Design Issues for Compact Interior Heat Exchangers

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with support from:
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VDA Alternate Refrigerant Wintermeeting
Automotive Air Conditioning and Heat Pump Systems

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Content

- Compact Heat Exchanger Technology
- Major Design Issues
- Simulation/Experimental Results & Analysis
  - Cooling Mode
  - Heating Mode
- Recommended Heat Exchanger Designs
- Conclusions

Compact Heat Exchanger Technology

Characteristics of Automobile Compact Heat Exchangers, from Cowell and Achaichia (1997)

Heat Exchanger	Compactness $[m^2/m^3]$	Performance $[kW/m^3K]$	Weight [kg]	Operating Temp. [°C]
Radiator	1000-1500	30-200	1.5-5	80-125
Condenser	950-1300	20-100	1.2-4	75-100
Heater Core	1800-2800	65-130	0.5-1.2	80-125
Evaporator	900-1000	40-80	1.2-3.5	3-7
Charge Air Cooler	600-900	20-60	0.6-1.5	120-200

Major Design Issues 1(*4*)

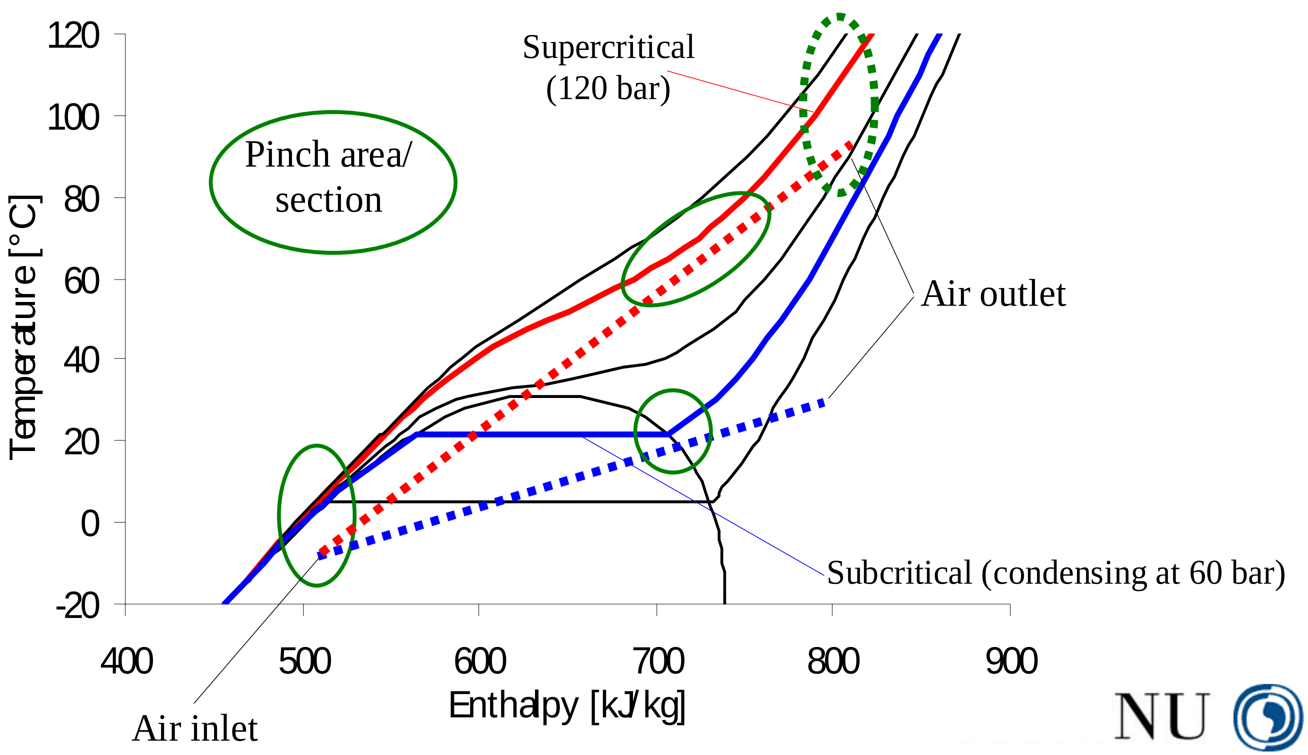
- Reversible Heat Exchanger Operation
  - burst pressure requirements
  - counter (cross) flow arrangement
  - maximum temperature restrictions

- Refrigerant Flow Distribution
  - parallel flow arrangements with many microchannels
  - refrigerant maldistribution reduces efficiency, capacity and increases temperature uniformity

- Air Temperature Uniformity
  - comfort and control issue
  - heat rejection at gliding refrigerant temperatures, thus air temperature depends on tube circuiting
  - mixing of air at different temperature causes exergy loss

Major Design Issues 2(*4*)

- Temperature Approach
  - System COP depends (mainly) on gascooler exit temperature
- Pinch Problem
  - part load operation
  - low heat flux, inefficient section



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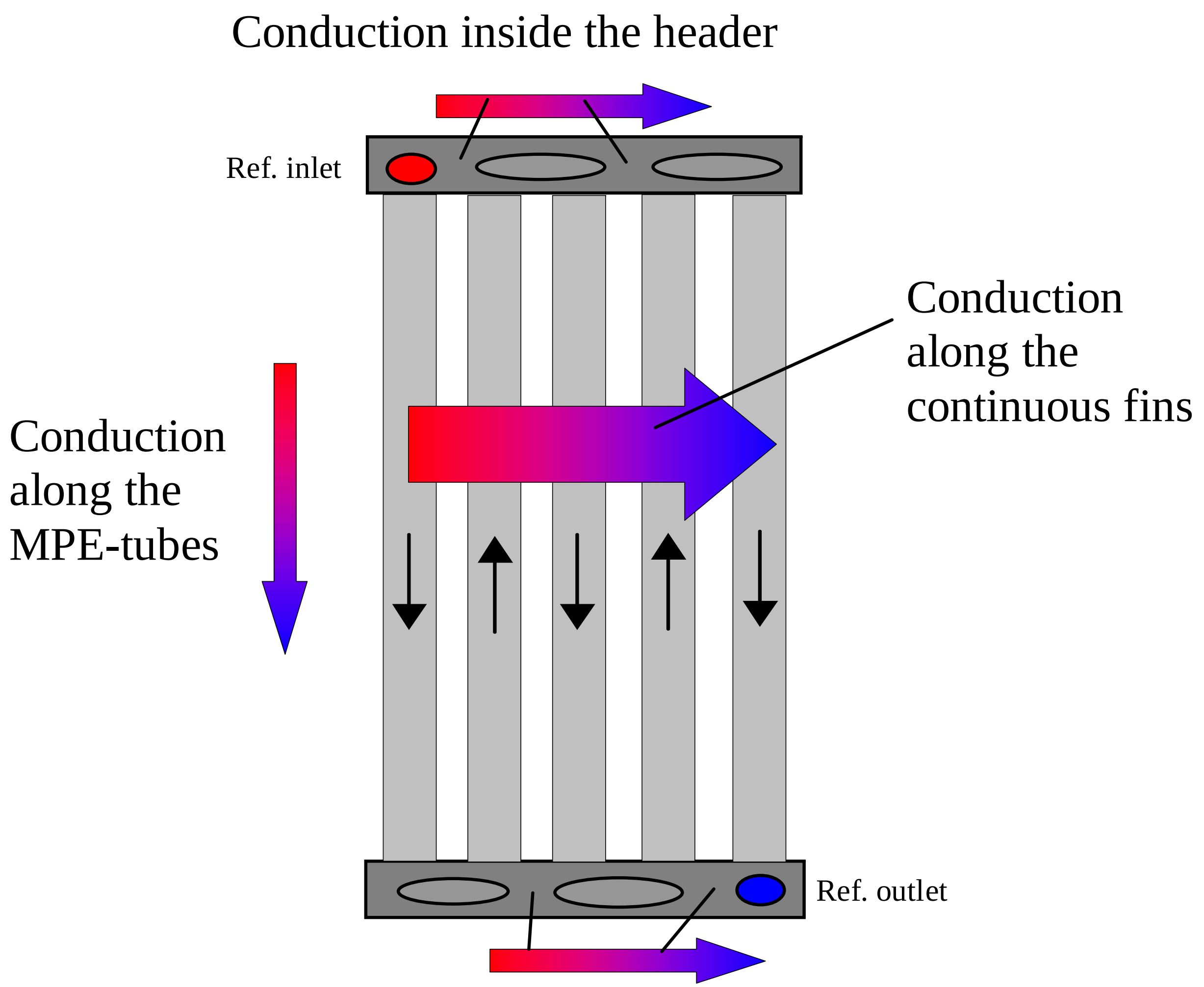
Maior Design Issues 3(*4*)

