NIST
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Seminar 11 - Optimization for Next Generation Systems

Optimization of Air-to-Refrigerant Evaporator with Low-GWP Refrigerants

Piotr A. Domanski

National Institute of Standards and Technology

piotr.domanski@nist.gov

KANSAS CITY

Learning Objectives

- Explain how circuitry optimization affects both heat exchanger performance and the system performance
- Describe how multi-objective optimization is needed to improve heat exchanger performance according to multiple performance criteria
- Understand the potentials of buildings as virtual batteries
- Understand how to use AMPL for building modeling and optimization

Acknowledgements

Honghuyun Cho

Chosun University, S. Korea

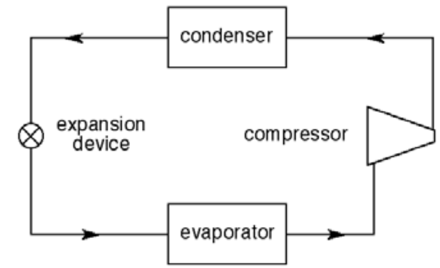
This presentation is based on the paper:

Cho, H., Domanski, P.A., 2016. Optimized Air-to-Refrigerant Heat Exchanger with Low-GWP Refrigerants, 12th IIR Gustav Lorentzen Conference on Natural Working Fluids, Edinburgh, UK, August 21-24, 2016. DOI:10.18462/iir.gl.2016.1140

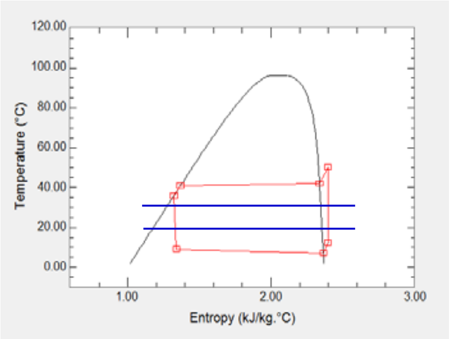
Outline/Agenda

- Evaluation of Alternative Refrigerants Performance
- Studied Case
  - Refrigerants
  - Evaporator Design and Air Distribution
- Refrigerant Circuitry Optimization Process
- Optimization Results
- Conclusions

Evaluation of Alternative Refrigerant Performance



- Cycle simulations
  - Semi-theoretical models
- Drop-in system tests with 'soft optimization'
  - Changed: expansion device
    refrigerants charge
    lubricant
  - Unchanged: compressor (volumetric displacement, design)
    evaporator and condenser (refrigerant circuitry)



Question:

How much different will be air conditioner capacity and COP when the evaporator circuitry is optimized?

- Tests in optimized systems

Abdelaziz, O., Shrestha, S., Munk, J., Linkous, R., Goetzler, W., Guernsey, M., Kassuga, T., 2015. Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners, ORNL/TM-2015/536

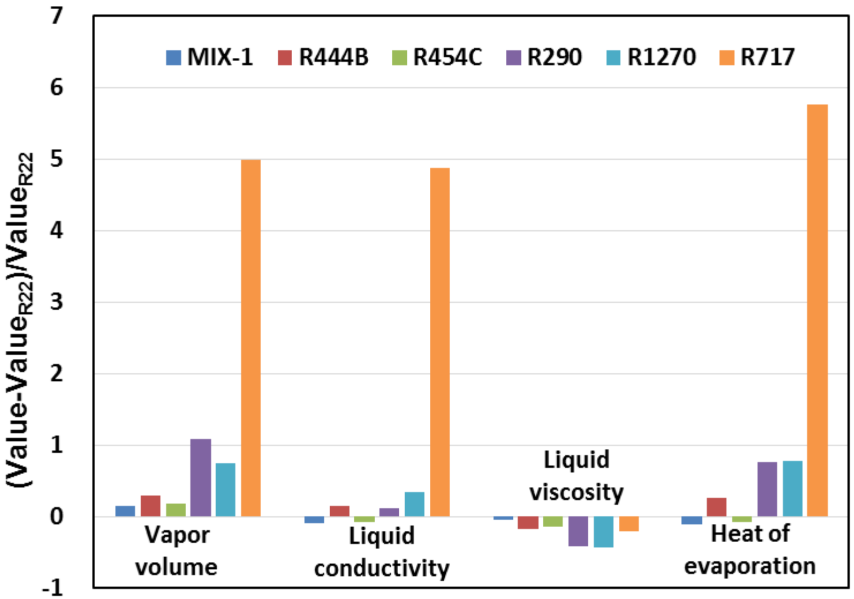
Studied Refrigerants

Fluid	Composition	Mass fraction (%)	Temperature glide (K)	Safety classification	GWP
R22 group					
R22	**R22**	**100**	**0**	**A1**	**1760**
MIX-1	R32/R125/R134a/R1234yf	13/13/31/43	4.0	A1*	904
R444B	R32/R152a/R1234ze(E)	41.5/10/48.5	7.9	A2L	295
R454C	R32/R1234yf	21.5/78.5	6.1	A2L	146
R290	R290	100	0	A3	3
R1270	R1270	100	0	A3	2
R717	R717	100	0	B2	<1
R410A group					
R410A	**R32/R125**	**50/50**	**0.1**	**A1**	**1924**
MIX-2	R32/R1234yf/R1234ze(E)	68/26/6	1.7	A2L*	461
R32	R32	100	0	A2L	677
MIX-3	R32/134a/1234ze(E)	76/6/18	2.7	A2L*	593
R452B	R32/R125/R1234yf	67/7/26	1.0	A2L	676
R447A	R32/R125/R1234ze(E)	68/3.5/28.5	3.8	A2L	572
R744	R744	100	0	A1	1

