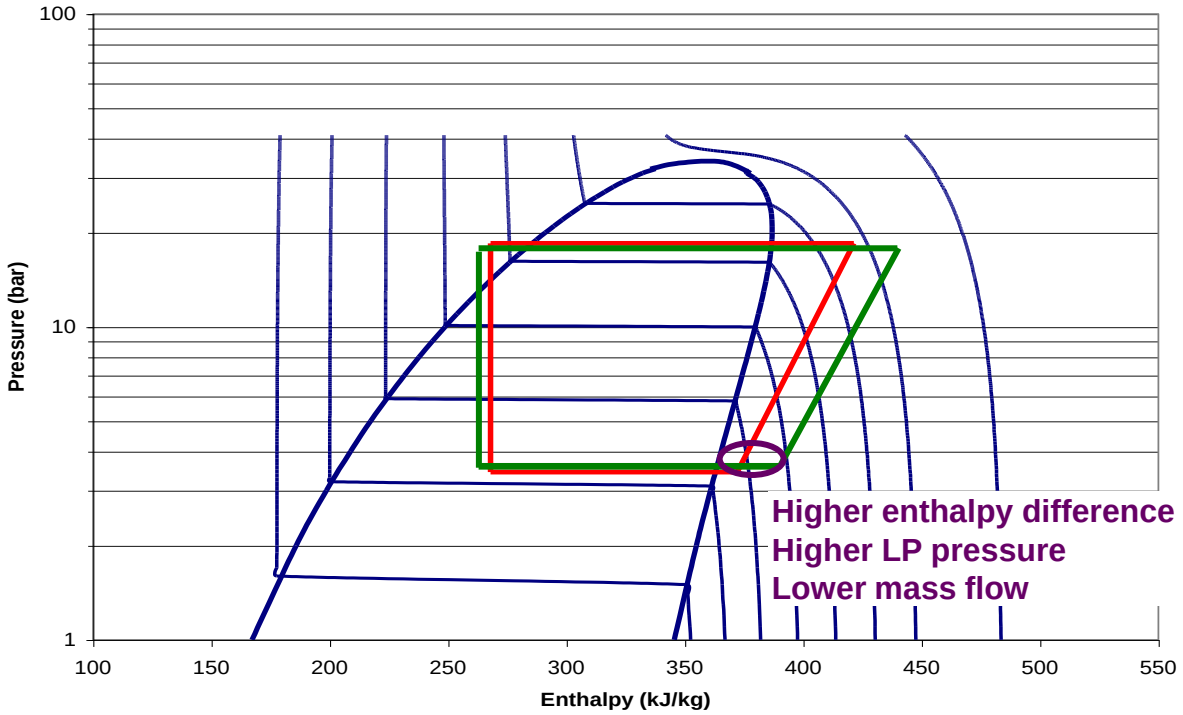
Cooling capacity at same volumetric flow is reduced by - 8 to -10%

R-1234yf & Thermo cycle basics

Impact of enhanced evaporator and adapted TXV



The R-1234yf has a lower evaporating enthalpy than R-134a



R-1234yf enhanced evaporator needs an adapted TXV:

- to increase the low side pressure (due to better core efficiency)

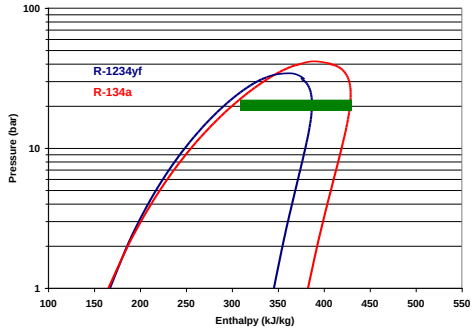
- to increase the superheat (better temperature unbalance)

