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Heat Transfer Technologies

International Copper Association
Copper Alliance

Simulation of the effects of copper tube diameter on refrigerant charge reduction in split AC systems and refrigerated cabinets

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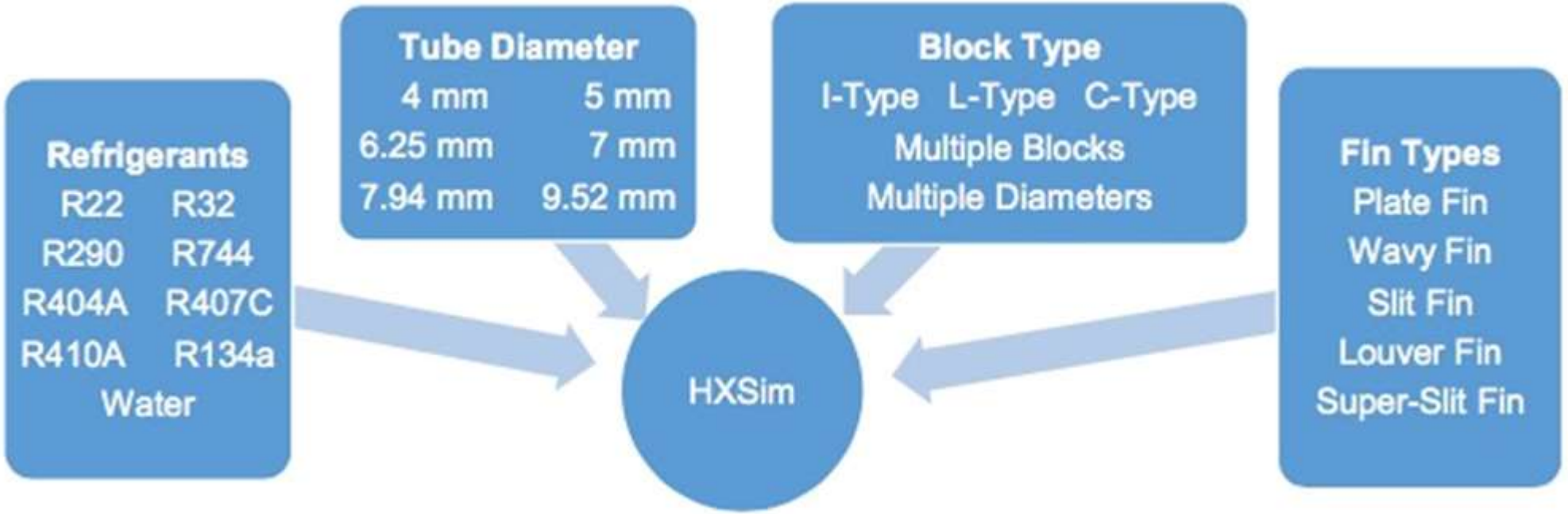
Summary

- Small diameter tube heat exchangers have the following attributes:
  - Higher efficiency
  - Low refrigerant charge
  - Compact
- Using simulation software allows engineers to design such heat exchangers
  - HXSim design software specially developed for small diameter tube heat exchangers for HVAC&R
  - Two case studies reviewed

Introduction

Coil design has yielded to fast computer-based numerical calculations. The equations governing heat transfer and mass flow can now be employed in software that calculates the performance of tube-fin heat exchanger coils to a high degree of accuracy. What's more, a wide range of parameters can be varied with ease in the latest generation of coil simulation software. Three-dimensional graphical representations of coil design inputs and 3D output of performance results are now routine.