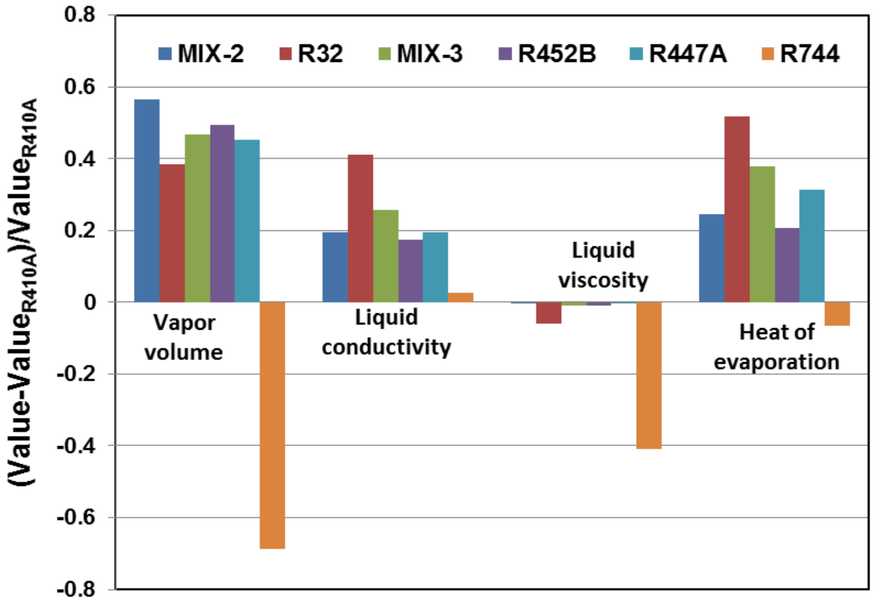
* Blend not classified by ASHRAE

Refrigerant Properties
referenced to R22 or R410A

R22 group



R410A group

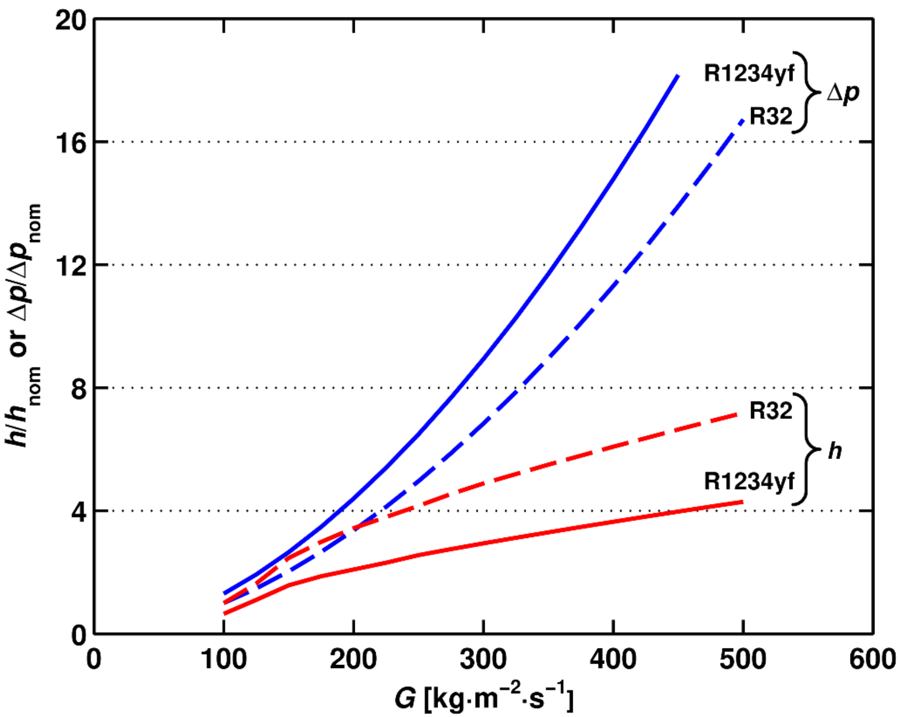


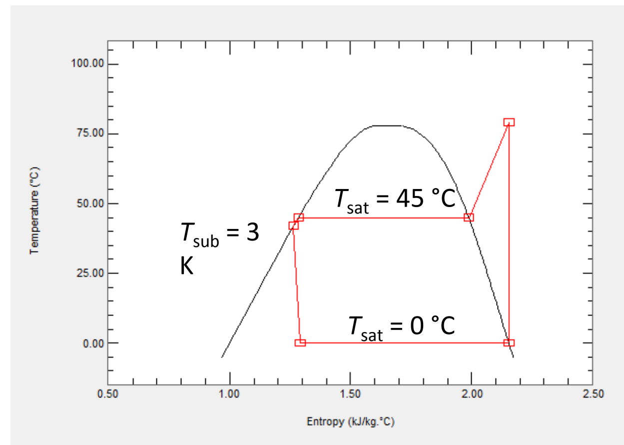
Liquid conductivity → heat transfer coefficient

Liquid viscosity → pressure drop

Vapor specific volume → pressure drop, dT_{sat}/dP

Effect of refrigerant mass flux on heat transfer coefficient (*h*) and pressure drop (Δ*p*)





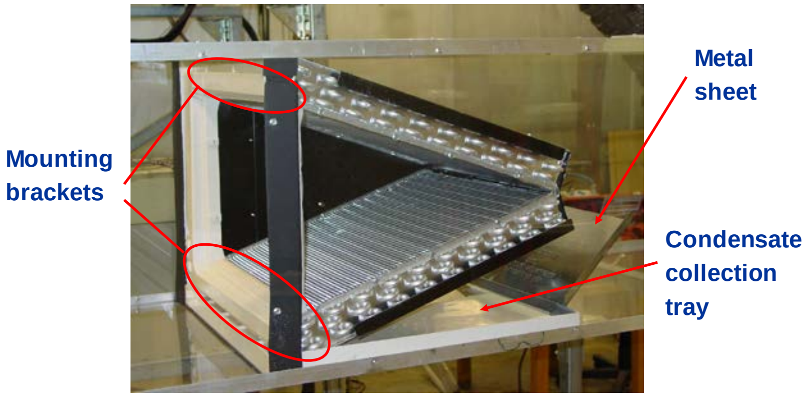
All values are normalized by *h* and Δ*p* values for R-32 at G = 100 kg·m^2·s^{-1}.