Internal Heat Conduction

- causes exergy losses



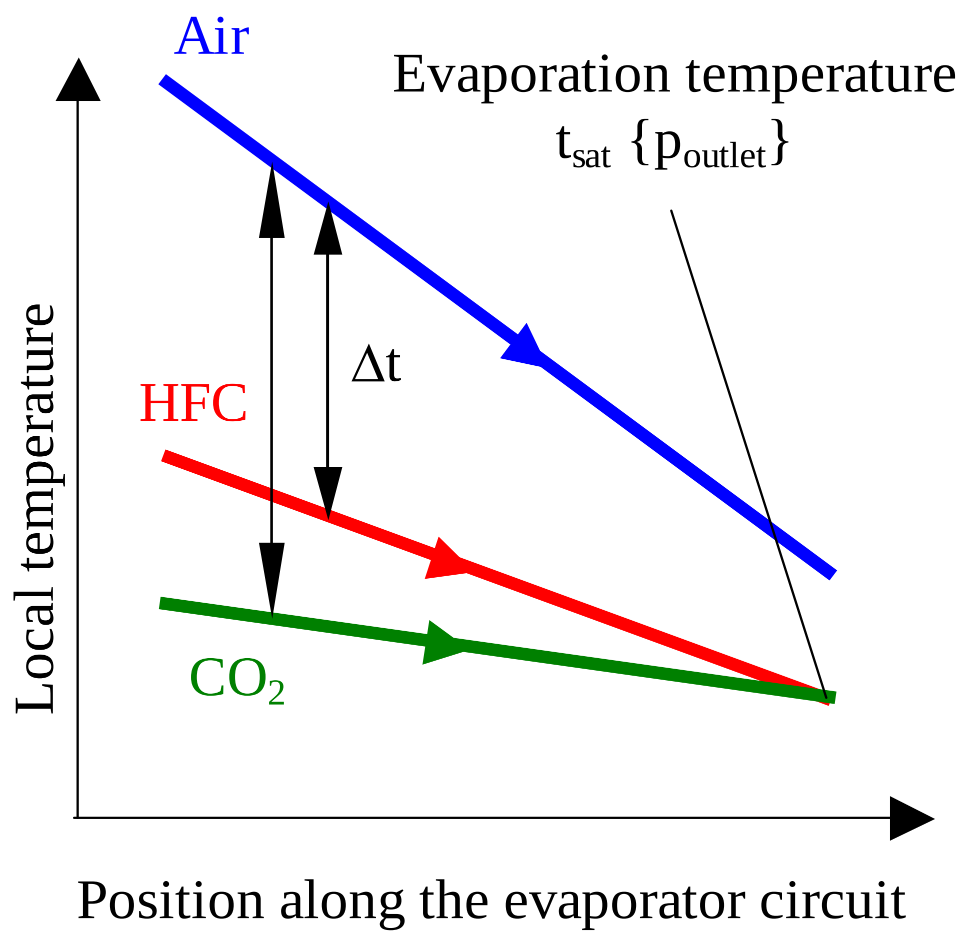
Side view of 5-row heat exchanger

Maior Design Issues 4(*4*)

Refrigerant Side

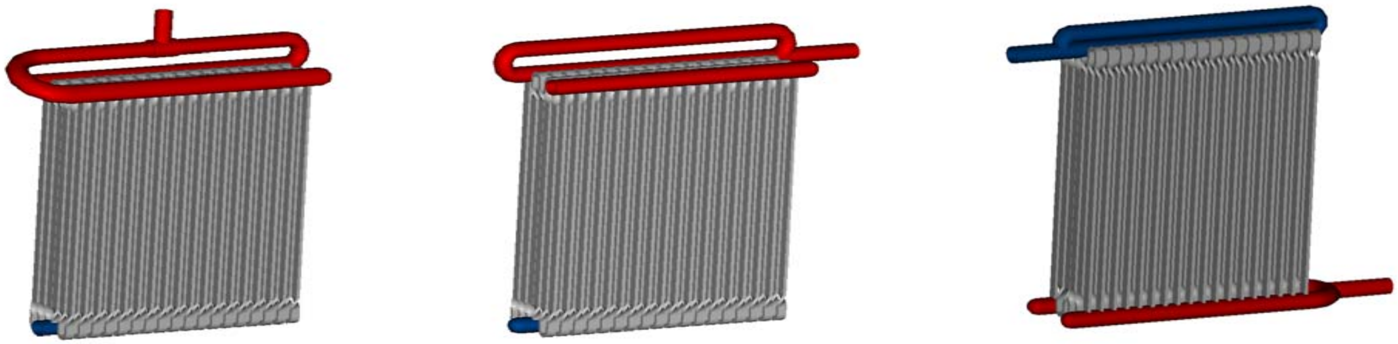
Pressure Drop

– local saturated refrigerant temperature
– ≠ tube wall temperature

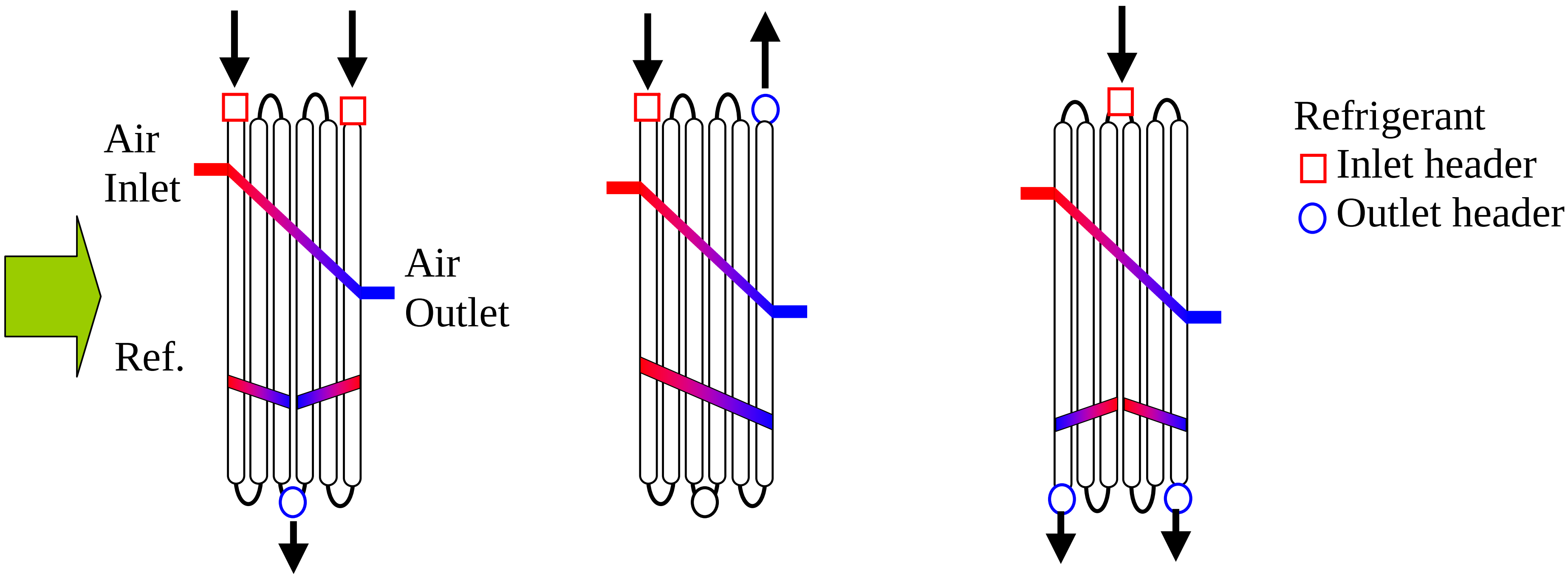


Side view of 5-row heat exchanger

Temperature Profiles (*qualitative*)



