Heat Transfer Technologies

Hot Water Forum

Presented at the 2022
Hot Water Forum Virtual,
March 21-23

Simulations Demonstrate the Advantages of Smaller Diameter Copper Tubes in Heat Pump Water Heaters

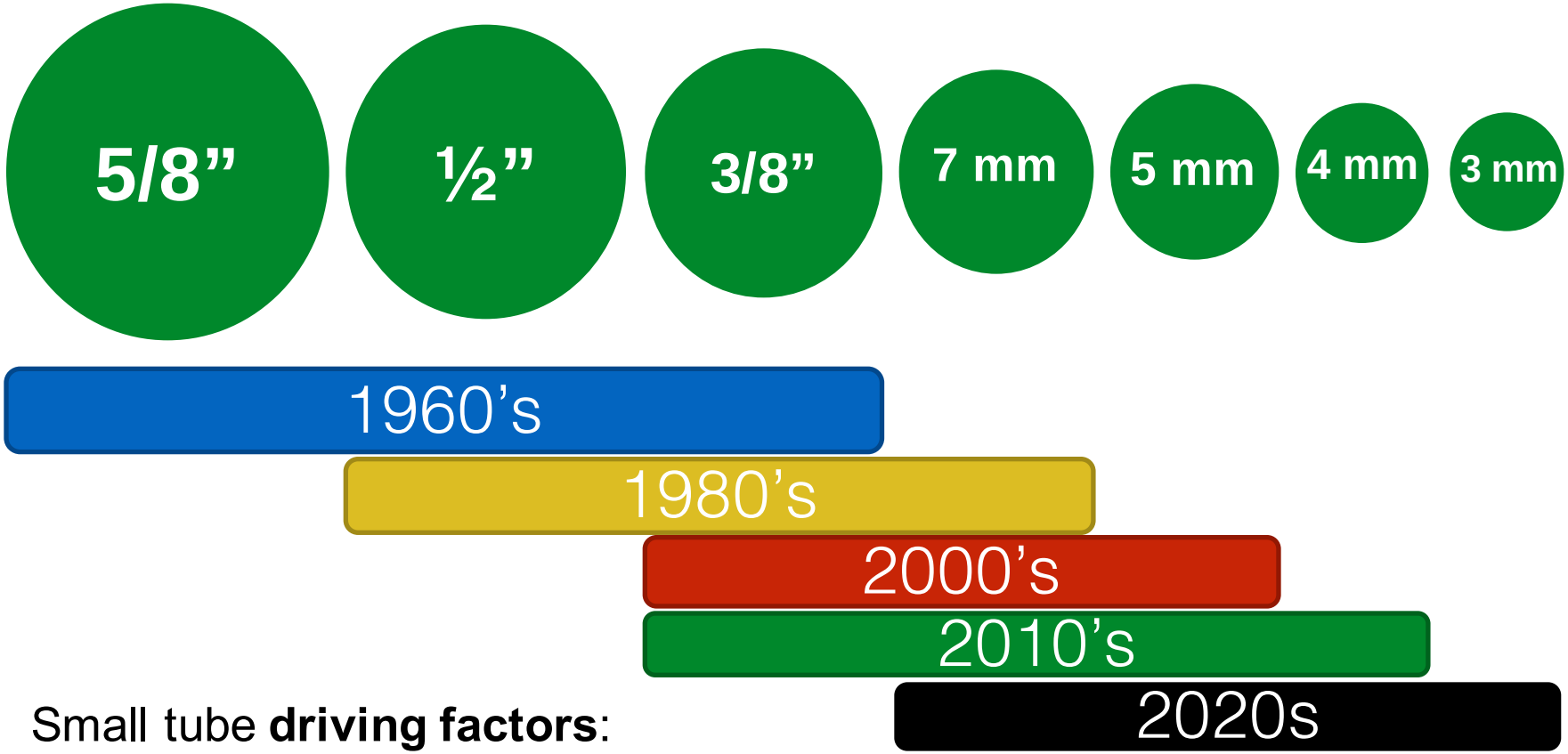
Yoram Shabtay, President, Heat Transfer Technologies, Prospect Heights, Illinois
Consultant to International Copper Association for MicroGroove Technology