➔ slight improvement of the thermodynamic cycle

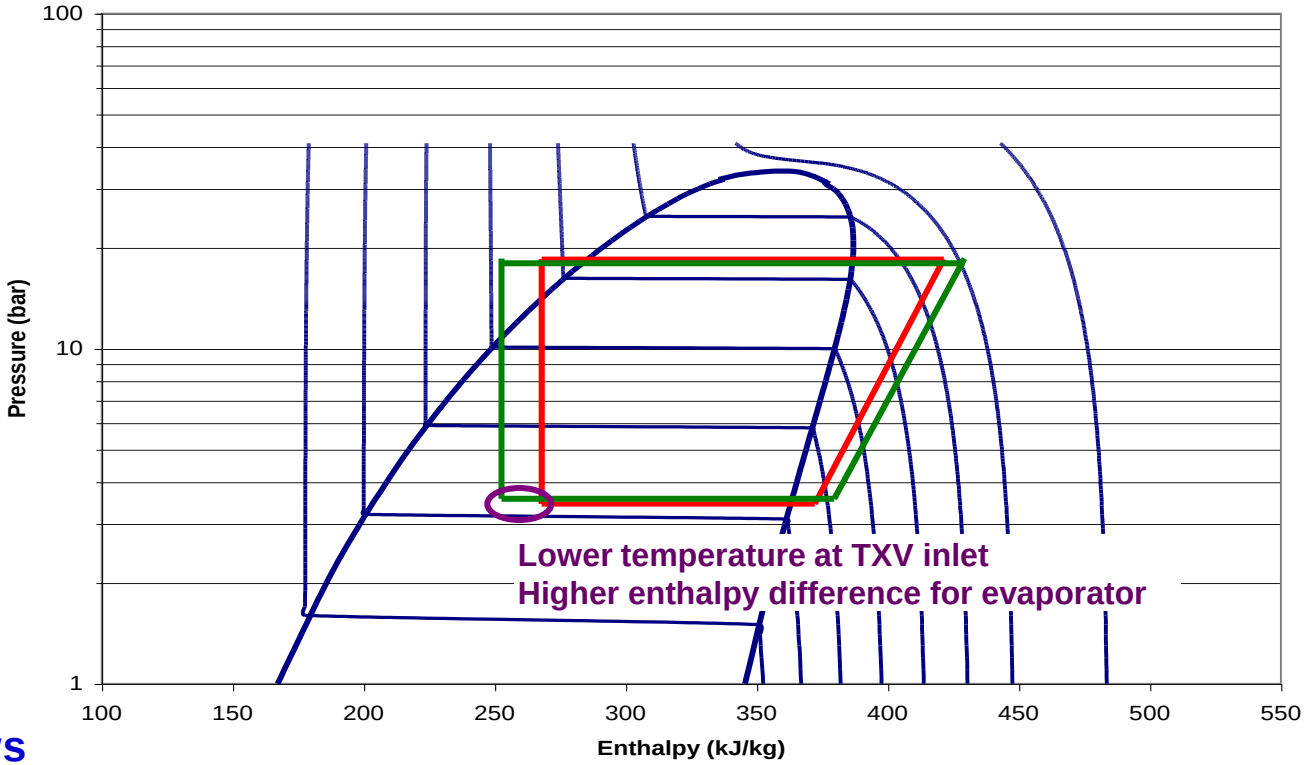
Basically the Evaporator keeps its usual role to reveal the improvements which are done on other portions of the cycle

R-1234yf & Thermo cycle basics

Impact of enhanced condenser



The R-1234yf has a lower condensing enthalpy than R-134a



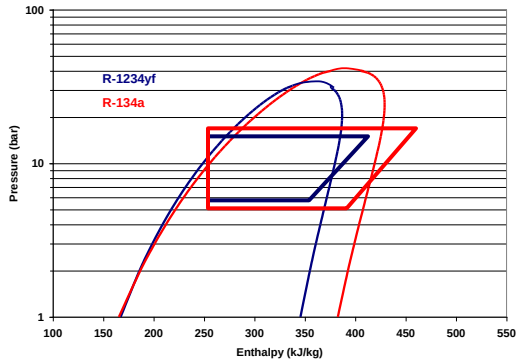
Enhanced condenser allows

- to decrease the t° at TXV inlet without increasing the HP = an "extended" sub-cooling
➔ to increase the cooling capacity & thus reduce the basic gap R-1234yf vs R-134a

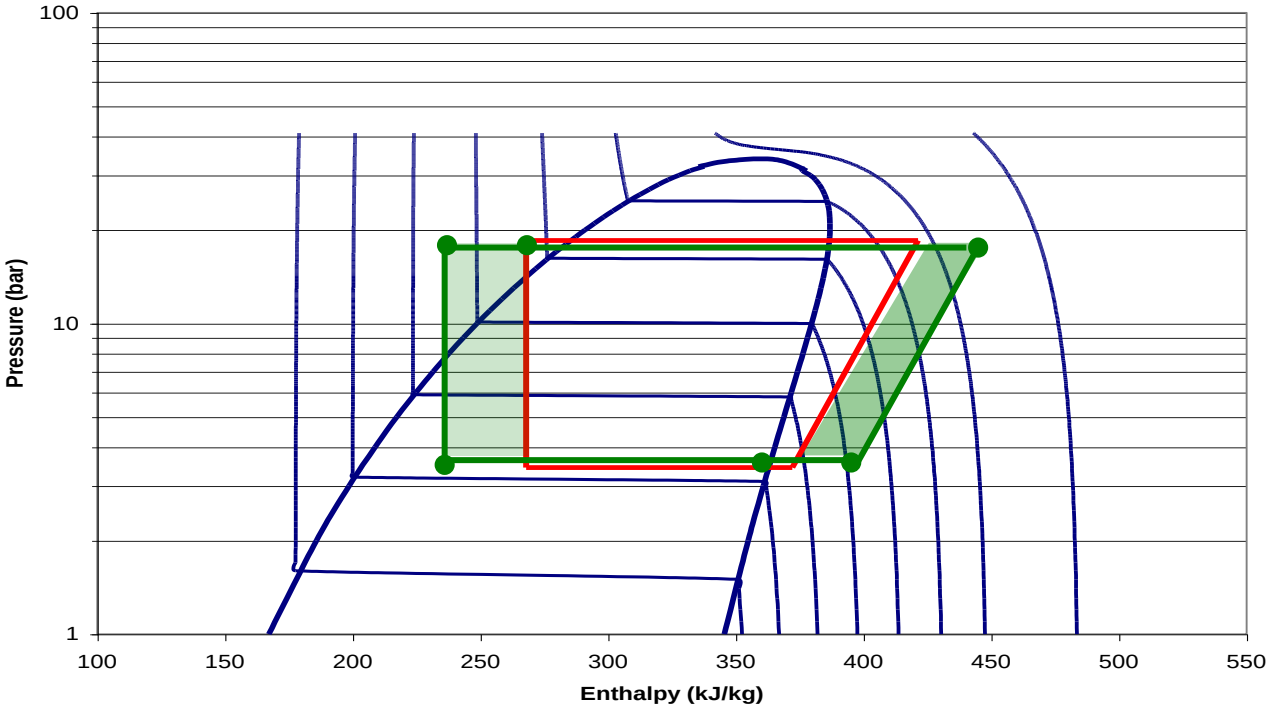
Improved condenser is playing a more important role to optimize R-1234yf