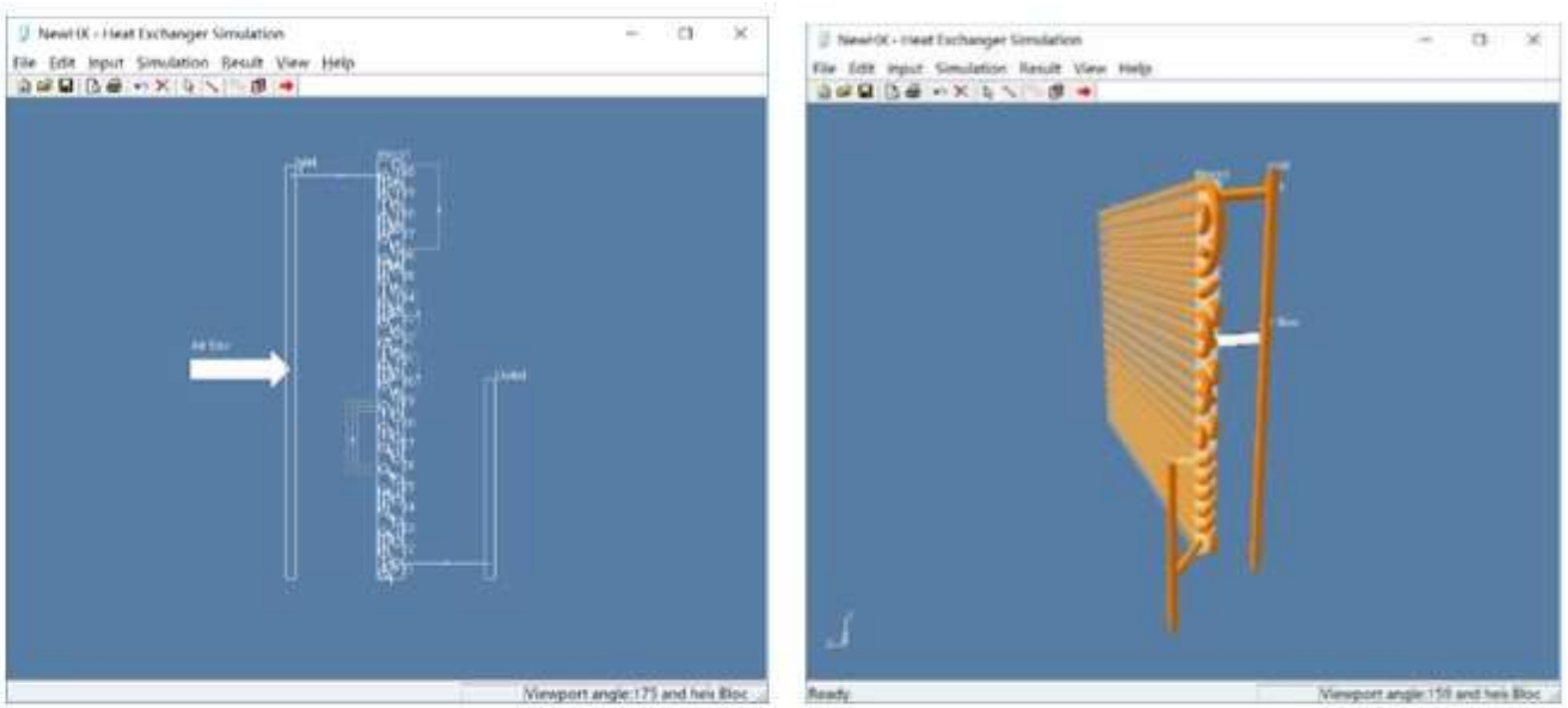


Simulation background

Simulation software uses empirical correlations for a wide variety of fin designs and internally enhanced tubes. The designer can pull down menus, choose the feature to be varied, and select from an extensive list of types of fins and tubes.

Two application design case studies are demonstrated in this paper, showing the capabilities and simplicity of HXSim software and the advantages of using small diameter tubes.