Heat Transfer Technologies

Cu 国际铜业协会 Copper Alliance

Heat Transfer Technologies

Tube size Historical trend



Small tube **driving factors**:

- Need for higher efficiency systems
- Refrigerant changes / Charge Reduction
- Material & labor costs
- HX size reduction

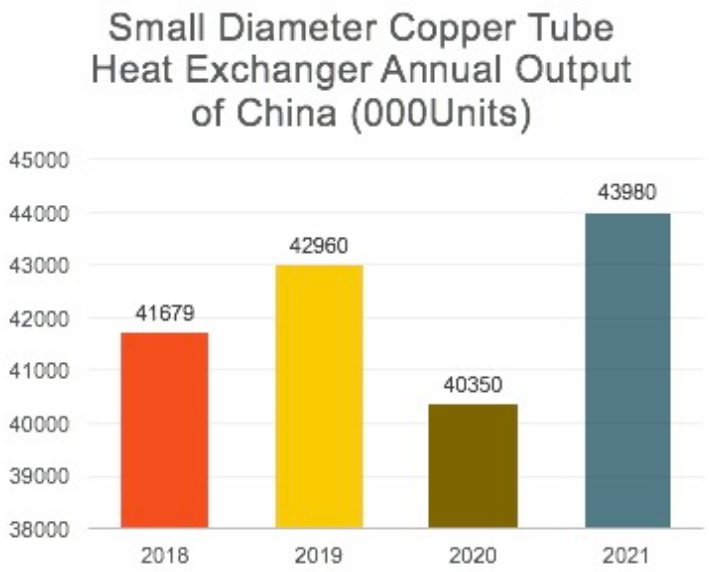
Introduction

Why Smaller Diameter Copper Tubes?

Fantastic Success in AC and Refrigeration

A. Refrigerant Advantages
- Flammable Refrigerants (A3 and A2L)
- Less Volume of HFCs or HFO blends

B. Performance Advantages
- Higher COP
- Smaller Size HX for Same Capacity



In 2021, 44 million RAC were made using small diameter copper tubes.
Source: Fbetter

Examples to Demonstrate A & B
- Charge Reduction from 9.52 to 5 mm (Display cabinet)
- Low GWP Refrigerant HPWH design (R410A to R290) (Lordan)