R-1234yf & Thermo cycle basics

Impact of Internal Heat eXchanger (IHX) introduction



The R-1234yf cycle is shorter than R-134a one



IHX function allows

- to have an "new added" sub cooling at TXV inlet so that the cycle is wider & more efficient
- mass flow rate is reduced thus leads to less Delta P & less compressor shaft power

➔ the discharge t° is higher but thanks to R-1234yf properties, it can be kept below 130°C whatever the test conditions with a 60% efficiency IHX

IHX is playing a bigger role for R-1234yf vs R-134a specifically when improved idle & high efficiency of the whole A/C system are targeted

Test conditions for A/C cycle energy analysis

	HVAC position	MAEI (kg/h)	TAEI (°C)	HRAEI (°C)	MAGI (kg/h)	TAGI (°C)	N (rpm)	TAEO (°C)
High thermal loads								
Valeo Sizing	Fresh air	540	45	40	2300	45	1850	Min
Valeo IDLE	Fresh air	540	45	40	1300	45	1000	Min
VDA ILDE	Fresh air	520	40	40	1000	40	1000	Min
VDA 4	Recirculation	465	35	30	1500	45	1500	8 or min
VDA 3	Fresh air	540	35	40	1500	35	1500	8 or min
Average and low thermal loads								
IH 35	Recirculation	465	25	40	1600	35	1600	9
IH 30	Fresh air	520	30	40	1600	30	1600	12
IH 25	Fresh air	260	25	55	1600	25	1600	8
IH 20	Fresh air	260	20	70	1600	20	1600	8
IH 15	Fresh air	180	15	90	1600	15	1600	8
Cool down								
CD1	Recirculation	540	46,5	15,5	2300	46	2500	Min
CD2	Recirculation	540	37	17	2300	46	2500	Min
CD3	Recirculation	540	28	24	2300	46	2500	Min
CD4	Recirculation	540	30	30	1600	55	1000	Min

IH points are used to estimate the AC cycle energy efficiency in EU climatic conditions. Combined with below occurrences they bring the Annual Power Consumption (APC):

Temperature (°C)	*35°C*	*30°C*	*25°C*	*20°C*	*15°C*
Occurrence (%)	2%	8%	18%	32%	40%

A 2nd occurrence estimates a test point tentatively close to coming regulations (REG):

Temperature (°C)	*30°C*	*25°C*
Occurrence (%)	33%	67%

$$REG = 0{,}33.Wshaft_{IH30} + 0{,}67.Wshaft_{IH25}$$

All those reference testing points give:

- a good view of the A/C system adaptability to various conditions

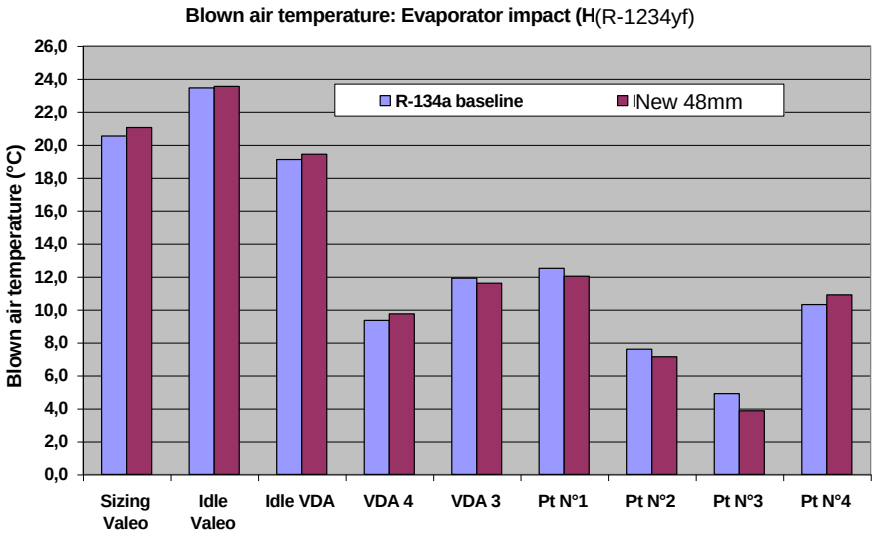
- an accurate view of A/C cycle efficiency for a given climate