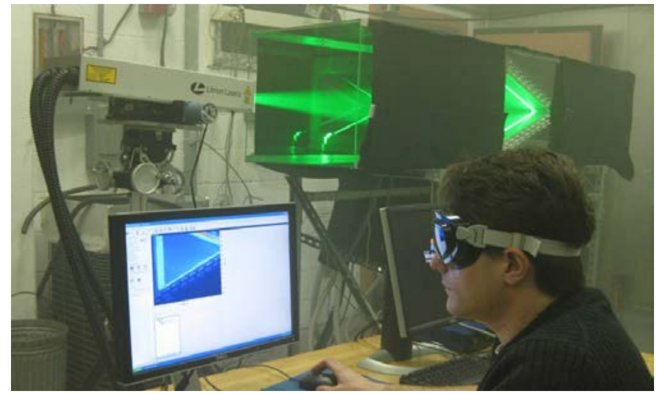
These are average values across the evaporator.

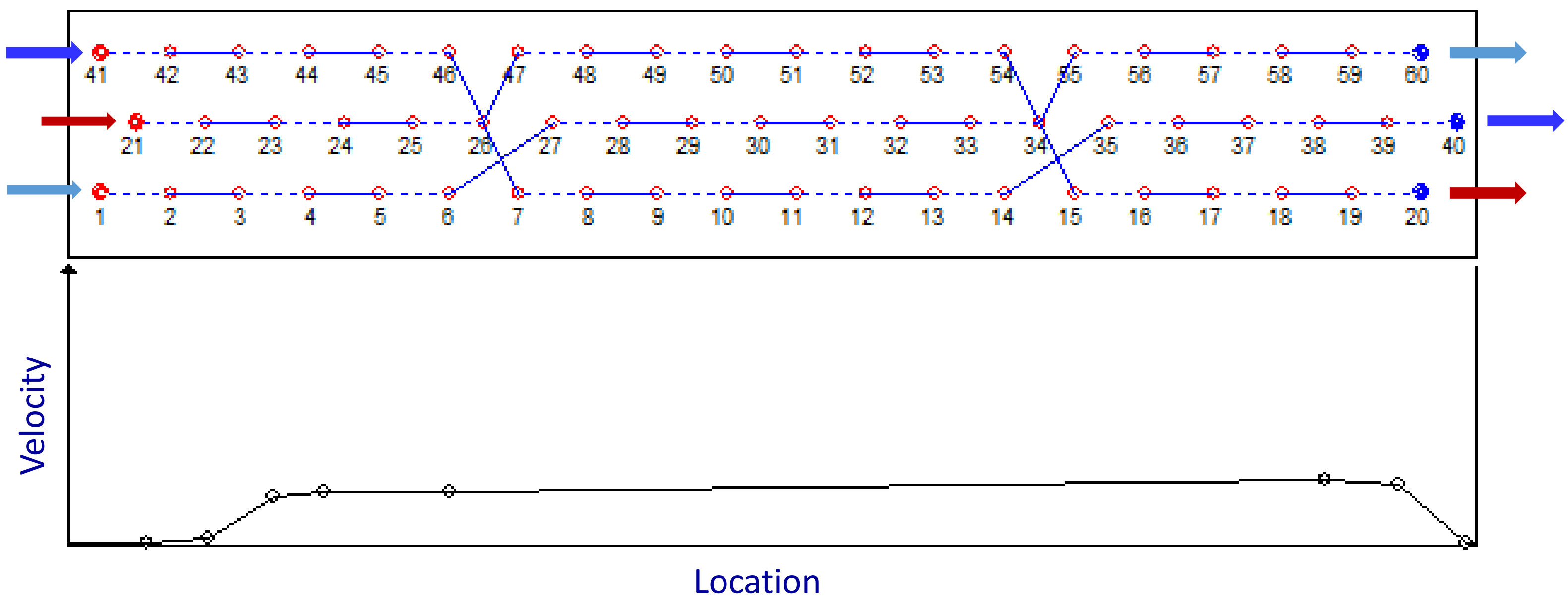
(Smooth tube, D = 7.0 mm, q=10.0 kW·m^2)

Brignoli, R., Brown, J.S., Skye, H., Domanski, P.A., 2017. Refrigerant Performance Evaluation Including Effects of Transport Properties and Optimized Heat Exchangers, Int. J. Refrig., 80: 52-65. doi:10.1016/j.ijrefrig.2017.05.014

Evaporator Design and Air Distribution







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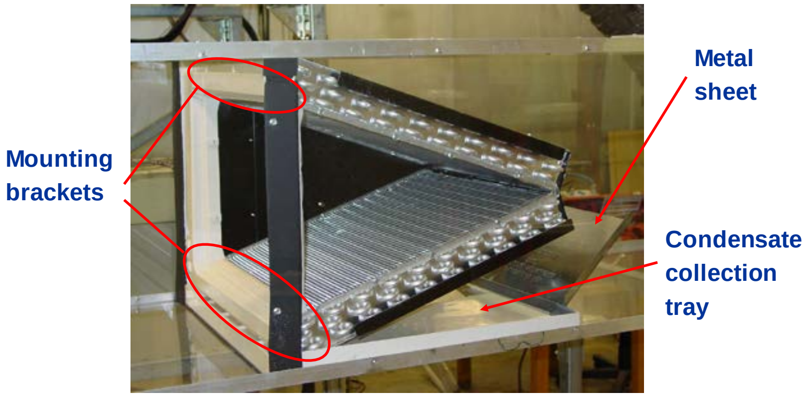