Examples of connecting the inlet/outlet headers

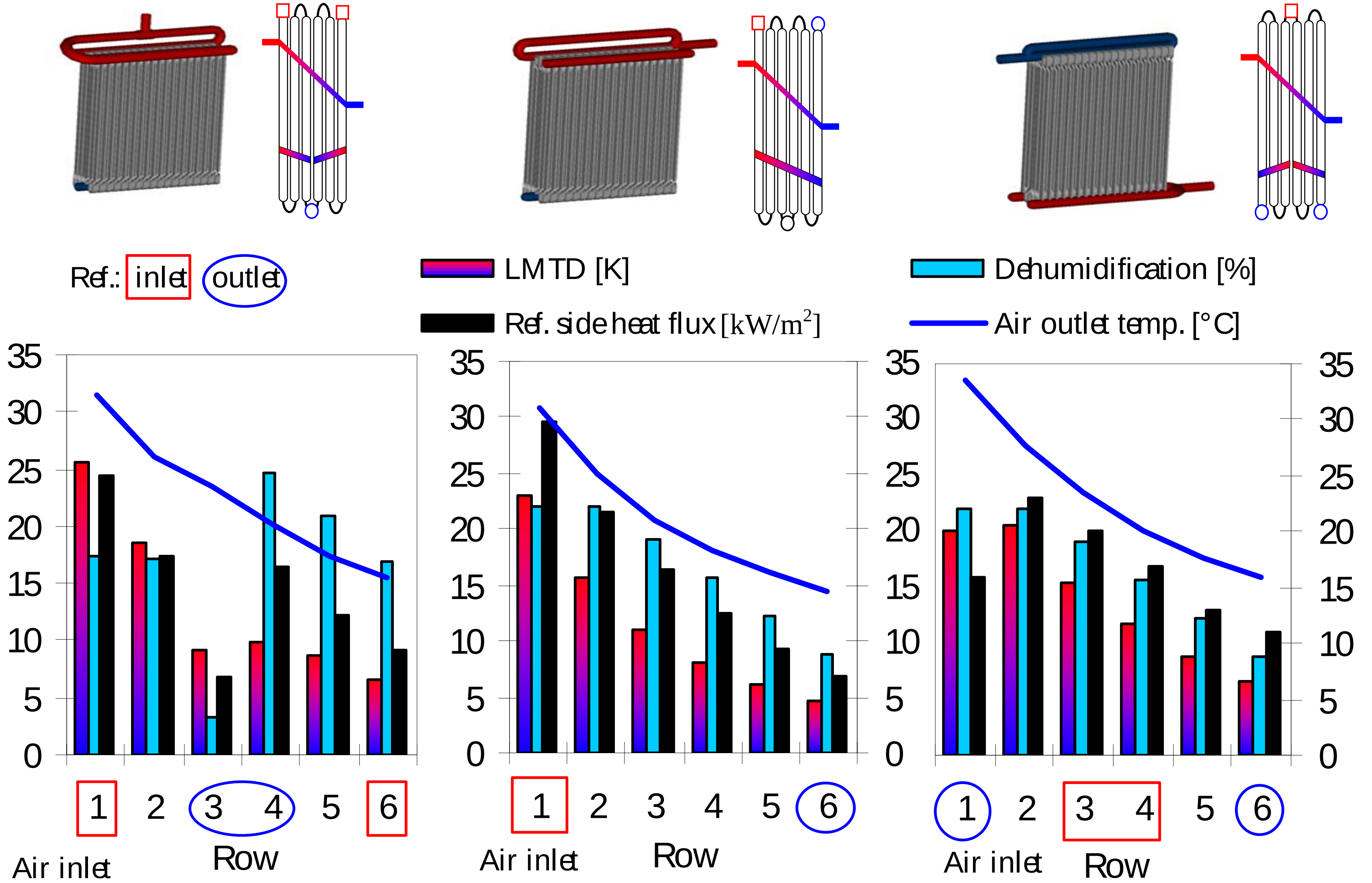


2x3-row 6-row 2x3-row

AC-mode

Performance (measured & calculated)

(inlet & outlet conditions were measured, performance / row was calculated with *hXSIM*)

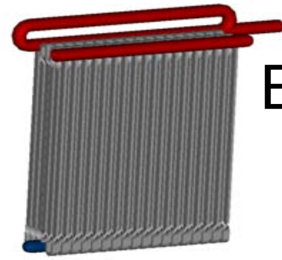


Rel. $\dot{Q}_o$ = 100 % 101 % 90 %

AC-mode

Local Heat Transfer Coefficient & Tube Wall Temperatures

B



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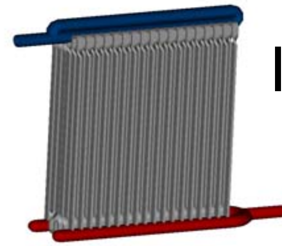
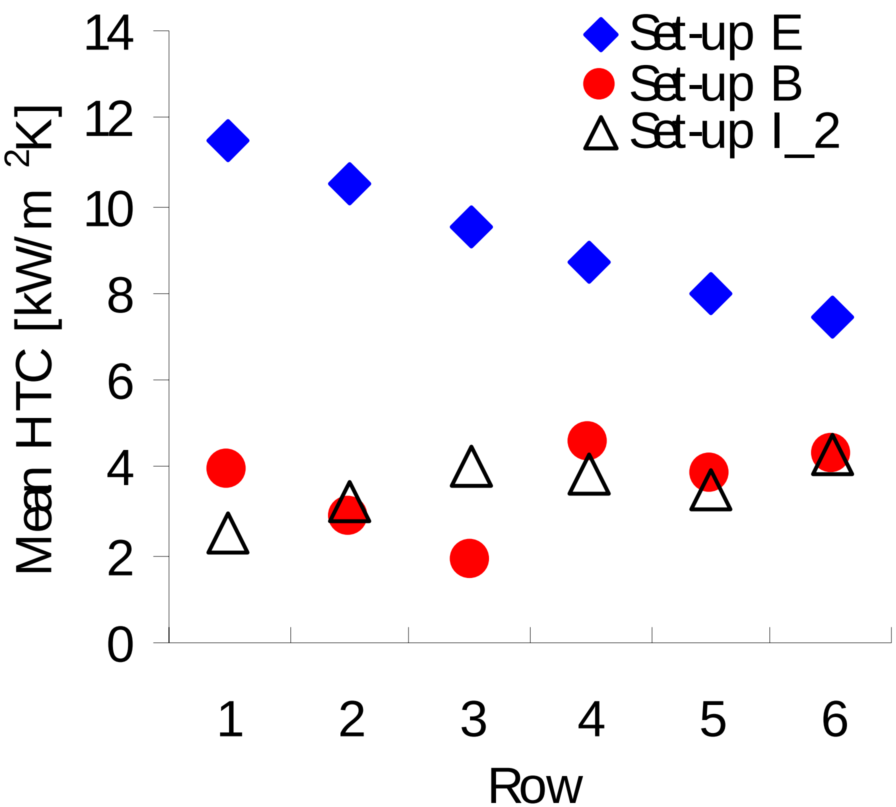


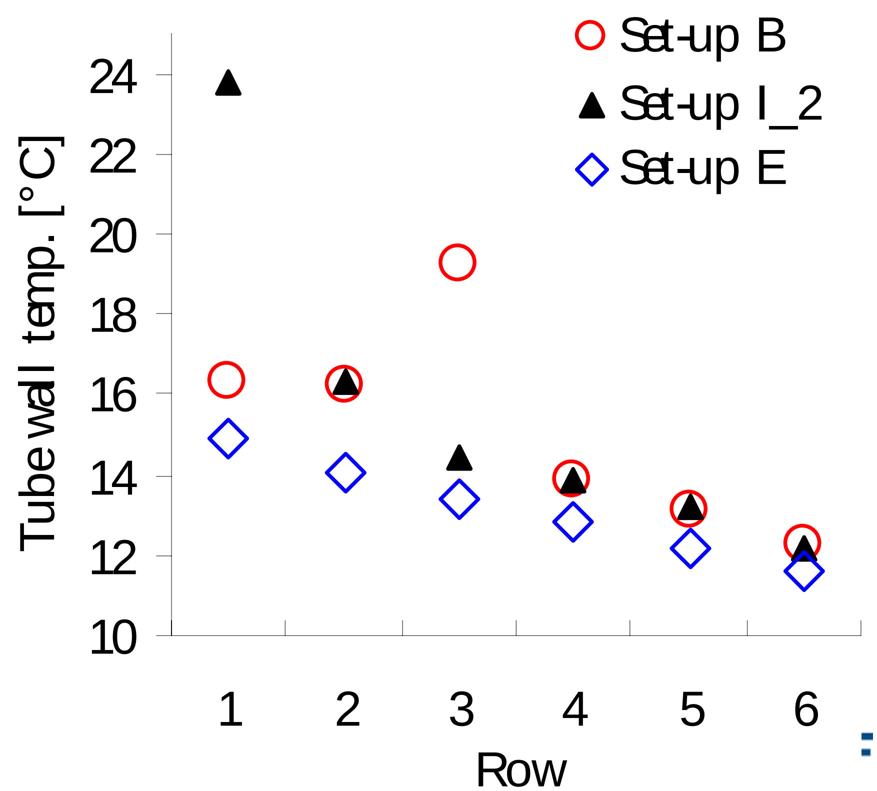
I_2

Measured: Δp_{ref} = 0.44 bar Δp_{ref} = 2.7 bar Δp_{ref} = 0,68 bar

Heat transfer coefficient / row



Tube wall temperature / row

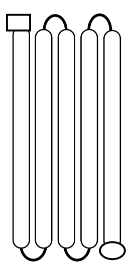


Analysis of Evaporator Designs

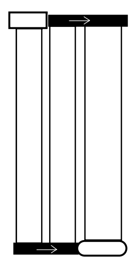
Air inlet temperature	40	[°C]
Air inlet relative humidity	40	[%]
Evaporation temperature (outlet)	1	[°C]
Vapour fraction inlet/outlet	0.49/0.95	[-]
Air volume flow rate	410	[m^3/h]
Core size of the heat exchanger (h-w-d)	200-210-50	[mm]
Number of MPE-tubes	20	[-]
Number of microchannels per MPE-tube	32	[-]
Fin pitch	15.4	[FPI]
Refrigerant side heat transfer correlation	*VDI*	*VDI-HEAT ATLAS (1993)*
Pressure drop correlation	*Fuchs*	*FUCHS (1975)*