Evaporator and TXV impact

Cooling Performances and energy performances

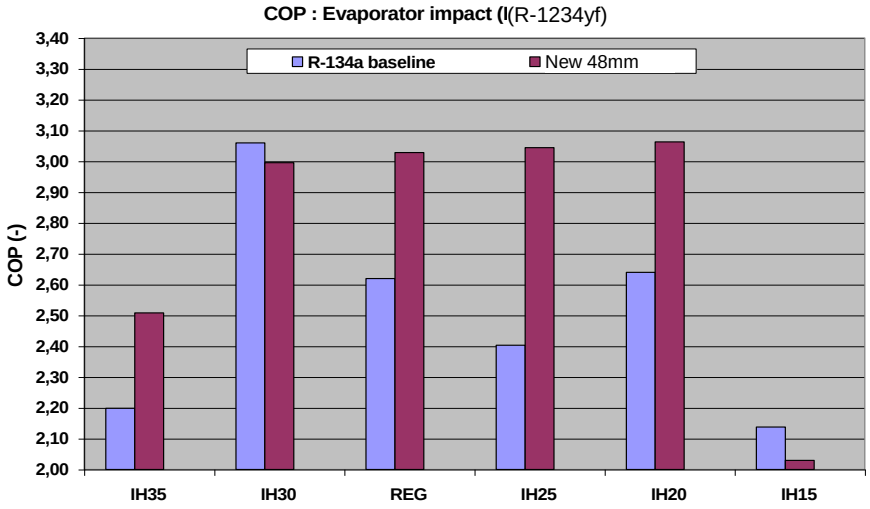
Baseline R-134a: 60 mm Evaporator / 170cc ECC
R-1234yf: 48mm enhanced Evaporator + adapted TXV / 170cc ECC

	R-134a	R-1234yf
APC	578 W	519W
REG	927 W	810 W



Enhanced Evaporator 48mm coupled with adapted TXV allows to reduce the performance gap vs R-134a.

In some conditions, it is even possible to improve them

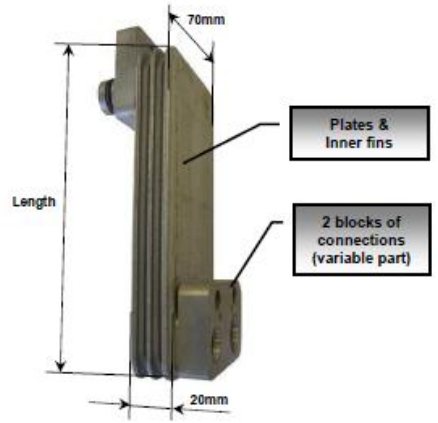


Good t° unbalance & stability helps to tune the TXV in order to improve A/C loop efficiency

Cycle efficiency is improved significantly for R-1234yf

Good matching of Evaporator with TXV is needed to give a value to other intended changes among the A/C components

High efficiency IHX technology with high density packaging



Packaging 5 layers [3 LP & 2 HP]		
Width	70 mm	
Thickness	20 mm	
Length (Variable)	200mm	150mm
Weight	489g	396 g
Connections (Variable)	2 blocks of double connections	

High performance density compared to coaxial IHX

- 0,73 l coax vs 0,33 l plate (@ 60% eff. w/ 1500mm coax)
- Better vehicle implantation flexibility

Pulsation damping effect of plate IHX (muffler function)

Less sensitive to refrigerant flow fluctuations

- Higher system robustness, thus development time reduction
- Less sensitive to Front End Module airflow constraints

Standard sizing cross platform and OEM

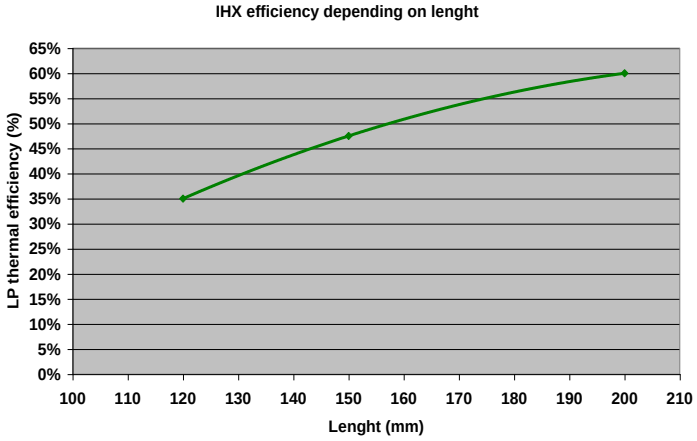
- Less part references @ OEM (independent to lines routing)
- Less development & validation leads to time & cost reductions