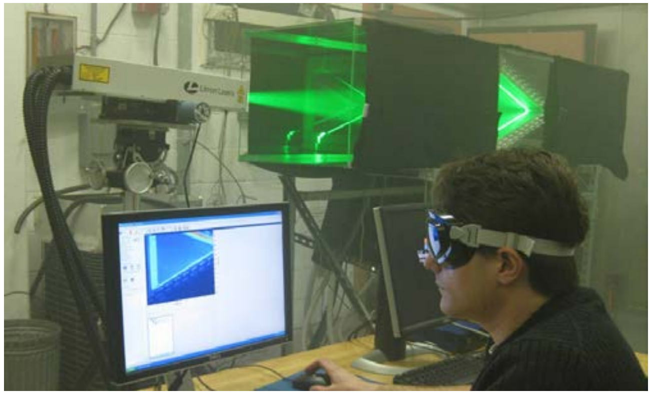

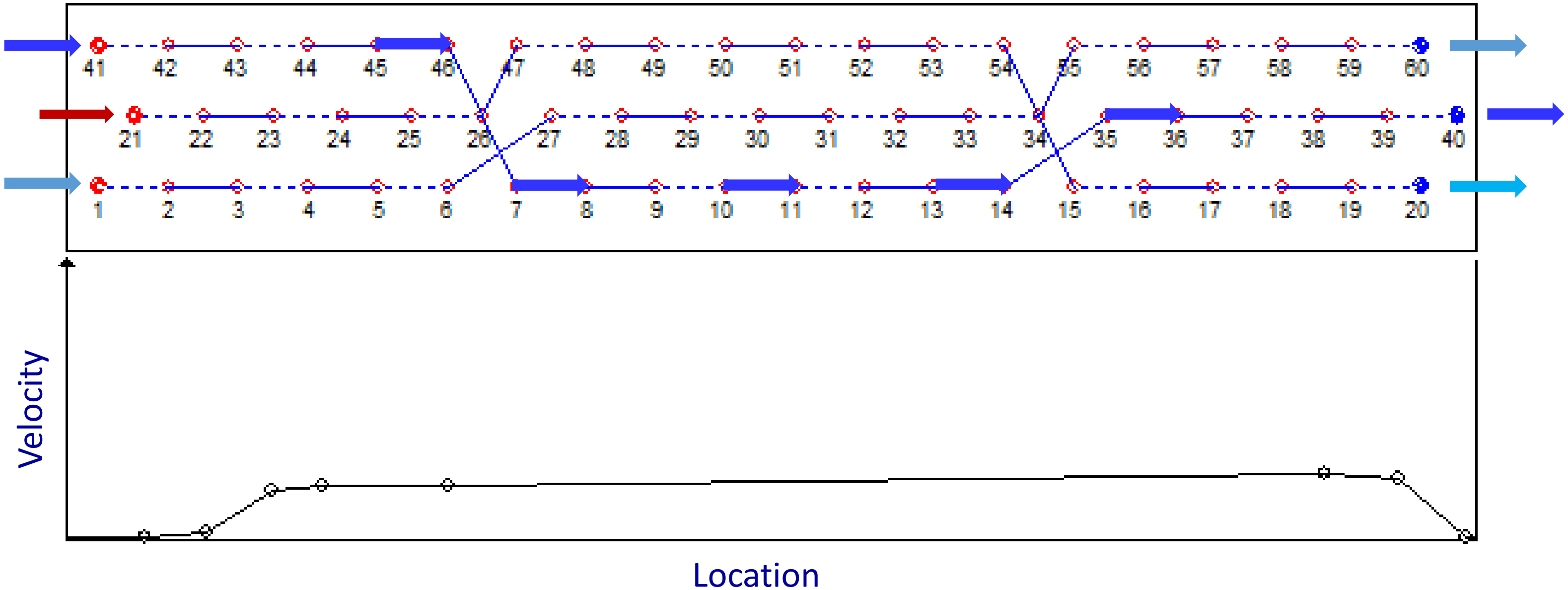

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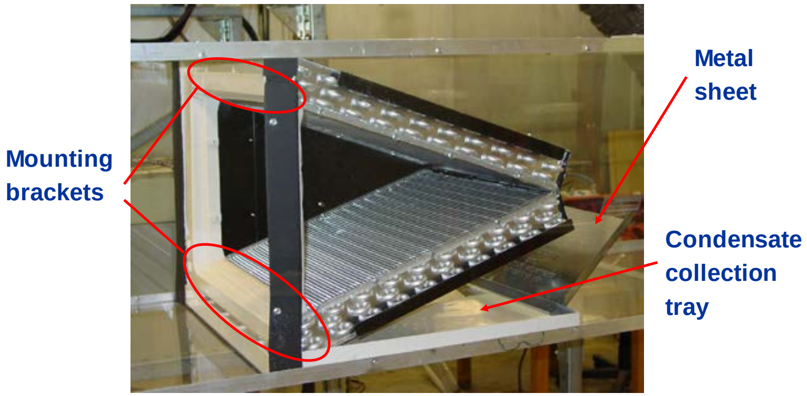