Evaluated Designs

side views

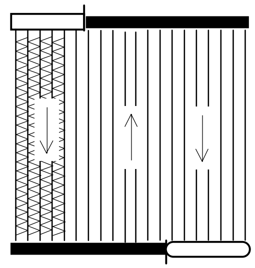


Single-pass serpentine (twist) x-row

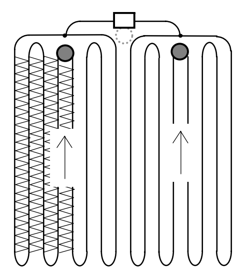


Single-pass x-row parallel flow

front views



Single-row x-pass parallel flow



Single-row x-pass serpentine flow

x=1-2-3-4-5

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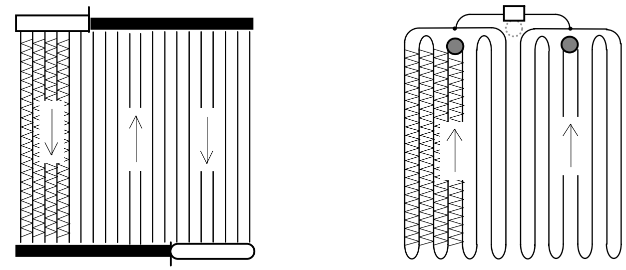
Mean Temperature Difference at varying Refrigerant Mass Fluxes