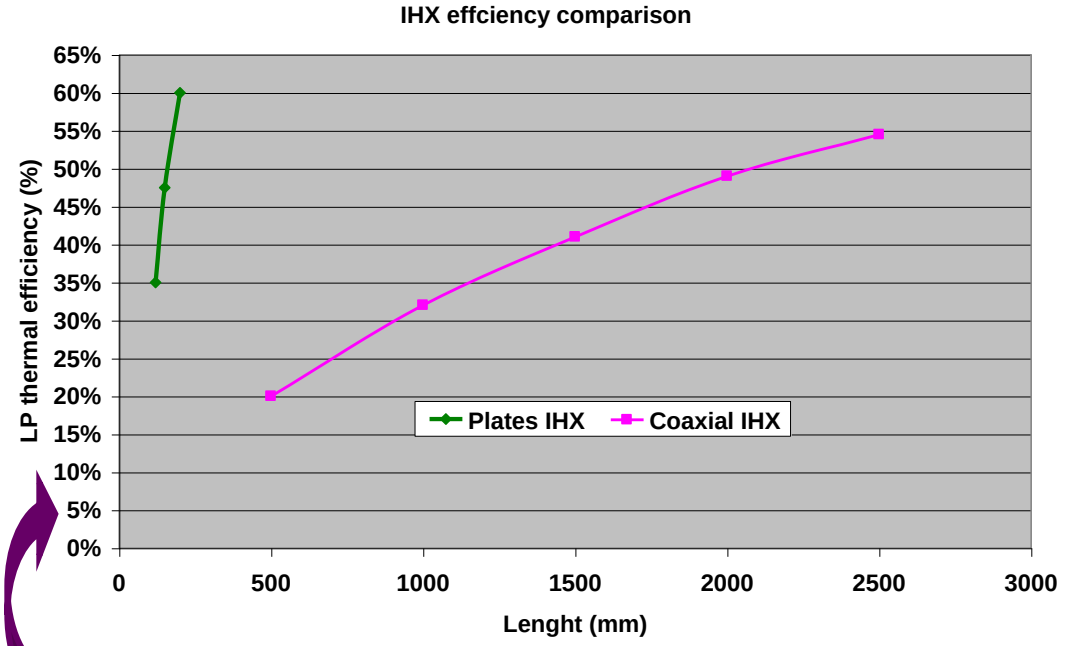
For A/C systems targeting: very good idle performances (usually under constrains due to front end issues) AND high efficiency with R-1234yf

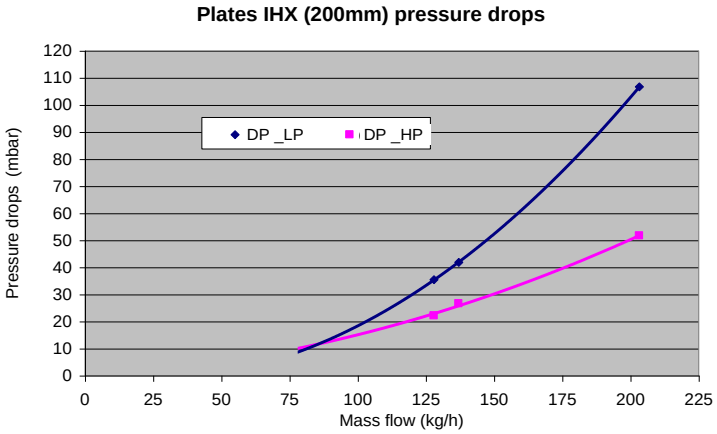
➔ the use of a sufficiently high efficiency IHX is recommended

IHX impact

Thermal efficiency and pressure drop vs packaging







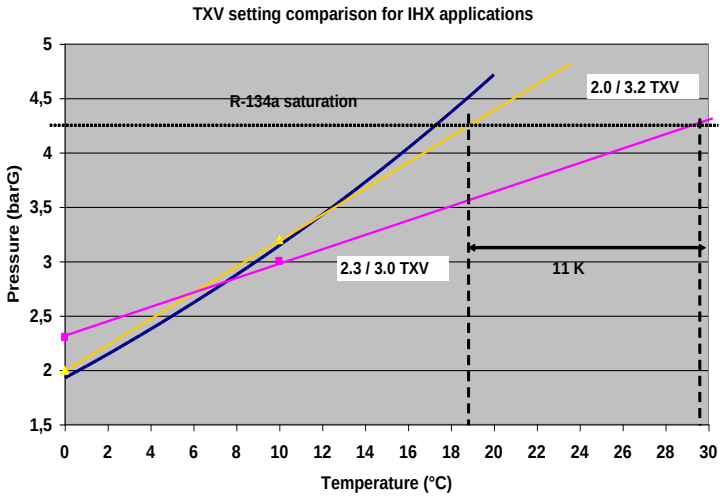
Thank to its very high heat exchange rate & flux density a plate IHX shows clearly very high efficiencies in small packaging

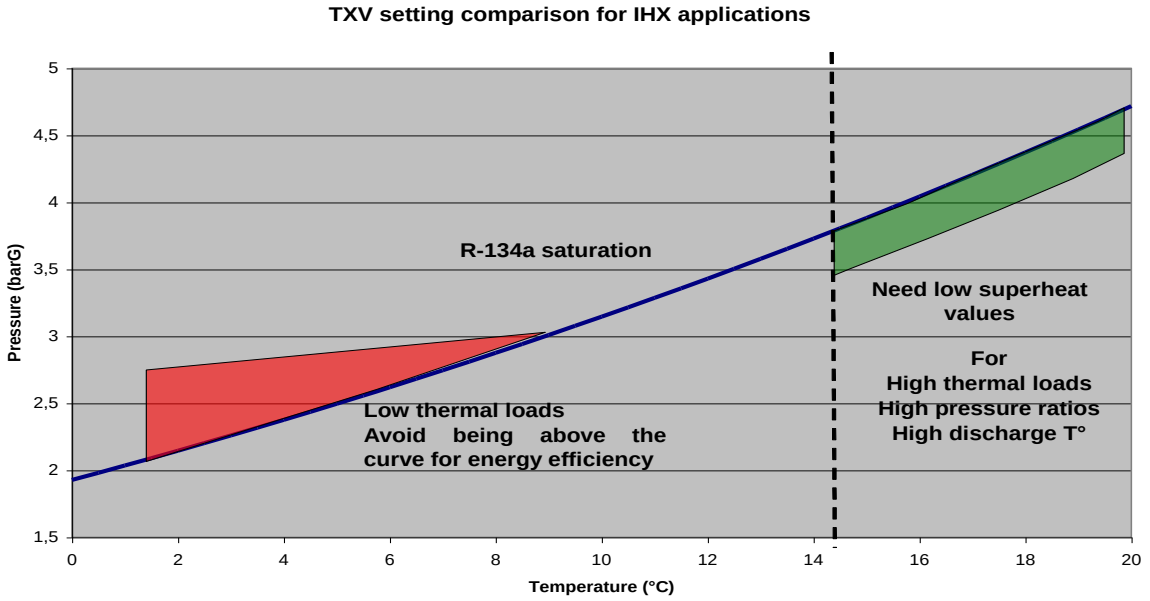
Moreover, the internal pressure drops, even at high refrigerant mass flow rates are rather small compared to other IHX types