HXSim for small diameter copper tubes

Heat Transfer Technologies

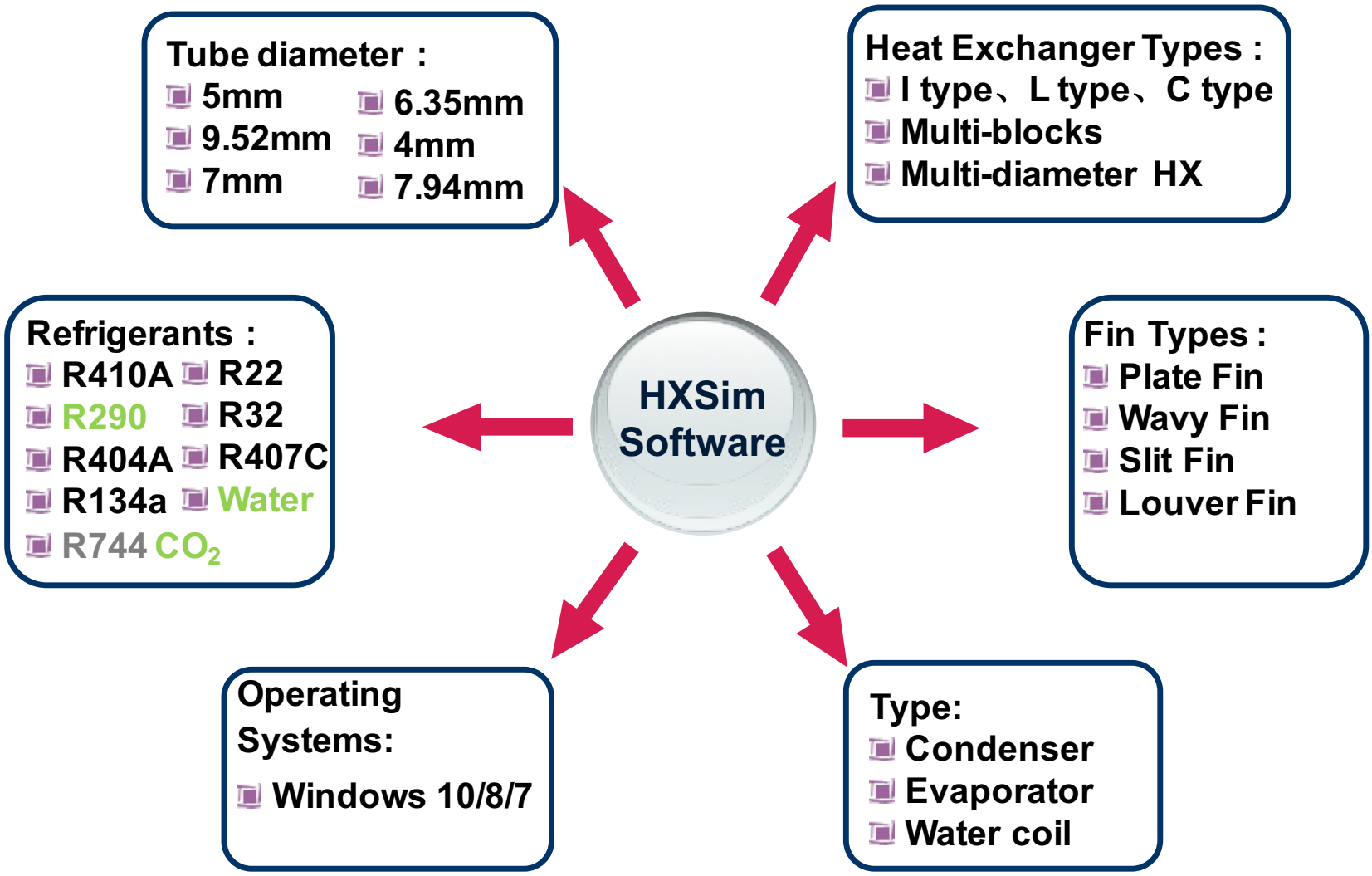
HXSim software was developed in China with ICA support to help manufacturers optimize heat exchanger designs using smaller diameter copper tubes.

More than 200 engineers use HXSim to design and optimize heat exchangers:

HXSim for small diameter copper tubes

Heat Transfer Technologies

HXSim Capabilities

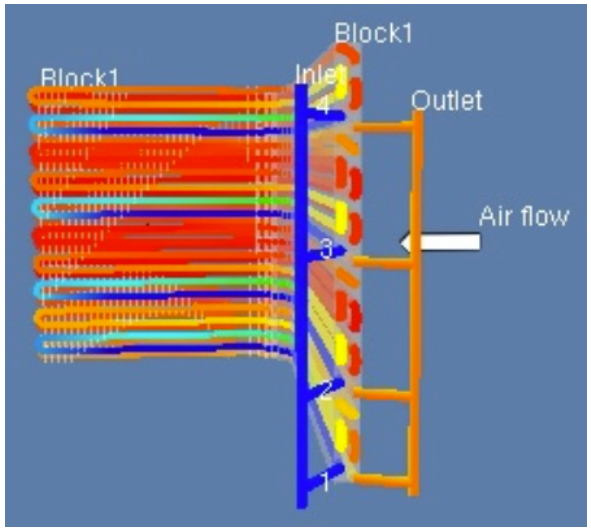


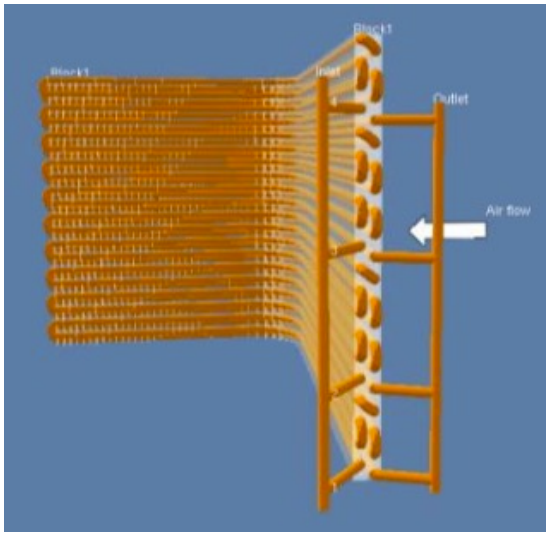
HXSim for small diameter copper tubes

Heat Transfer Technologies

HXSim

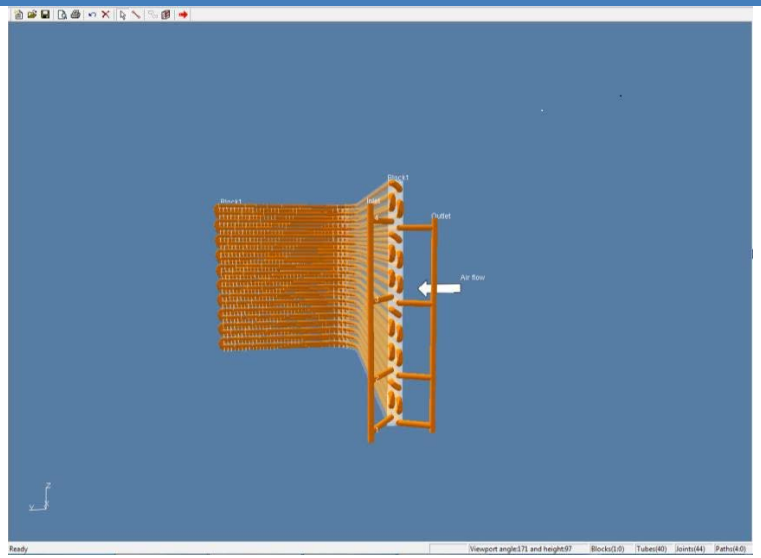
- Select Tube Size, Enhancements, Circuitry and Fin Types
- Make the connections
- Specify working parameters
- Output as Tables, Charts or 3D Visualizations