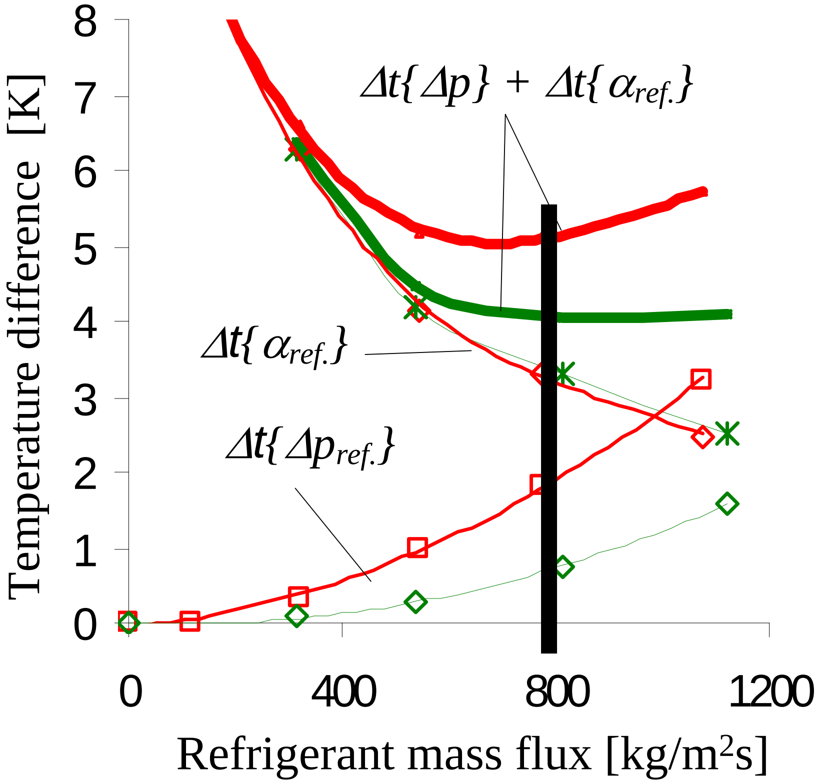
Single-pass serpentine (twist) x-row

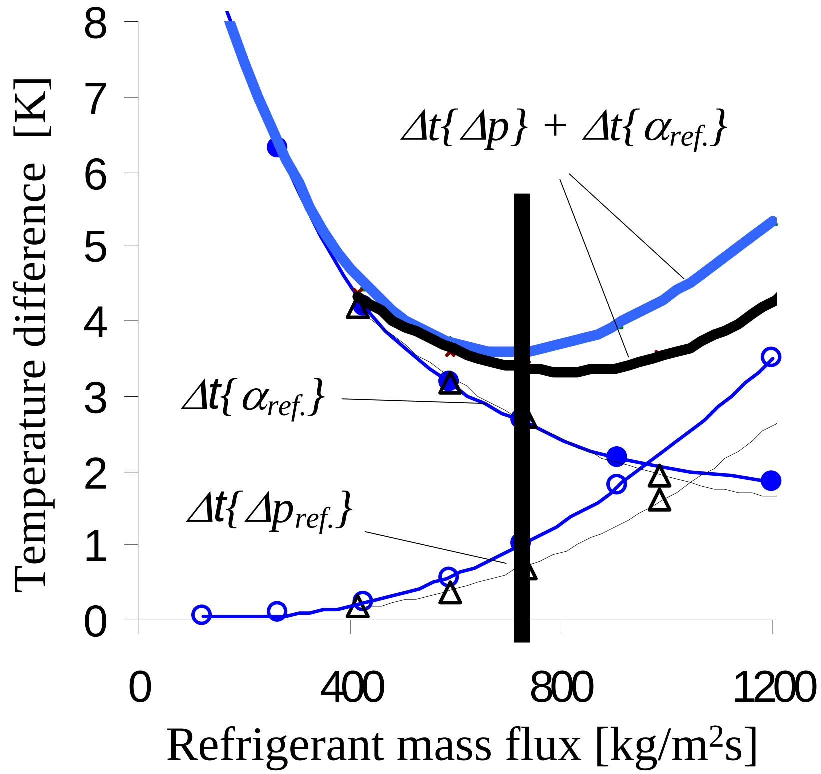
Single-pass x-row parallel flow



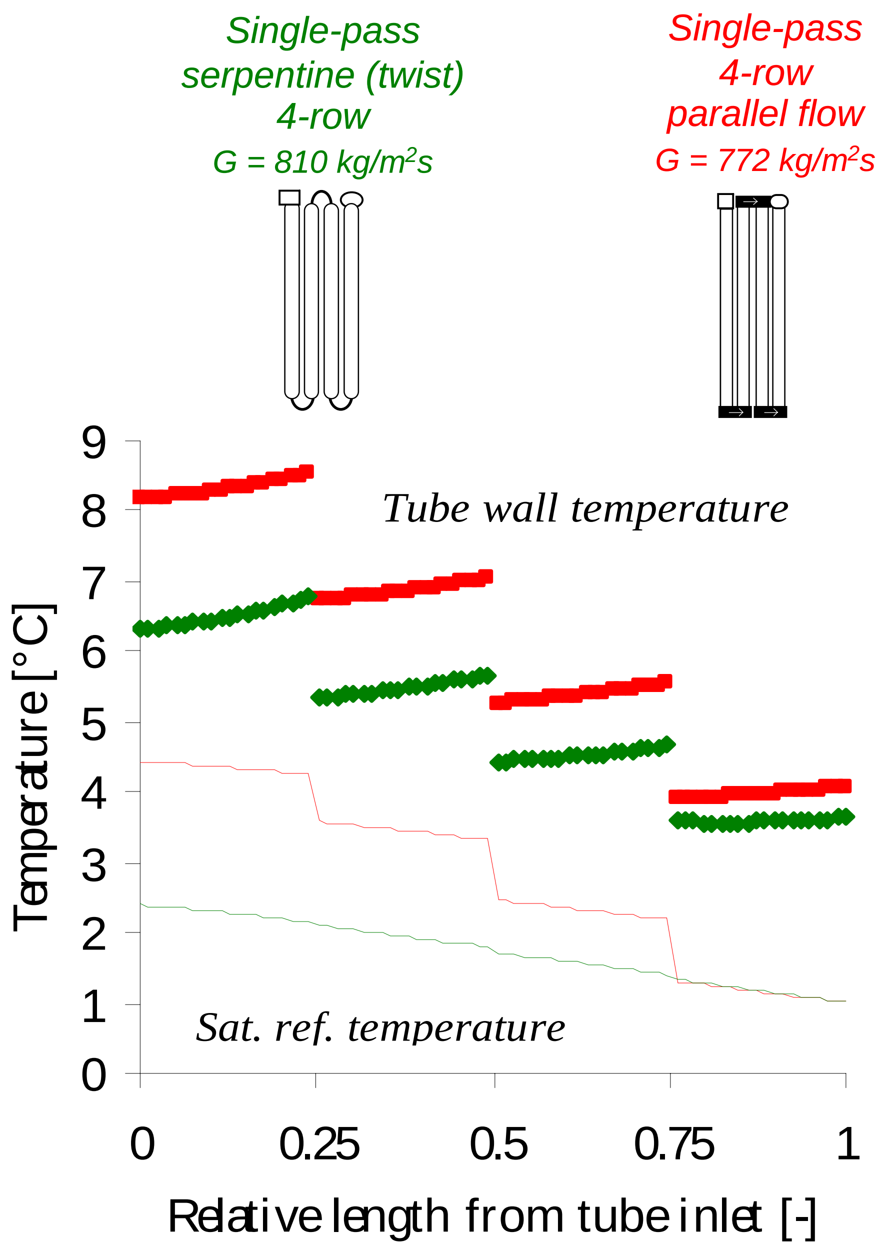
Single-row x-pass parallel flow

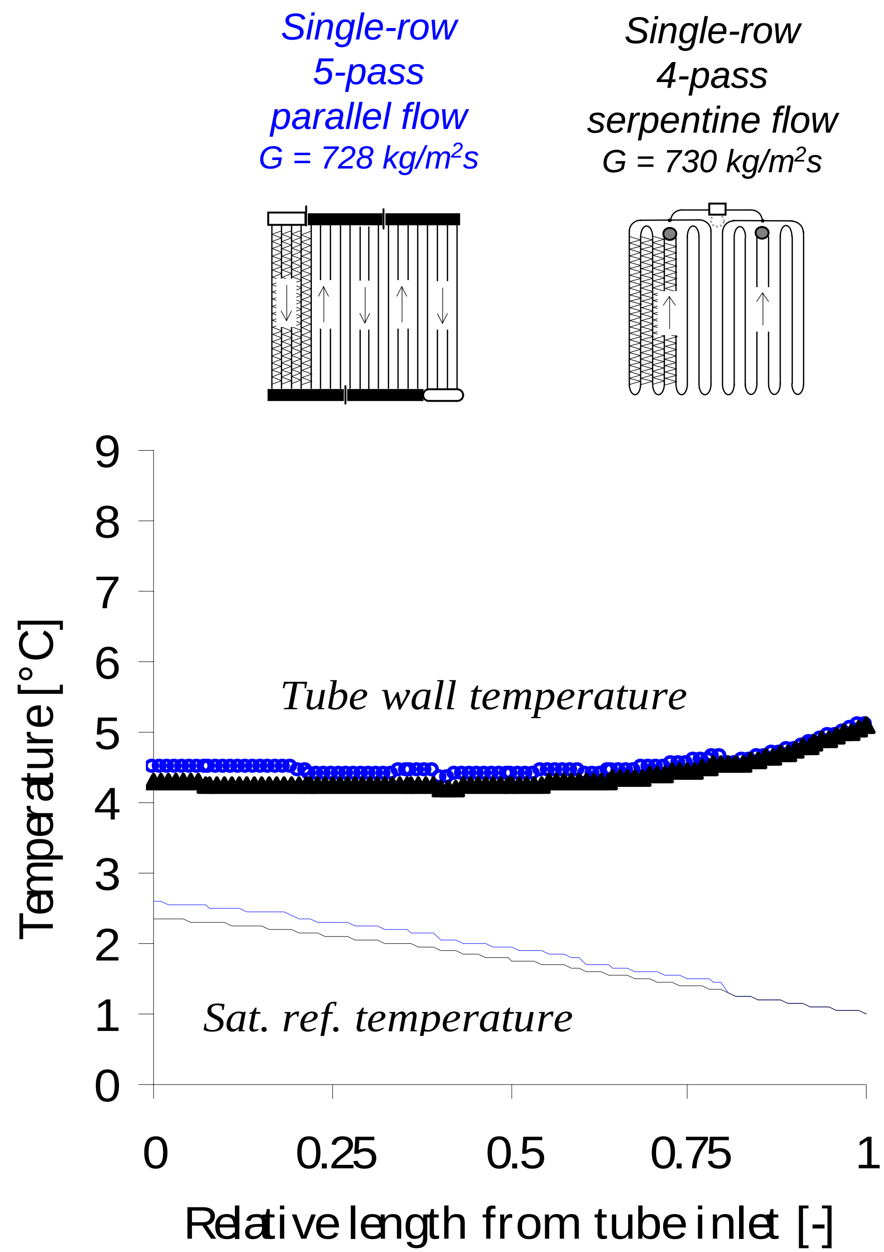
Single-row x-pass serpentine flow



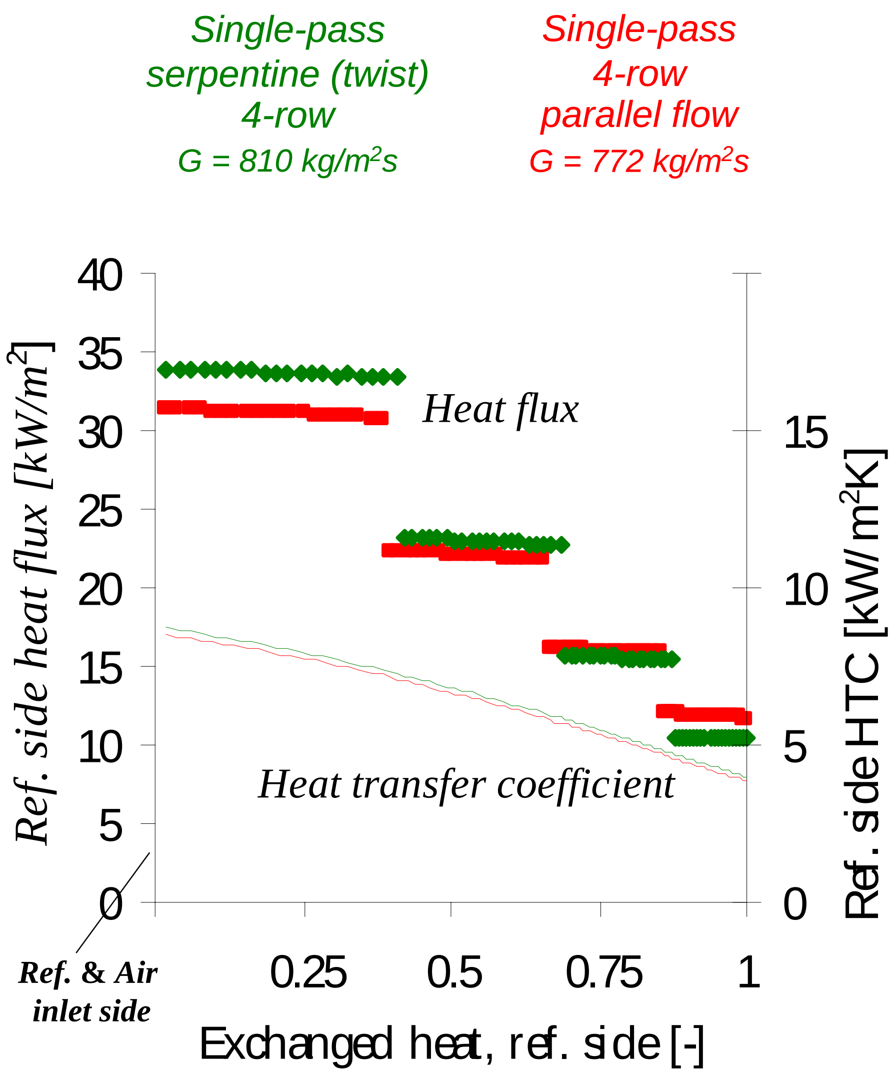


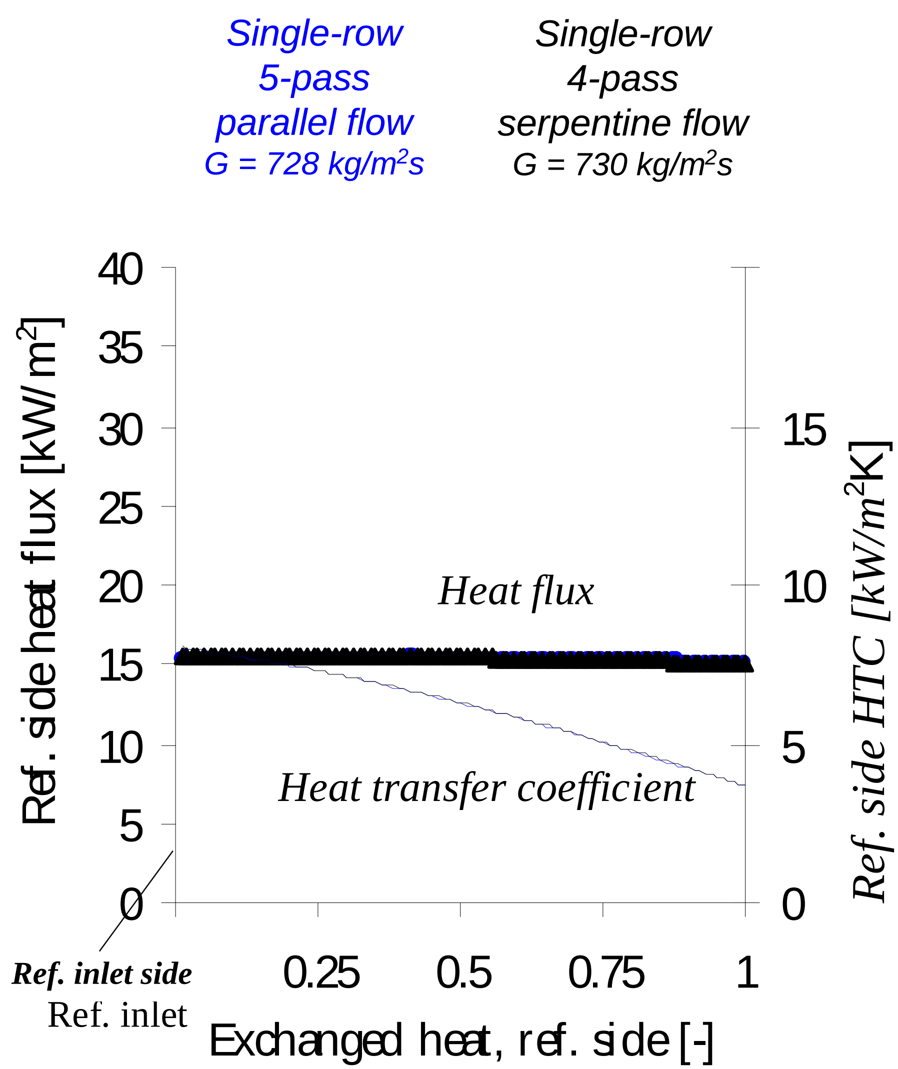