Plate IHX has well adapted design criteria to improve R-1234yf A/C system

IHX impact

IHX efficiency and TXV settings





TXV set up according to IHX efficiency:

- for low efficiency IHX, use of cross charge TXV (slope 0.7) is preferred without any discharge t° big issue

- for high efficiency IHX, it is necessary to use parallel charge TXV

➔ this set up choice allows to enter in the IHX with refrigerant conditions close to the saturation which usually represents the best option for systems using IHX)

➔ this also helps to reduce the compressor discharge t° and to improve the cycle efficiency

For R-1234yf, usually the setting point has an offset of + 0.15 bar vs R-134a values

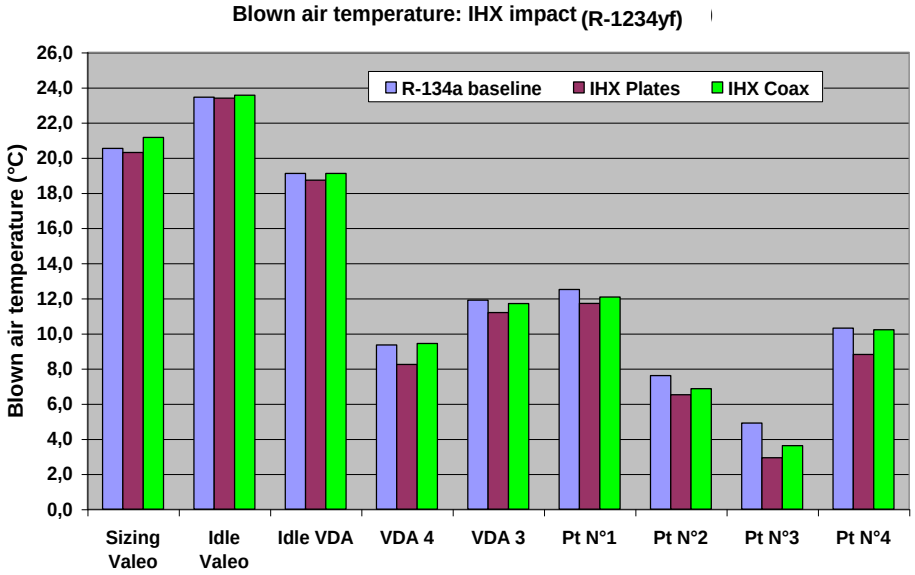
When needed inside A/C system targeting the highest efficiency, the introduction of plate IHX must be combined with specific adapted tunings

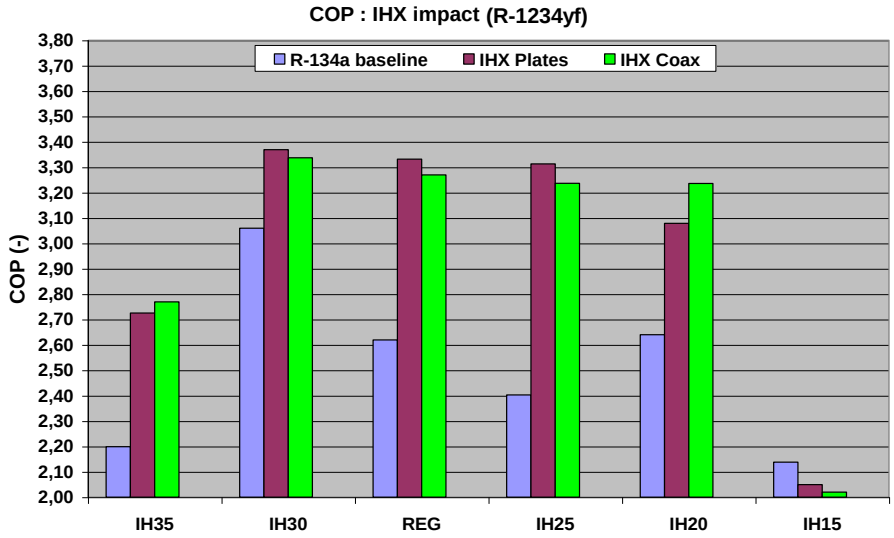
IHX impact

Cooling Performances and COP

	R-134a	Plates IHX	Coax IHX
APC	578 W	506 W	500W
REG	927 W	737 W	756 W

Baseline R-134a: 60 mm evaporator / 170cc ECC (R-134a)
R-1234yf : 48 mm enhanced evaporator / 170cc ECC / IHX plates (60%) & IHX coax (35%)





Cooling capacity results :