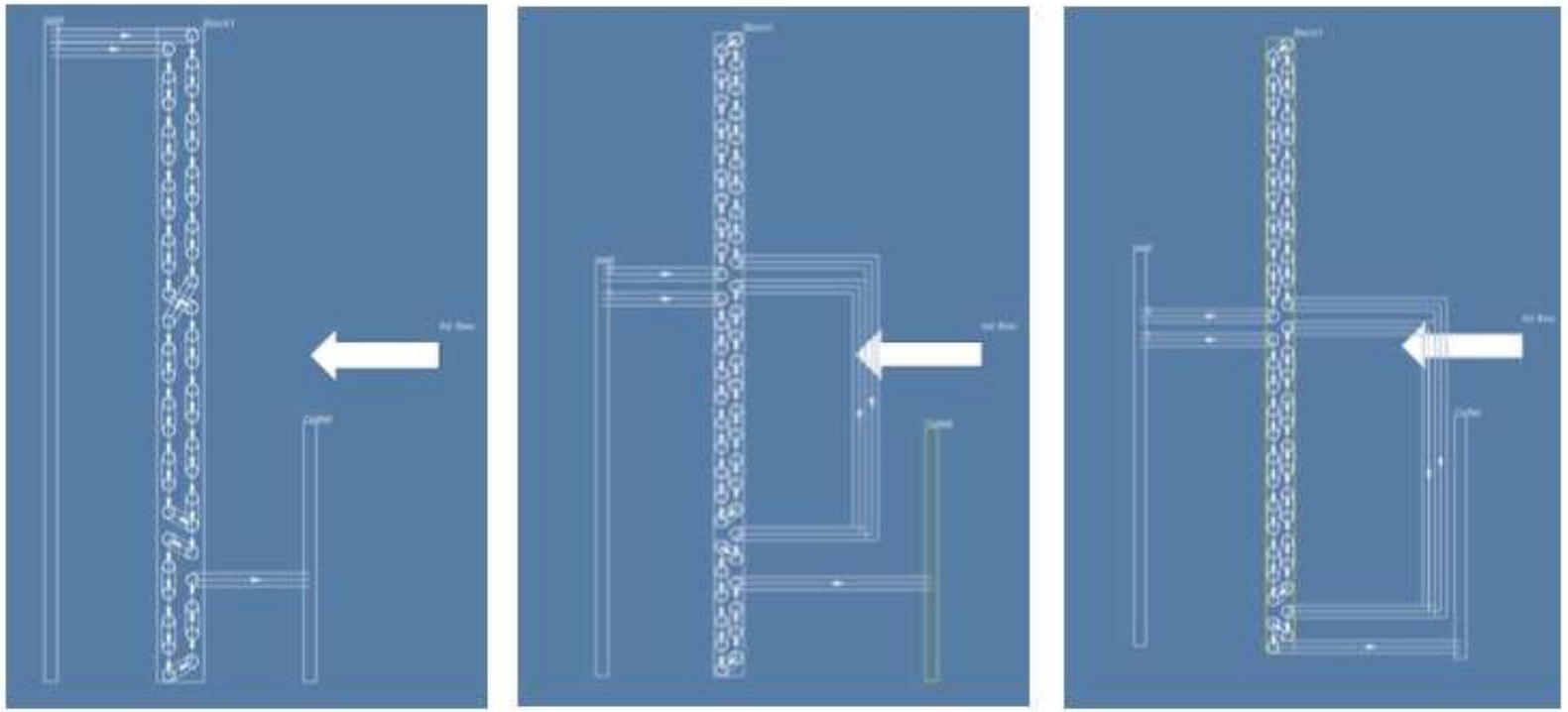
HXSim graphical design example in 2-D and 3-D



Case study 1: Split AC unit

Split AC unit I-Type tube-fin condenser coil. Circuitry (left to right) of the original design (7 mm tubes), first prototype and second prototype (5 mm tubes).

Design Objectives: The original AC has an EER of 3.6 and a rated cooling capacity of 3500 W.