Local Temperatures





Local Heat Flux and Refrigerant Side Heat Transfer Coefficients





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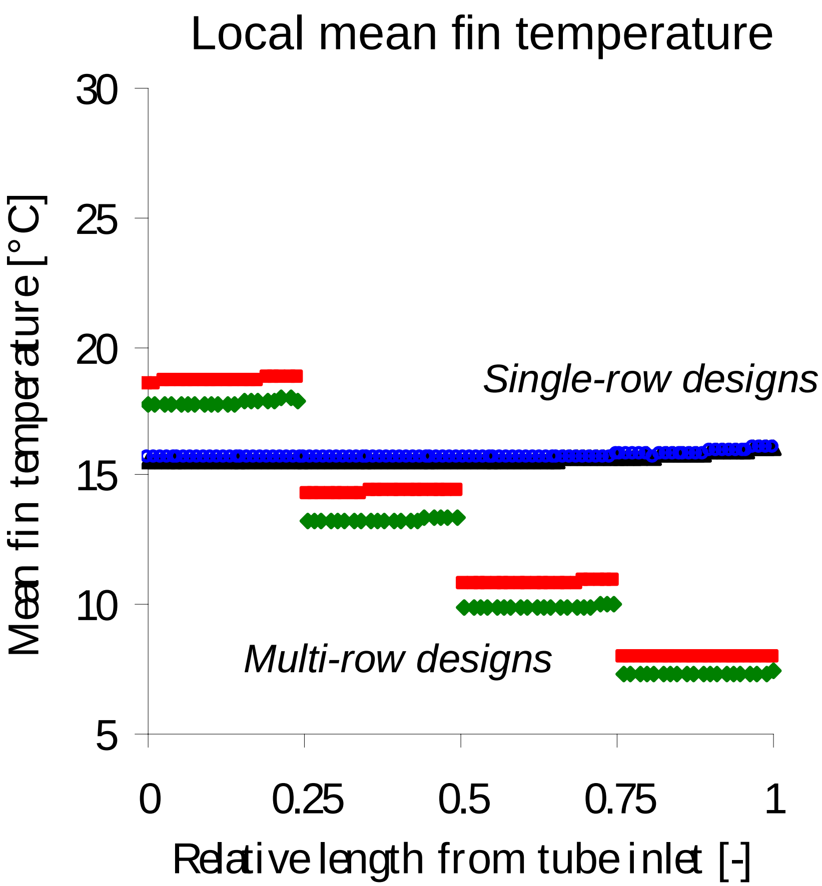
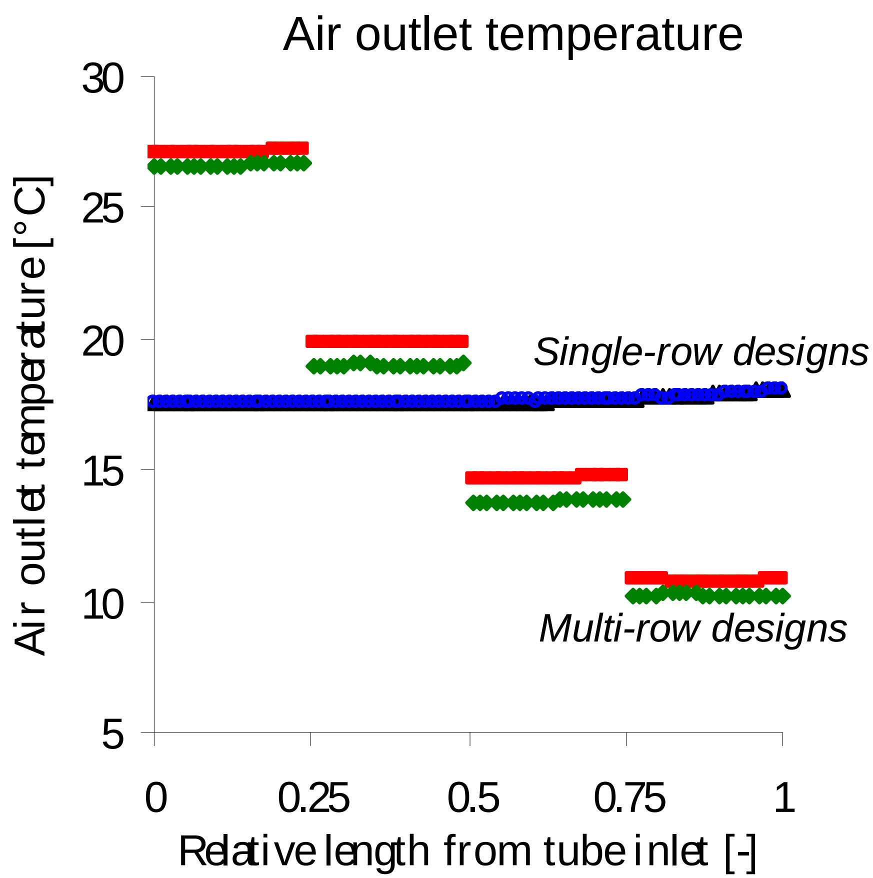
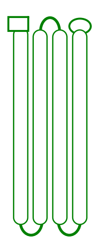
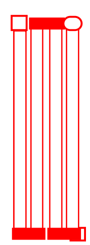
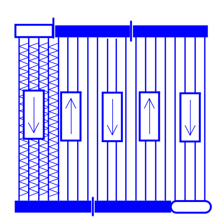
Local Mean Fin Temperature and Air Outlet Temperature