- 200 mm plates IHX : improve cooling capacity vs. baseline (lover blown air t°)
- 750 mm coaxial IHX: bring a performance gap reduction vs. baseline

Cycle efficiency:

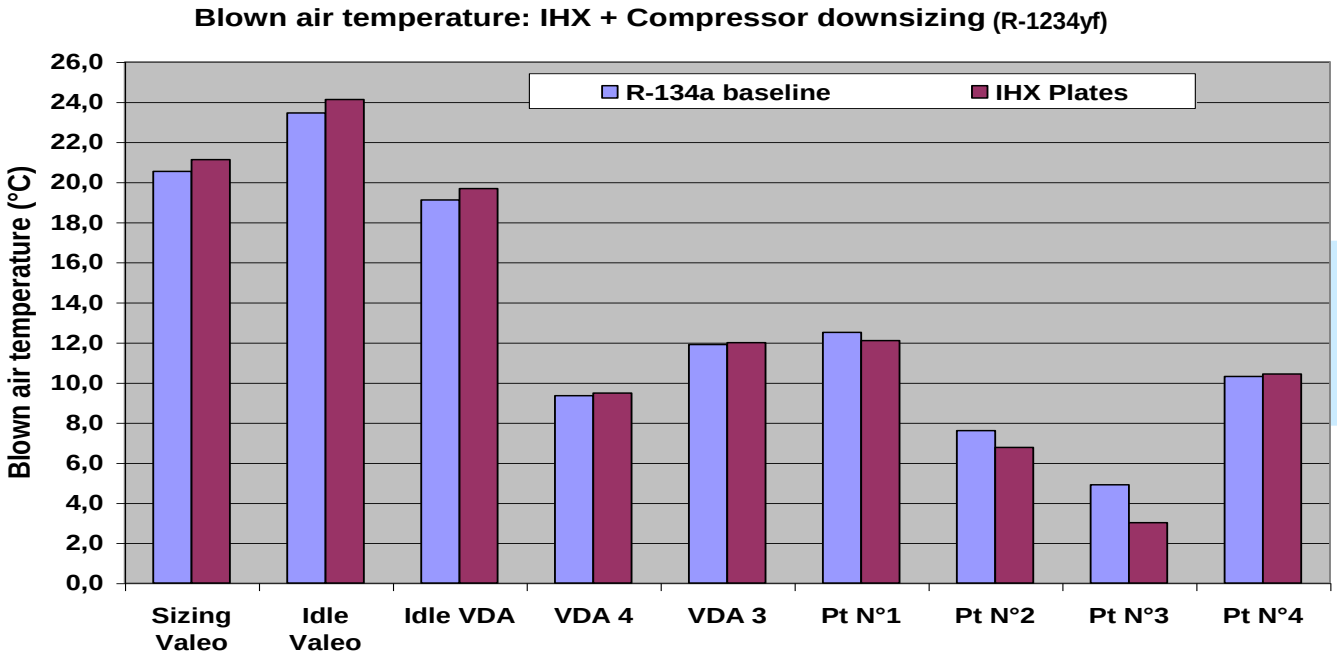
- IHX (associated with a 48 mm enhanced evaporator) is improving efficiency from 20°C to 35°C.
- Plate IHX show the best results between 22°C and 32°C

High efficient plate IHX brings performances advantages in addition to packaging, pulsation and standardization benefits

IHX use and compressor downsizing

Cooling Performances

Baseline R-134a: 60 mm evaporator / 170cc ECC
R-1234yf: 48mm enhanced evaporator / 140cc ECC / IHX plates (60%)



	R-134a	Plates IHX 140cc
APC	578 W	505 W
REG	927 W	744 W

Effect on compressor downsizing from 170cc to 140cc (i.e. -20%)