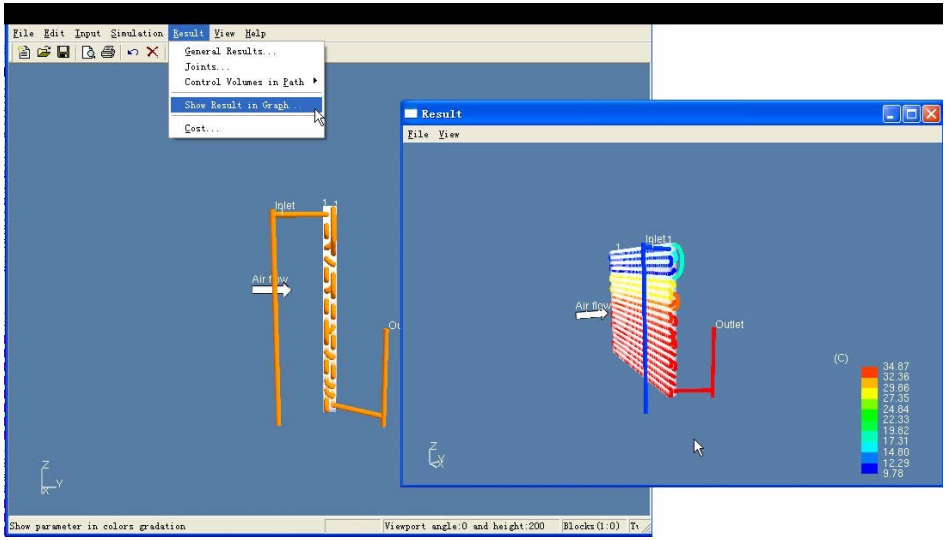


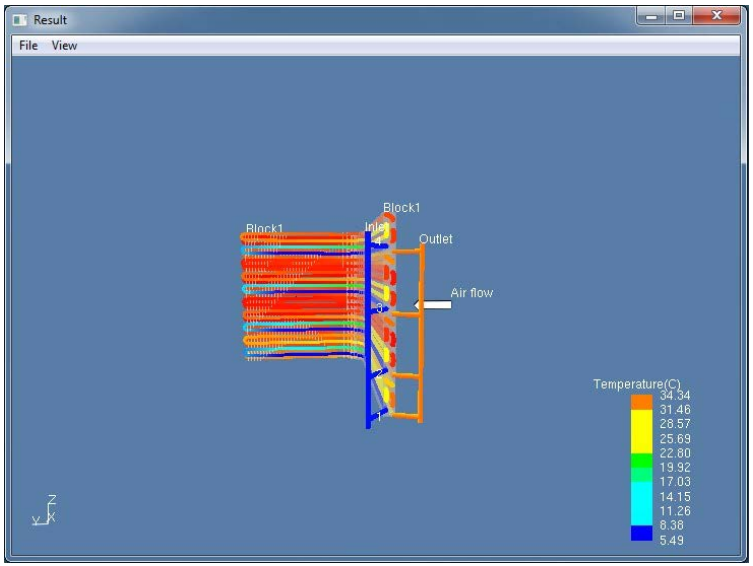


Evaporator Design.
Blue = Cold Inlet.