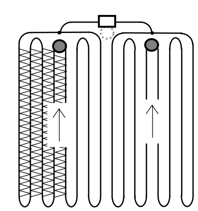












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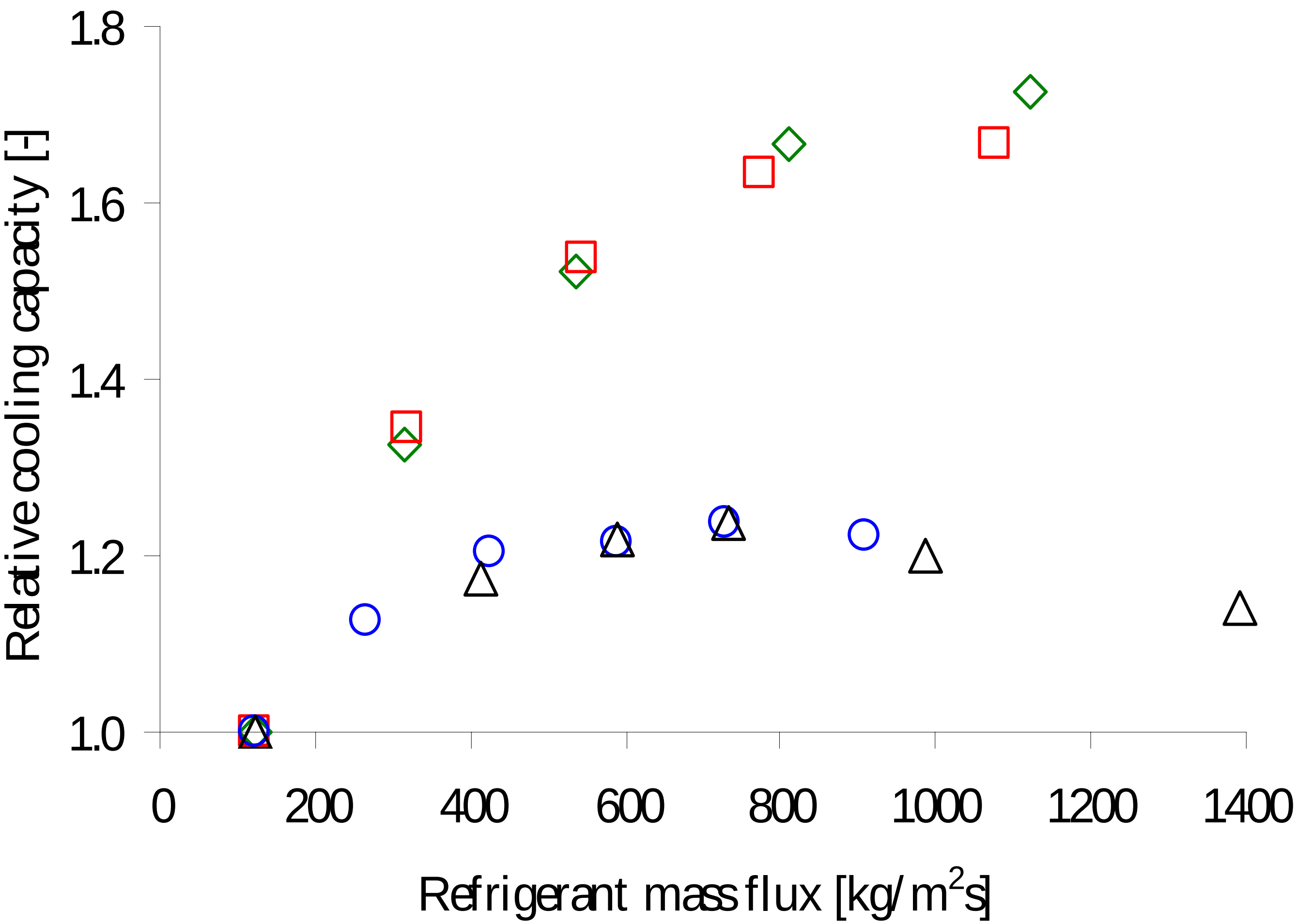
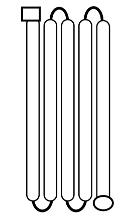
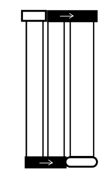
Relative Cooling Capacity versus Refrigerant Mass Flux

Pull-down conditions (t_{air}=40°C, t_o=1°C, fixed ref. inlet and outlet)
Equal core size.
Baseline design (1.0), single-row single-pass heat exchanger

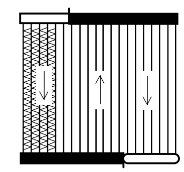




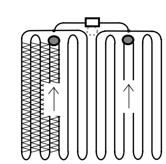
Single-pass serpentine (twist) multi-row



Single-pass multi-row parallel flow



Single-row multi-pass parallel flow



Single-row multi-pass serpentine flow

Summary Cooling Mode Investigations

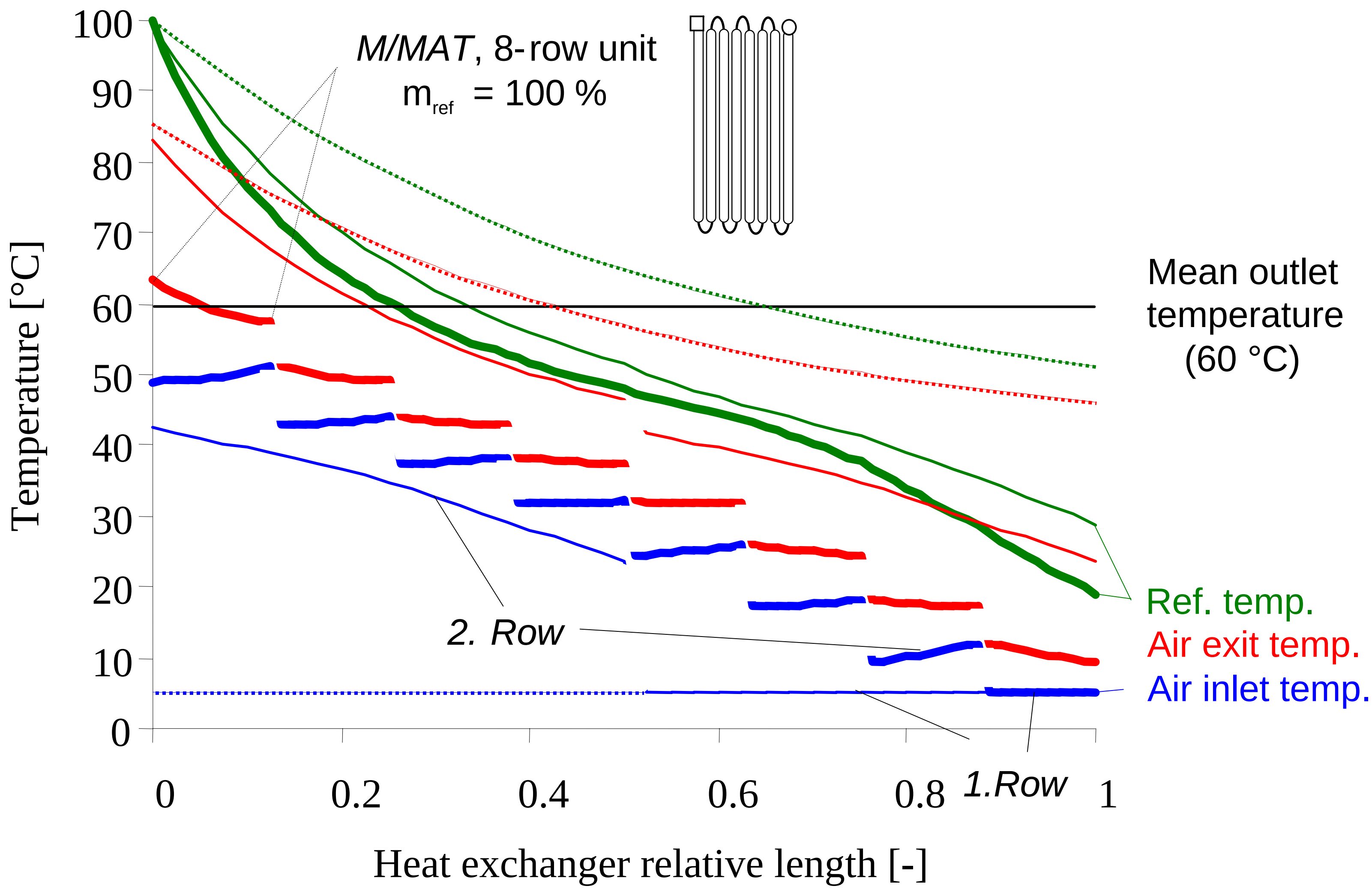
- The heat exchanger design (multi-row or multi-pass) prescribes the 'tolerable' refrigerant side pressure drop.
- The highest capacity/core volume can be obtained with serpentine multi-row designs.
- Uniform refrigerant distribution is a major issue, since the refrigerant flow is mostly unmixed inside the heat exchanger.
- Refrigerant mass flux inside the tubes has to be higher than 400 to 500 kg/m^{2}s.

<u>As presented at the 2003 VDA-Alternate Refrigerant Wintermeeting:</u>

- Flash gas bypass improved airside temperature uniformity, however, the cooling capacity did not improved, due to reduced refrigerant side heat transfer coefficients.
- Pump circulation improved the performance of any heat exchanger:
  - The higher the refrigerant mass flux the higher the heat transfer coefficients.
  - Excellent air temperature uniformity, due to single phase inlet conditions.