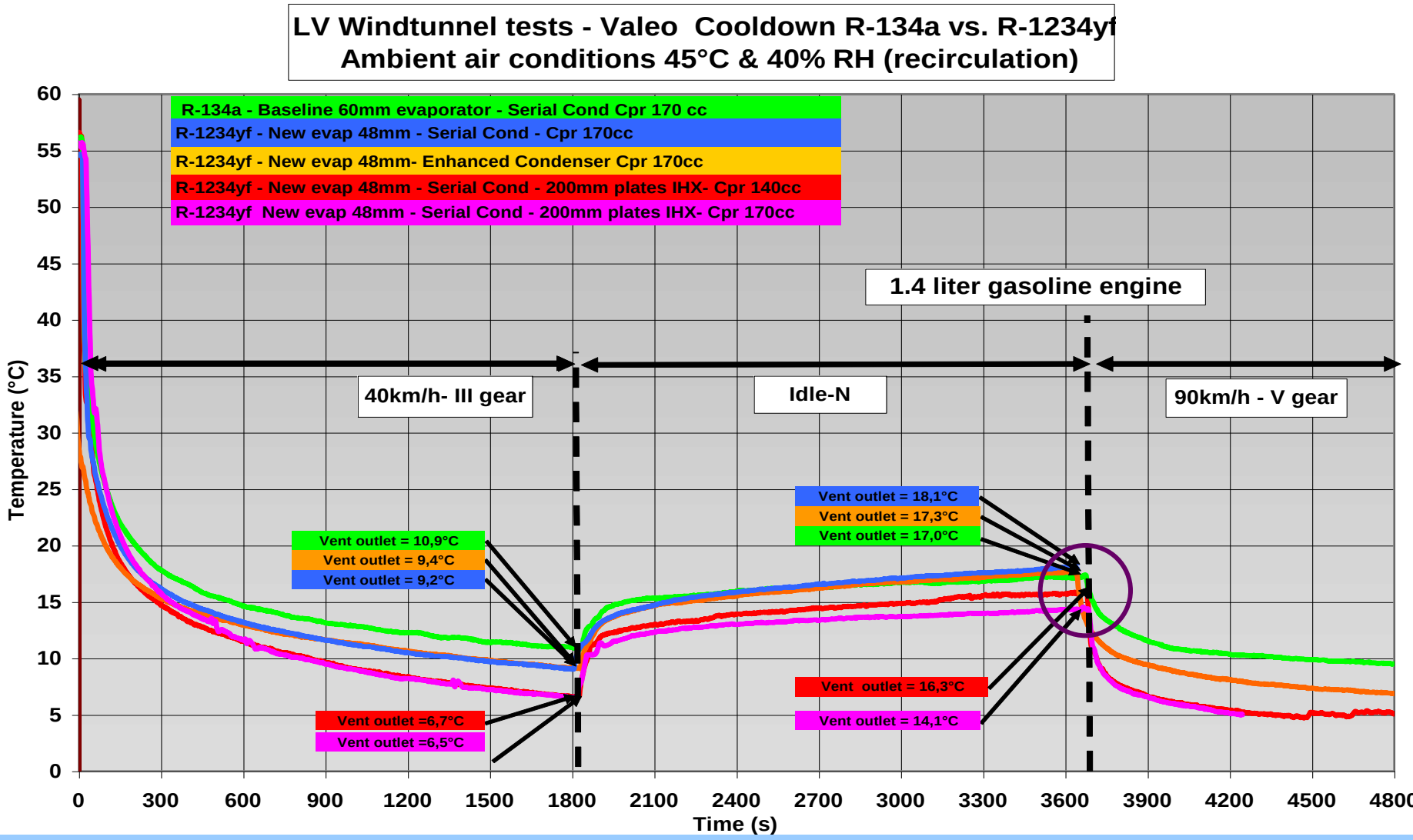
Test results show the following trends:

- cooling capacity: plates IHX allow to keep R-1234yf level same as R-134a one

- energy efficiency: similar improvements come with 140cc

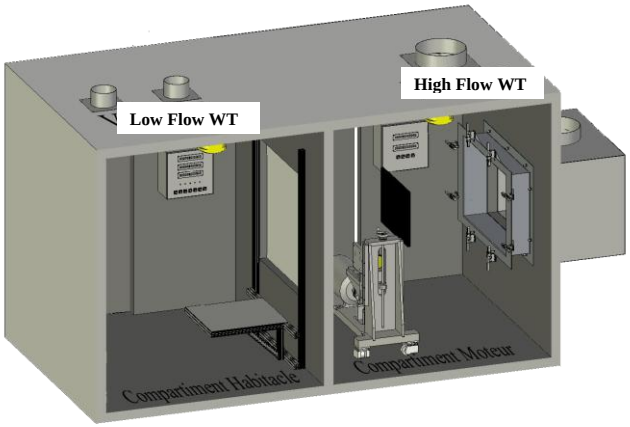
Downsizing is one option as far as other components are well adapted

Test results on cars in Wind tunnel



Results on car in Wind tunnel are confirming A/C system tests at bench ➔
Idle test results are specifically important to take into consideration

A/C system durability test results



High flow and low flow chambers in the insulated shed

Compressor module

Test bench technical characteristics

- **High Flow tunnel**
  - Simulate the air flow on the vehicle front end module
  - Air mass flow : 600 à 6000 kg/h
  - Temperatures : from 0°C to +70°C
- **Low Flow tunnel**
  - Simulate HVAC air flow
  - Air mass flow : from 100 to 800 kg/h
  - Temperature : from 0°C à +70°C
  - Relative humidity : from 10% to 90% HR
- **Compressor module**
  - Compressor rotation speed : from 600 to 9000 rpm
  - Compressor acceleration : up to 1000 rpm/s
- **Insulated shed**
  - Shed with two chambers
  - First chamber : compressor, condenser, pipes & hoses
  - Second chamber : HVAC module

As of today all durability test sequences realized

with various usage profiles inc. R-1234yf; Oil; humidity, Oil mix ,..

have demonstrate satisfactory A/C system durability performances

This confirms previous positive results obtained on component durability

Conclusions for mechanical A/C systems

Thanks to adapted components and deep A/C system engineering work:

Performances and efficiency with R-1234yf can be better than the today achieved ones with R-134a

Thanks to durability results on A/C systems and components:

R-1234yf already achieved a good level of confidence before market introduction

Refrigerant transition from R-134a to R-1234yf to reduce direct emissions seems now on track after more than 12 years of effort

Next Steps

Combined cooling loop and A/C system + electrification

New functions will impact today A/C system moving to R-1234yf such as: combined cooling loop + A/C system, electrification, battery TM,…

- **Will the move to electrified Thermal Systems require other 12 years ?**
- **Will this include a new refrigerant transition ?**
- **Will our expert group (as of today in Phoenix) play a role in this change ?**

Many thanks

for

your attention