Original 7 mm tube HX

New 5 mm tube HX

1. Split AC unit original 7 mm tubes results

COIL SIDE			
Fin Type	Corrugated	Utilized Tubes	48
Fin Material	Aluminum	Non Utilized Tubes	0
Fin Spacing [mm]	1.40	Circuits	3
Fin Thinkness [mm]	0.105	Tubes Per Circuit	16.00
Tube Type	Grooved	Coil Length [mm]	770.00
Tube Material	Copper	Coil Depth [mm]	36.40
Tube Dimension [mm]	7.00*0.23*0.10	Coil Height [mm]	504.00
Holes	24	Outer Area [m2]	19.380
Rows	2	Inner Area [m2]	0.759
Tube Vertical Space [mm]	21.00	Coil Face Area [m2]	0.39
Tube Horizontal Space [mm]	18.20	Inner Volume [L]	1.241
Header In [mm]	9.5	Header Out [mm]	9.5
AIR SIDE		**REFRIGERANT SIDE**	
Air Inlet DB. Temp. [°C]	35.0	Refrigerant	R32
Relative Humidity %	40.3	Discharge Superheat [°C]	22.50
Air Outlet DB. Temp. [°C]	42.8	Condenser Temp. [°C]	45.50
Relative Humidity %	26.5	Subcooling [°C]	5.87
Air Flow [m3/h]	1831.2	Mass Flow [kg/h]	59.0
Air Mass Flow [kg/h]	2352.0	Pressure Drop [kPa]	25.753
Frontal Velocity [m/s]	1.3	Outlet Pressure [kPa]	2801.995
Air Pressure Drop [Pa]	22.0	Ref. Charge [kg]	0.48
Atmospheric Pressure [kPa]	101.3	Ref. Side H.T.C. [W/m2*K]	4715.402
Air Side H.T.C. [W/m2*K]	71.911		
CAPACITY			
Total Capacity [kW]	4.523		

Notes:

Corrugated fin

7 mm tubes

Airside HTC: 71.9 W/m^{2}K

Refrigerant charge: 0.48 kg

1. Split AC unit original 7 mm tubes results

COIL SIDE			
Fin Type	Corrugated	Utilized Tubes	48
Fin Material	Aluminum	Non Utilized Tubes	0
Fin Spacing [mm]	1.40	Circuits	3
Fin Thinkness [mm]	0.105	Tubes Per Circuit	16.00
Tube Type	Grooved	Coil Length [mm]	770.00
Tube Material	Copper	Coil Depth [mm]	36.40
Tube Dimension [mm]	7.00*0.23*0.10	Coil Height [mm]	504.00
Holes	24	Outer Area [m2]	19.380
Rows	2	Inner Area [m2]	0.759
Tube Vertical Space [mm]	21.00	Coil Face Area [m2]	0.39
Tube Horizontal Space [mm]	18.20	Inner Volume [L]	1.241
Header In [mm]	9.5	Header Out [mm]	9.5

1. Split AC unit original 7 mm tubes results

AIR SIDE		REFRIGERANT SIDE	
Air Inlet DB. Temp. [°C]	35.0	Refrigerant	R32
Relative Humidity %	40.3	Discharge Superheat [°C]	22.50
Air Outlet DB. Temp. [°C]	42.8	Condenser Temp. [°C]	45.50
Relative Humidity %	26.5	Subcooling [°C]	5.87
Air Flow [m3/h]	1831.2	Mass Flow [kg/h]	59.0
Air Mass Flow [kg/h]	2352.0	Pressure Drop [kPa]	25.753
Frontal Velocity [m/s]	1.3	Outlet Pressure [kPa]	2801.995
Air Pressure Drop [Pa]	22.0	Ref. Charge [kg]	0.48
Atmospheric Pressure [kPa]	101.3	Ref. Side H.T.C. [W/m2*K]	4715.402
Air Side H.T.C. [W/m2*K]	71.911		
CAPACITY			
Total Capacity [kW]	4.523		