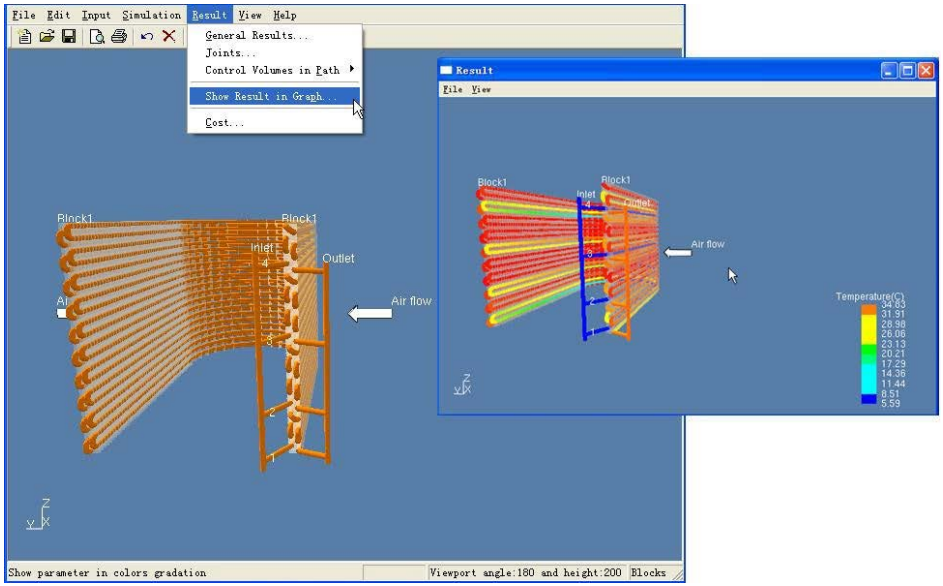
HXSim simulation examples







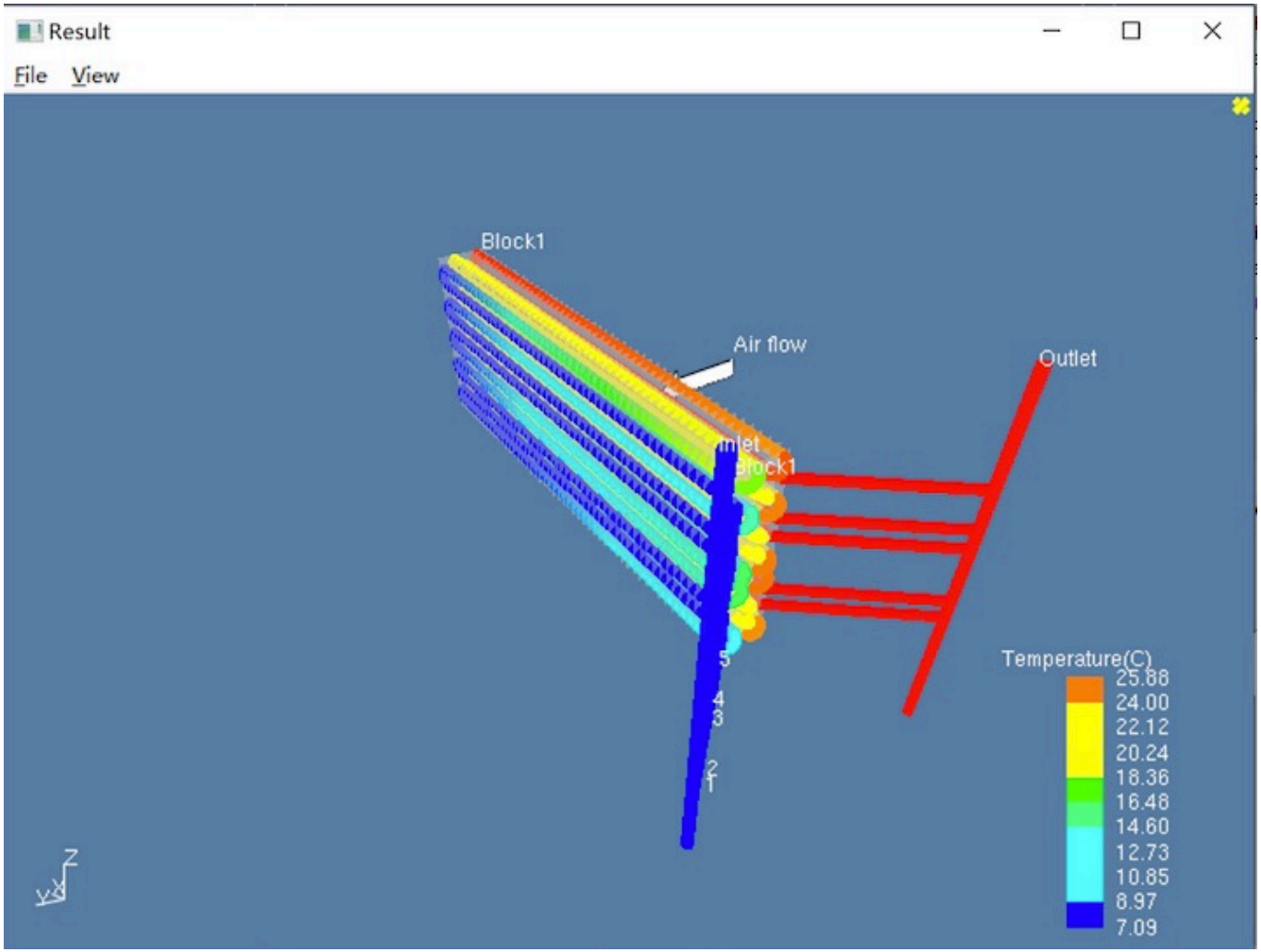
L-Type Block Design (*top*)
Result (*bottom*)



I-Type Block (*top*)
C-Type Block (*bottom*)