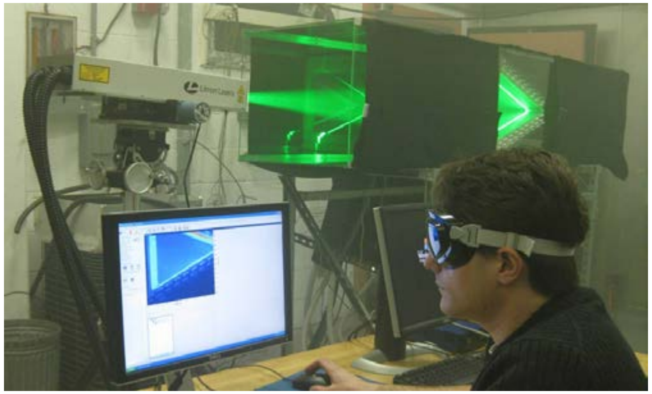
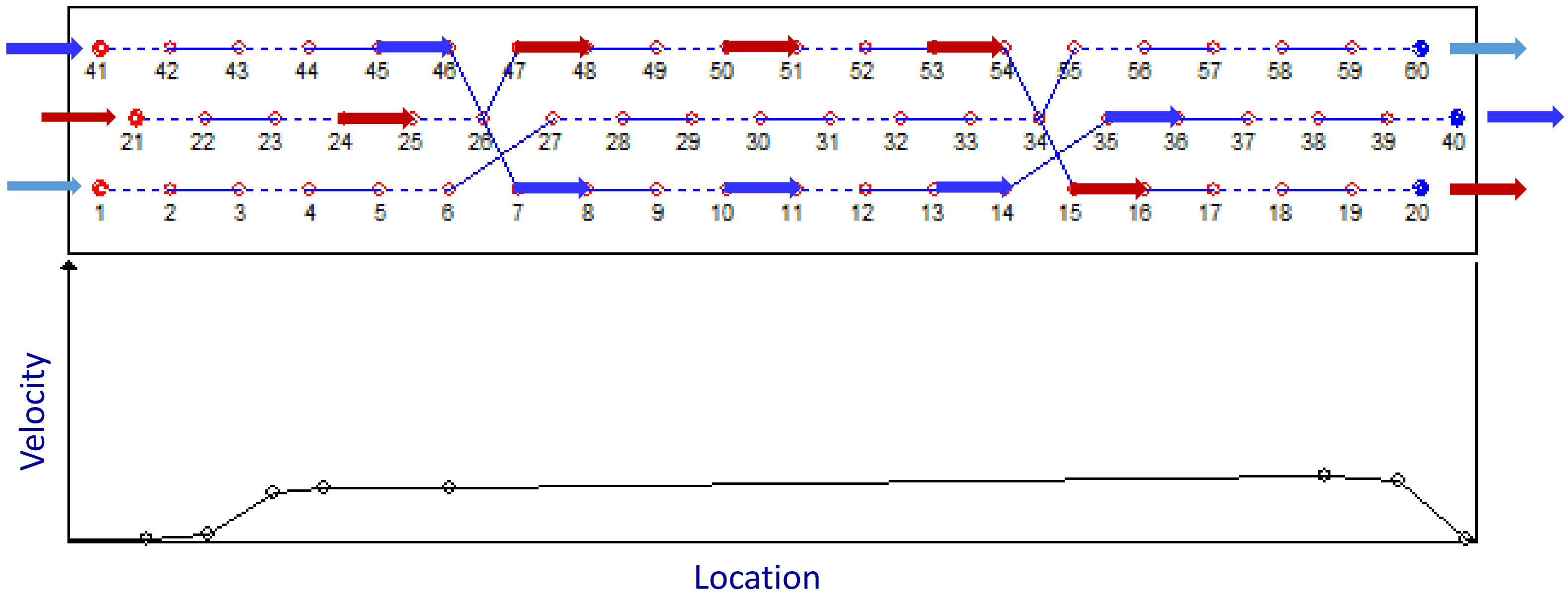
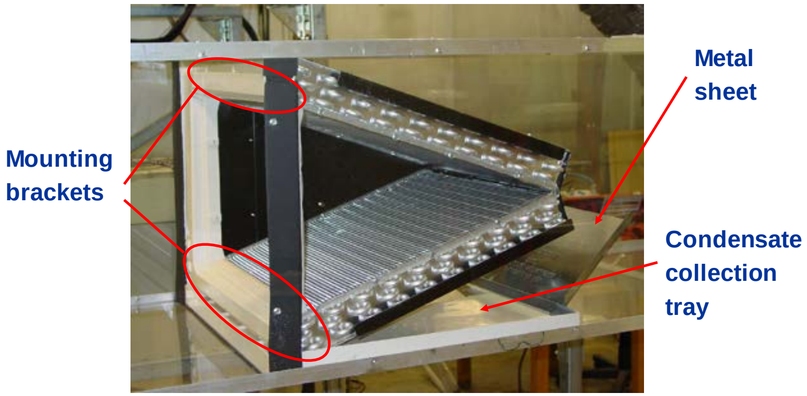
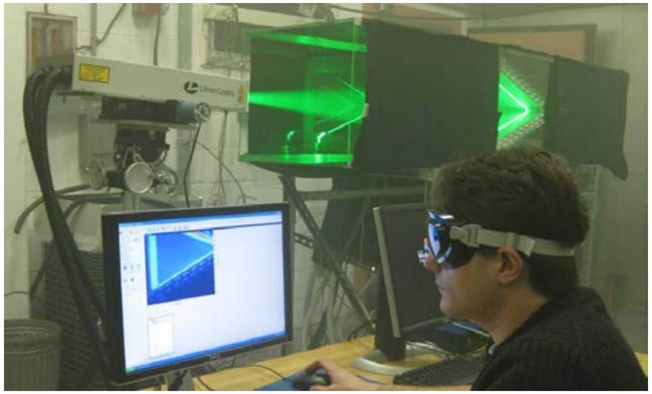