1. Split AC unit 5 mm tubes design results

COIL SIDE			
Fin Type	Slit	Utilized Tubes	52
Fin Material	Aluminum	Non Utilized Tubes	0
Fin Spacing [mm]	1.30	Circuits	3
Fin Thinkness [mm]	0.105	Tubes Per Circuit	17.33
Tube Type	Grooved	Coil Length [mm]	770.00
Tube Material	Copper	Coil Depth [mm]	23.20
Tube Dimension [mm]	5.00*0.21*0.14	Coil Height [mm]	507.00
Holes	26	Outer Area [m2]	13.166
Rows	2	Inner Area [m2]	0.576
Tube Vertical Space [mm]	19.50	Coil Face Area [m2]	0.39
Tube Horizontal Space [mm]	11.60	Inner Volume [L]	0.659
Header In [mm]	9.5	Header Out [mm]	9.5
AIR SIDE		**REFRIGERANT SIDE**	
Air Inlet DB. Temp. [°C]	35.0	Refrigerant	R32
Relative Humidity %	40.3	Discharge Superheat [°C]	22.50
Air Outlet DB. Temp. [°C]	43.0	Condenser Temp. [°C]	45.50
Relative Humidity %	26.3	Subcooling [°C]	7.01
Air Flow [m3/h]	1832.9	Mass Flow [kg/h]	59.0
Air Mass Flow [kg/h]	2354.2	Pressure Drop [kPa]	123.585
Frontal Velocity [m/s]	1.3	Outlet Pressure [kPa]	2704.164
Air Pressure Drop [Pa]	18.0	Ref. Charge [kg]	0.24
Atmospheric Pressure [kPa]	101.3	Ref. Side H.T.C. [W/m2*K]	3015.830
Air Side H.T.C. [W/m2*K]	183.770		
CAPACITY			
Total Capacity [kW]	4.613		

Notes:

Slit fin

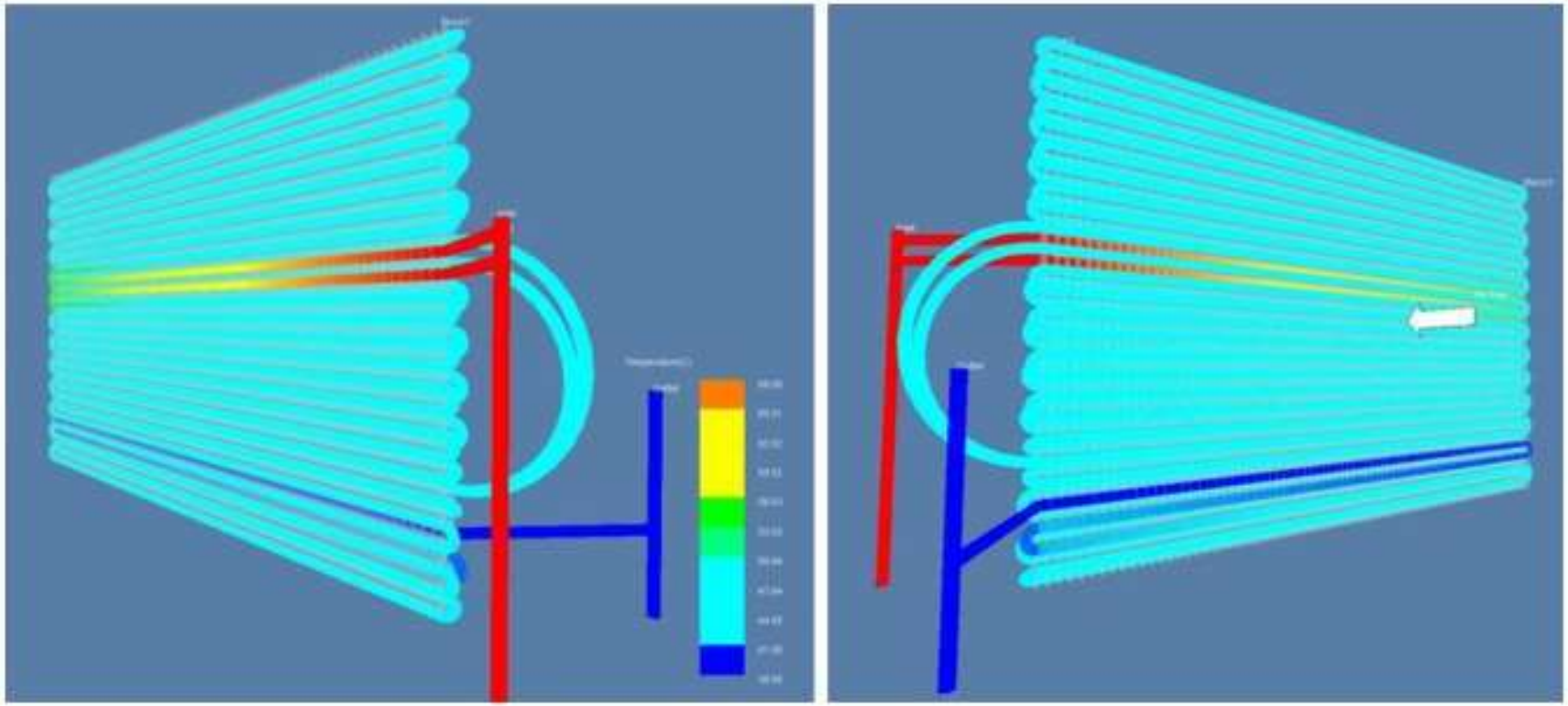
5 mm tubes

Higher airside HTC: 183.7 W/m^{2}K

Lower refrigerant charge: 0.24 kg

1. Split AC unit

3D visualization results for temperature gradations from two perspectives



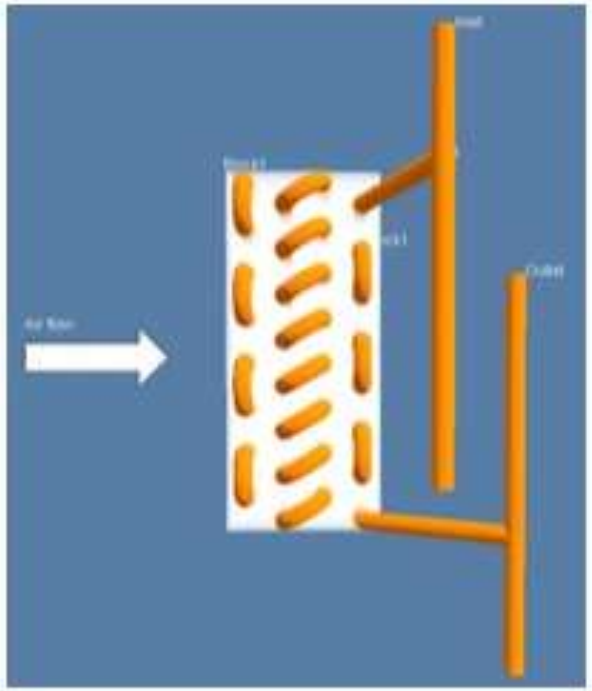
Case 2: Condenser coil for cooling cabinet

The original condenser has 9.52 mm tubes in four rows with eight tubes per row; the prototype has 5 mm tubes in four rows with ten tubes per row

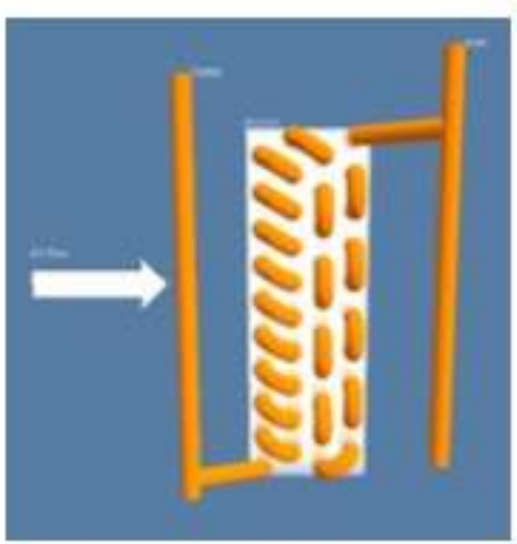
Parameters	Original	Prototype
Tube diameter (mm)	9.52	5
Tube length (mm)	278	278
HX depth (mm)	86.6	66
HX height (mm)	200	190.5
Number of columns	4	4
Tubes per column	8	10
Row spacing (mm)	21.65	16.5
Column space (mm)	25	19.05
Fin pitch (mm)	3	3