Airside Temperature Distribution of Different Heat Ex. Designs

equal capacity

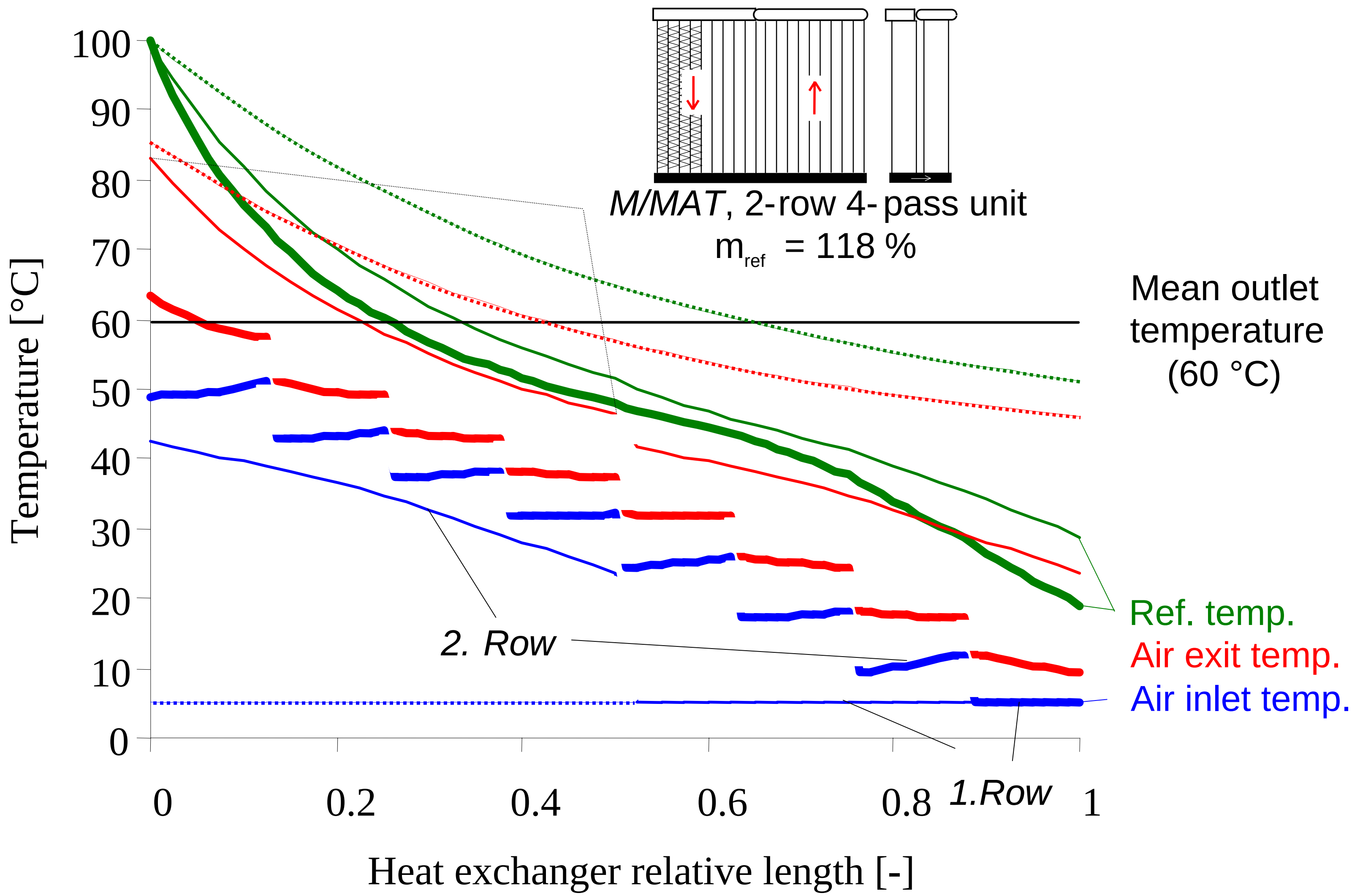


M/MAT = Maximum / Minimum Airside Temperature

HP-mode

Airside Temperature Distribution of Different Heat Ex. Designs

equal capacity

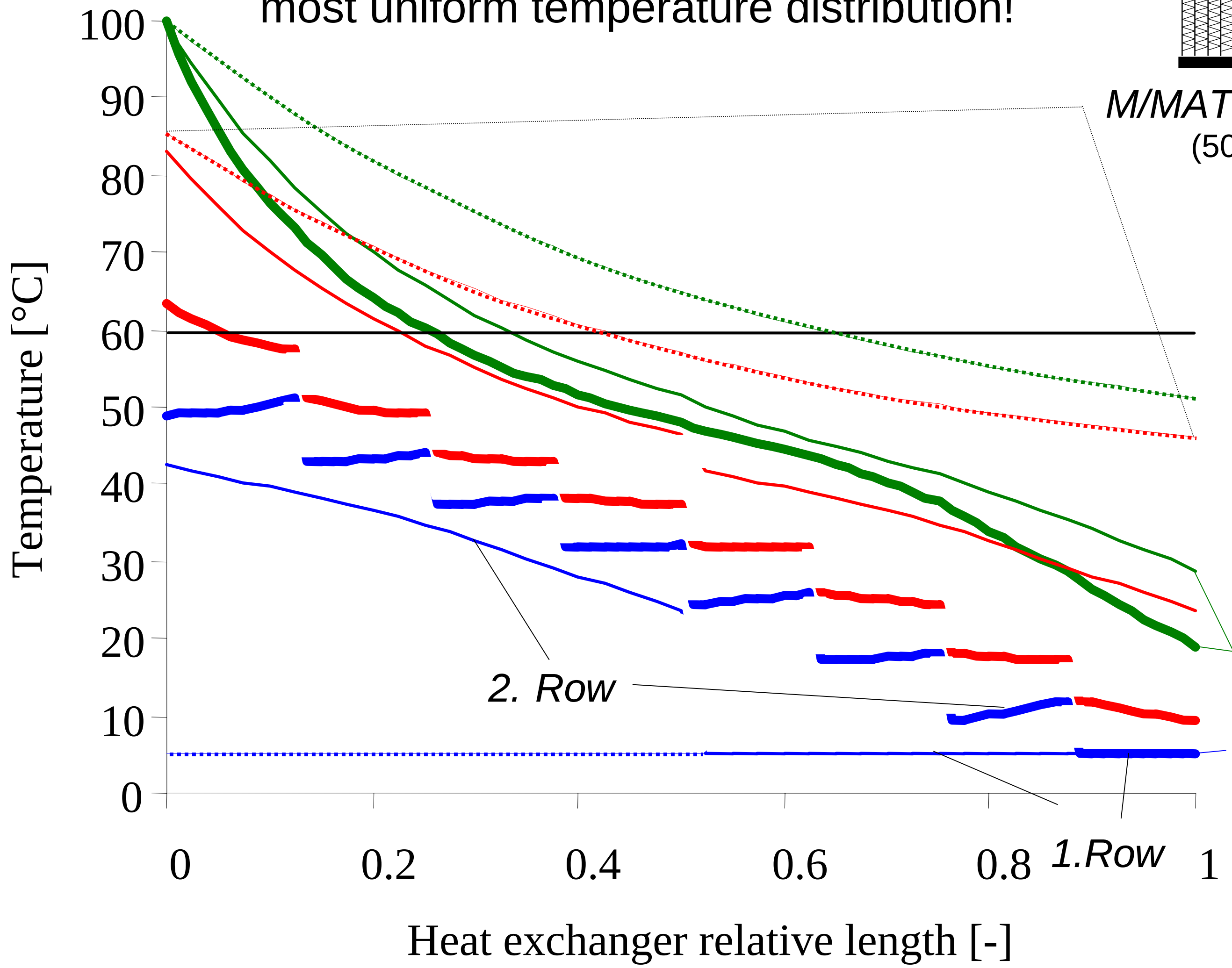


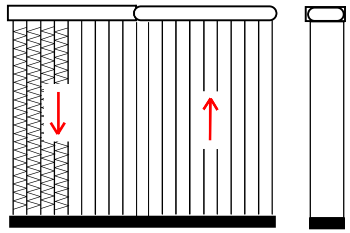
HP-mode

M/MAT = Maximum / Minimum Airside Temperature

Airside Temperature Distribution of Different Heat Ex. Designs

equal capacity





M/MAT, 1-row 2-pass unit
(50 % airside surface)
m_{ref} = 250 %

HP-mode

M/MAT = Maximum / Minimum Airside Temperature

Conclusion 1(2)

High efficient heat exchanges can be realized due to unique properties of CO_2 as working fluid. The cross sections of the heat exchanger tubes can be reduced, due to comparable higher refrigerant side heat transfer coefficients. The airside surface can be enlarged, which increases the compactness of heat exchangers.

Multi-row concepts are recommended designs to utilize ***physical co-current flow and thermal counter current flow***. Low temperature approach values and high efficiencies can be achieved with this kind of heat exchangers.

Conclusion 2(2)

Bent tube solutions, as well as ***split fins*** should be applied to **minimize exergy losses** in heat pump mode and **improve** the **water drainage** in cooling mode operation.

Refrigerant flow distribution challenges are solved with innovative manifold concepts. ***Counter-flow Header Channels***, ***Endless Headers*** or ***Spiral-Inlays*** are recommended to improve the refrigerant flow distribution.

Uniform airside temperature distribution can be achieved with **multi-row heat exchangers**.

Acknowledgement

- Hydro Pronova (Shecco Technology)
- Visteon