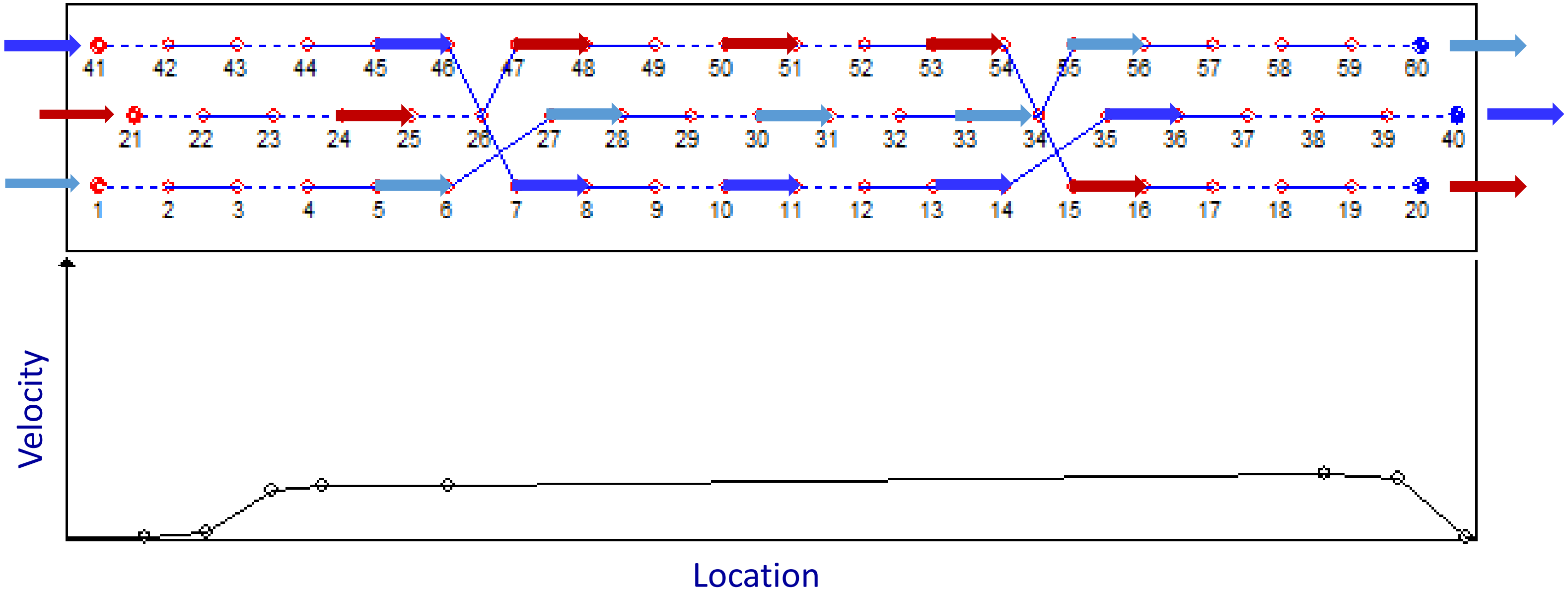




Evaporator Design and Air Distribution





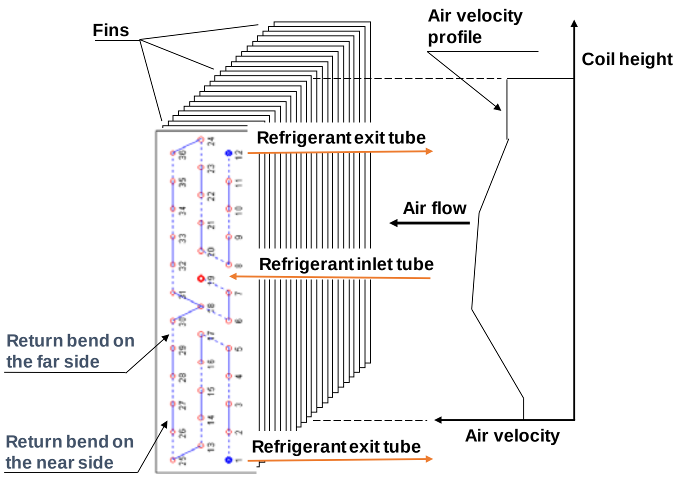


Refrigerant Circuitry Optimization Process

EVAP-COND: simulation package with refrigerant circuitry optimization module

Features:

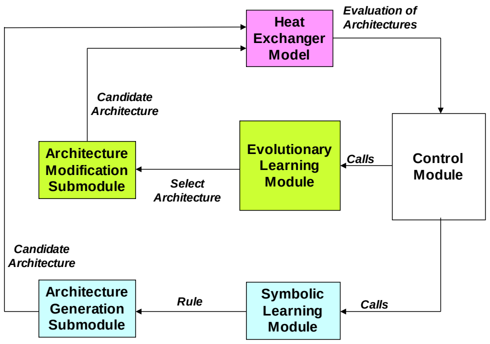
- Tube-by-tube or tube sectional simulation
- One-dimensional, non-uniform air distribution
- Simulation of refrigerant distribution
- Refrigerant circuitry optimization (ISHED)
  - evolutionary computation
  - knowledge based + symbolic learning



Optimization parameters:

- Number of members in a population: 40
- Number of populations: 300

12000 members evaluated in a single optimization run



Operating Conditions

Inlet air condition

Dry-bulb temperature: 26.6 °C

Relative humidity: 50 %

Pressure: 101.325 kPa

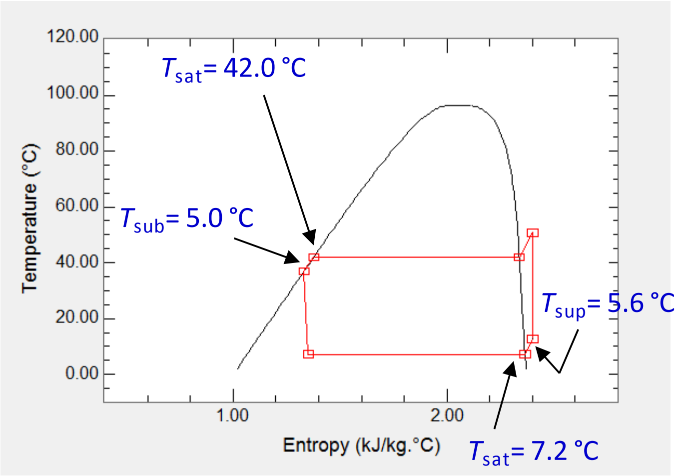
Refrigerant conditions

Exit dew-point temperature: 7.2 °C

Exit superheat: 5.6 °C

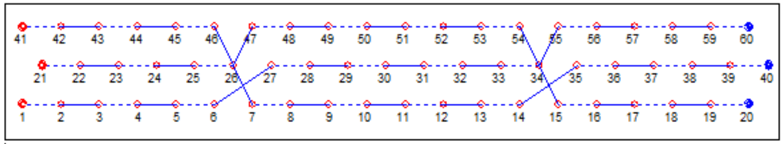
Inlet quality:

Refrigerant	Inlet quality (%)
R22	17.6
MIX-1	22.2
R444B	18.7
R454C	22.4
R290	20.8
R1270	20.3
R717	10.8
R410A	22.0
MIX-2	19.3
R32	17.6
MIX-3	18.1
R452B	19.7
R447A	18.6
R744	28.4



Three refrigerant circuitries considered

- Original

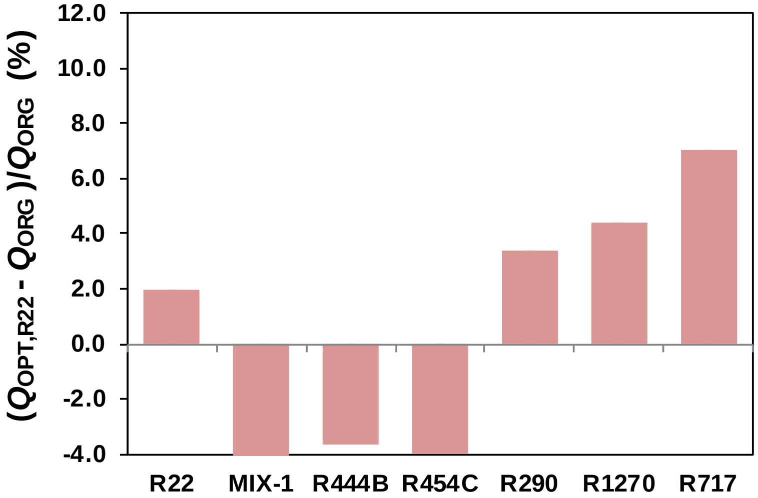


- Optimized for R22 or R410A
- Optimized for each refrigerant

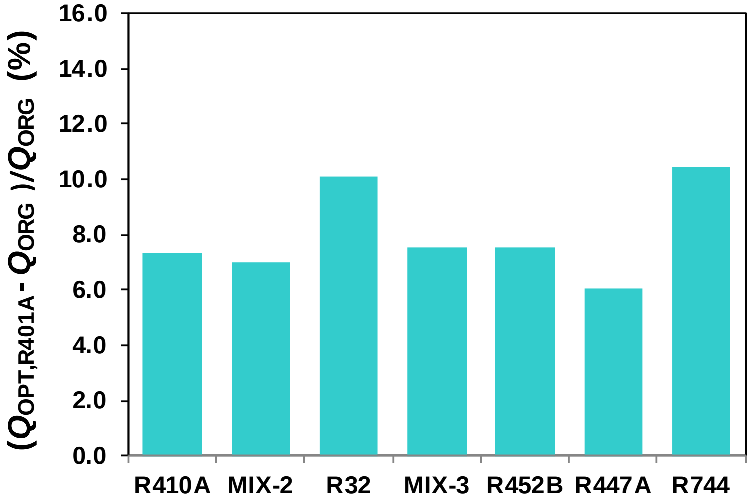
Capacity with Circuitry Optimized for R22 & R410A

referenced to the capacity with the original circuitry

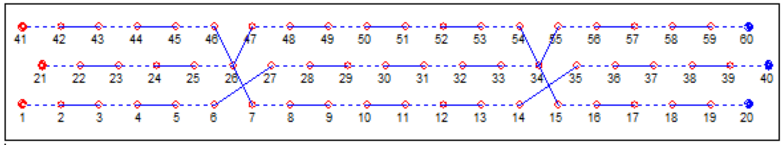
R22 group



R410A group



Original circuitry:



Optimized circuitries:

R22

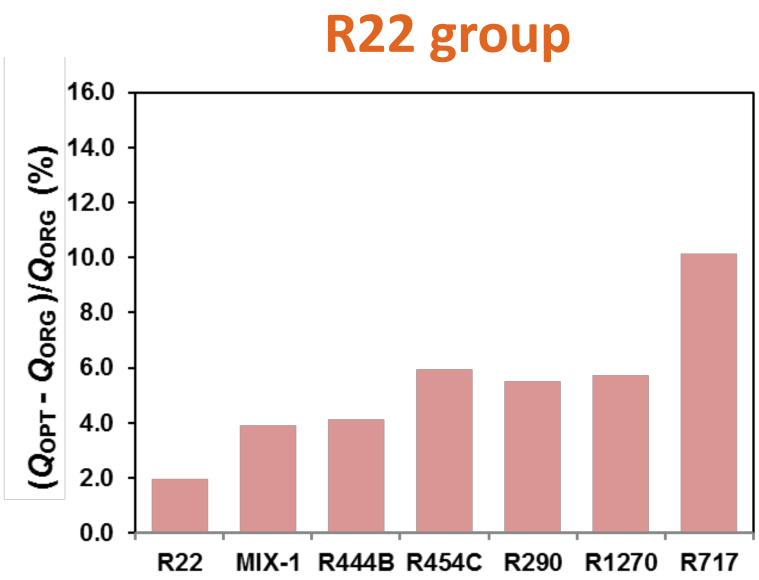
2 inlets → → 2 outlets

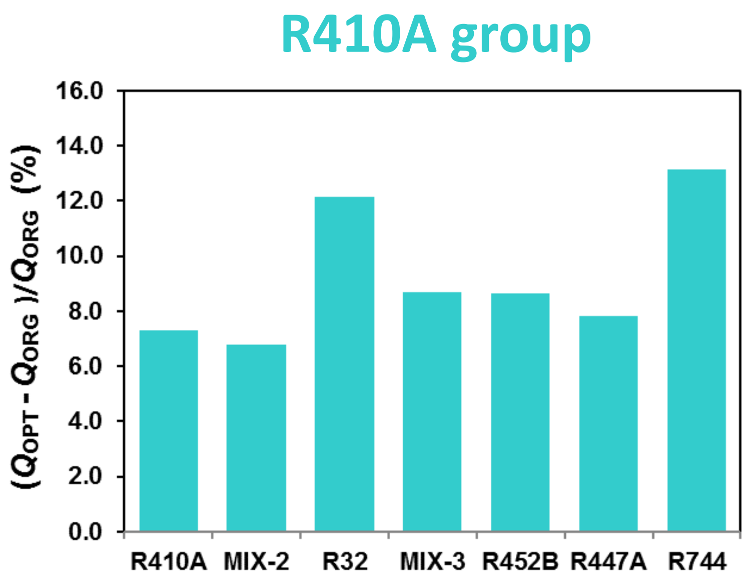
R410A

1 inlet → → 2 outlets

Capacity with Circuitry Optimized for Each Refrigerant

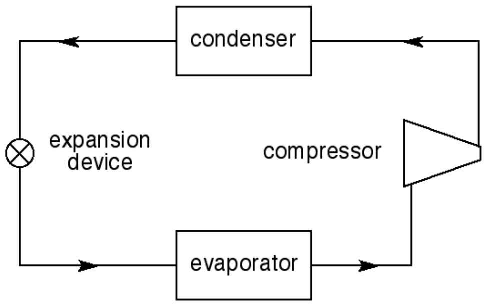
referenced to the capacity with the original circuitry



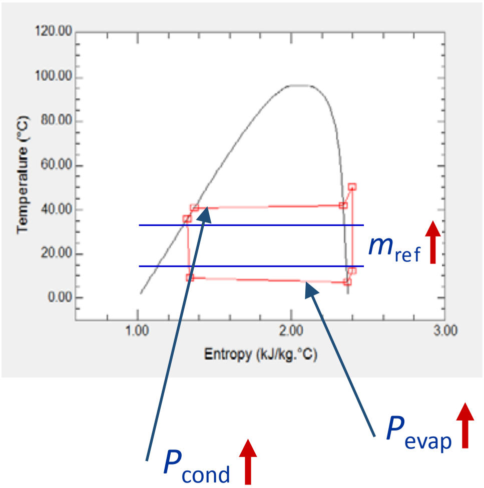


		Number of outlet tubes			
		1	2	3	4
Number of inlet tubes	1	R744	R410A, MIX-2, R32, R452B, MIX-3, R1270		
	2		R22, R444B, R290	R447A, R454C	MIX-1, R717

Impact on System Performance



When the evaporator is replaced, Q_{SYSTEM} and COP will scale with the ratio of coil capacities $\left.\frac{Q_{OPT}}{Q_{ORG}}\right|_{Tsat}$



$$\frac{Q_{SYSTEM,OPT}}{Q_{SYSTEM,ORG}} \approx \left(\frac{Q_{OPT}}{Q_{ORG}}\right)^{0.35} \qquad 1.12^{0.35} = 1.04 \quad (4\ \%)$$

$$\frac{COP_{OPT}}{COP_{ORG}} \approx \left(\frac{Q_{OPT}}{Q_{ORG}}\right)^{0.21} \qquad 1.12^{0.21} = 1.024 \quad (2.4\ \%)$$

Note: sensitive heat ratio will change

Domanski, P.A., 1989. Rating Procedure for Mixed Air Source Unitary Air Conditioners and Heat Pumps Operating in the Cooling Mode - Revision 1, NISTIR 89-4071

Conclusions

- We optimized refrigerant circuitry of an evaporator to account for thermophysical refrigerant thermophysical properties and non-uniform air distribution.
- All fluids benefited from optimization over the original R22 design. Higher-pressure fluids benefits more from optimization than lower-pressure fluids.
- Zeotropic blends with a significant temperature glide are particularly sensitive to the layout of refrigerant circuitry.
- Optimized evaporator circuitries would improve “drop-in” system capacities by 1 % to 4 % and COPs by 1 % to 2.4 %.

Bibliography

Abdelaziz, O., Shrestha, S., Munk, J., Linkous, R., Goetzler, W., Guernsey, M., Kassuga, T., 2015. Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners, ORNL/TM-2015/536

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Domanski, P.A., Yashar, D.A, Wojtusiak, J., 2014. EVAP-COND, Version 4.0: Simulation Models for Finned-Tube Heat Exchangers with Circuitry Optimization. National Institute of Standards and Technology, Gaithersburg, MD. https://www.nist.gov/services-resources/software/evap-cond

Questions?

Piotr Domanski

piotr.domanski@nist.gov

Thank you for your attention.