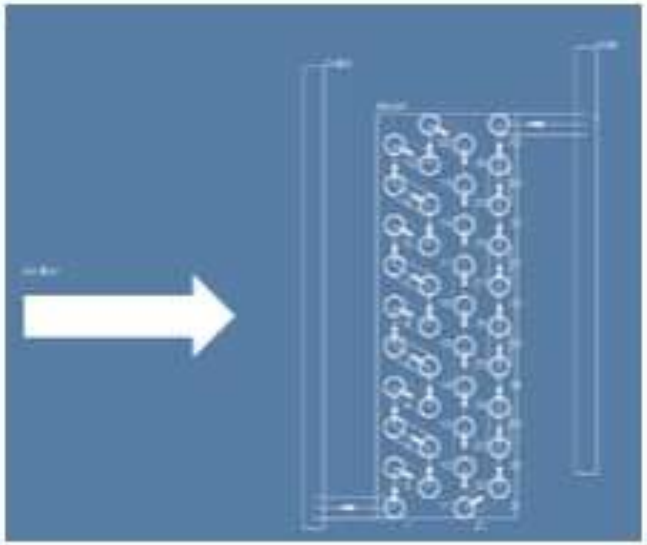
Case 2: Design objective

The purpose of the case study is to demonstrate refrigerant charge reduction using smaller tube diameter. Both heat exchangers of this case study use R290, which is a “natural refrigerant” with an ultralow GWP of 3. Holding the refrigerant type constant, simulations dramatically illustrate the charge reduction possible in switching from 9.52 mm (3/8 in. diameter) diameter copper tubes to 5 mm diameter copper tubes.



Original design 32 tubes 9.52 mm

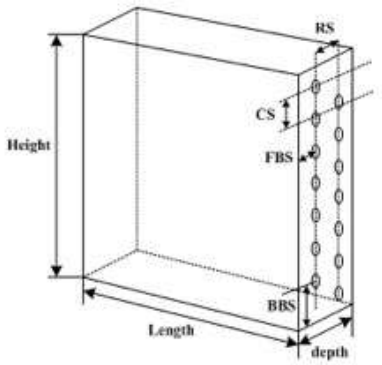




Simulation design, 40 tubes, 5 mm tubes

Case 2: Simulation results

Parameters	Prototypical condenser	Condenser B-1
Thermal capacity (W)	762	814
Inlet pressure (kPa)	1385	1385
Inlet Temp. (°C)	105	105
Mass flow rate (g/s)	3.7	3.7
Pressure drop (kPa)	2.3	40
HTC of Ref. (W/m^2K)	1130	2016
Sub-cooling (°C)	1.52	6.6
Weight of Ref (g)	135	100

No.	Parameters	Prototypical condenser	Condenser B-1	Note
1	Tube diameter, mm	9.52	5	
2	Tube length(Length), mm	278		
3	HX depth (Depth), mm	86.6	66	
4	HX height(Height), mm	200	190.5	
5	Row	4	4	
6	Column	8	10	
7	Row space(RS), mm	21.65	16.5	
8	Column space(CS), mm	25	19.05	
9	Fin pitch, mm	3	3	

With 5 mm tubes, coil capacity is higher, refrigerant charge is lower and coil envelope is smaller.

Conclusions

Simulation software is a great tool for the design of energy efficient and environmentally friendly heat exchangers.

Using small diameter tubes in heat exchangers can provide benefits in:

- Refrigerant charge reduction
- Smaller size
- Higher efficiency

For these reasons, the International Copper Association in collaboration with Shanghai Jiao Tong University is offering the HXSim heat exchanger software to qualified heat exchanger designers.

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