HXSim simulation examples

Heat Transfer Technologies

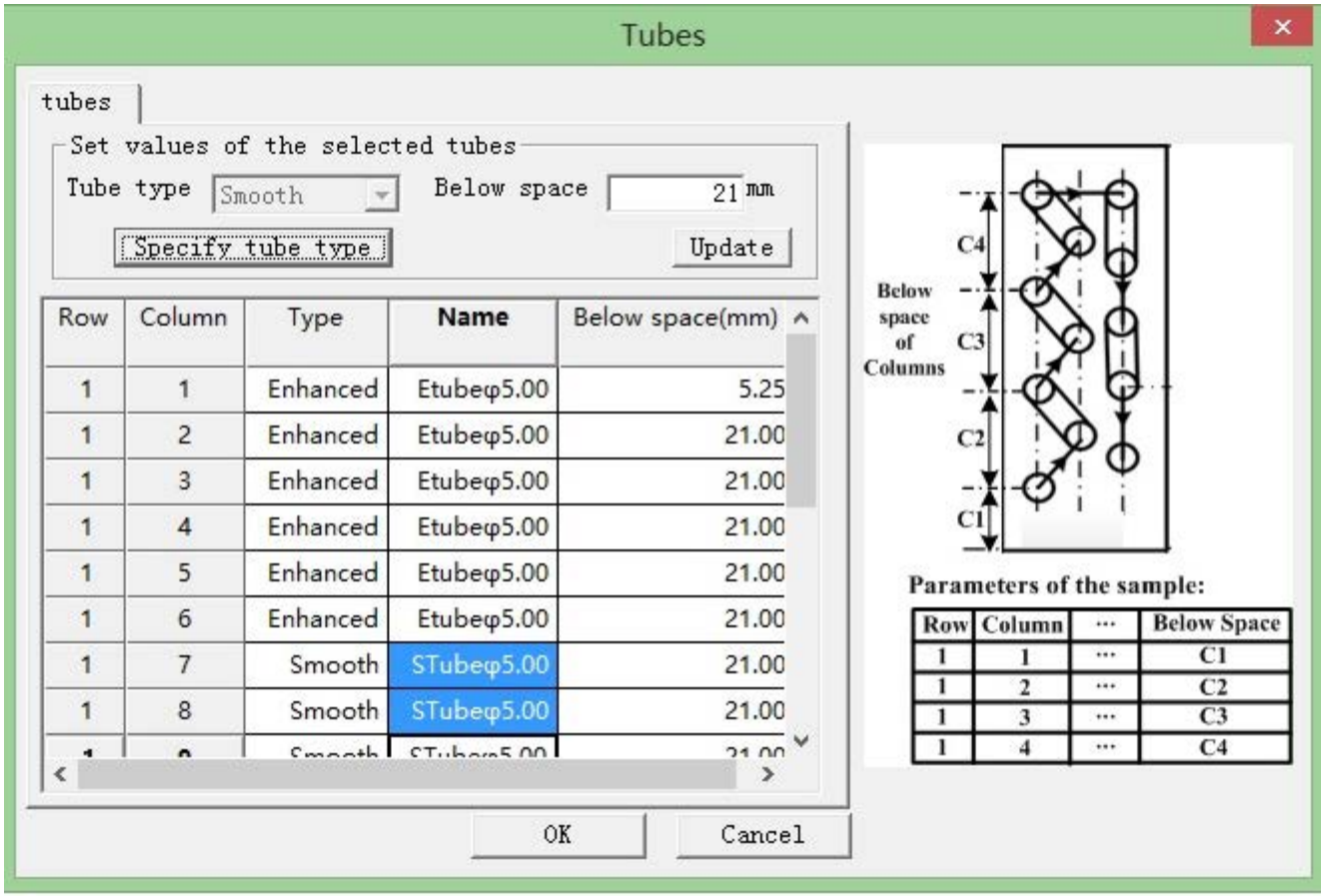


HPWH Evaporator design example: Blue = cold inlet

Shabtay – 4D

HXSim simulation examples

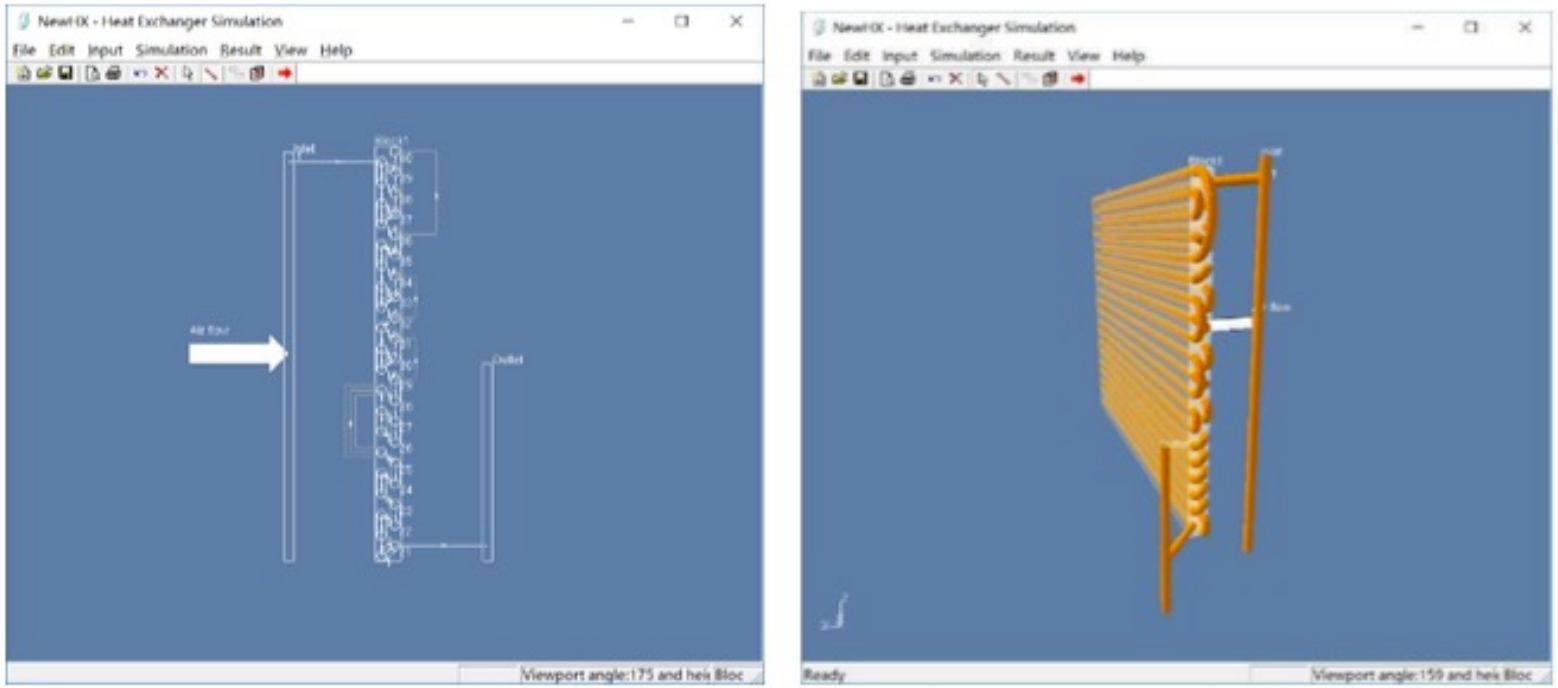
HXSim contains tube correlations for a wide variety of tube diameters and internal surface enhancements. Block type, dimensions, tube type, fin type and refrigerant are easily selectable through the graphical user interface.



HXSim simulation examples

Heat Transfer Technologies

Case studies show the advantages of using small diameter tubes.



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

Heat Transfer Technologies

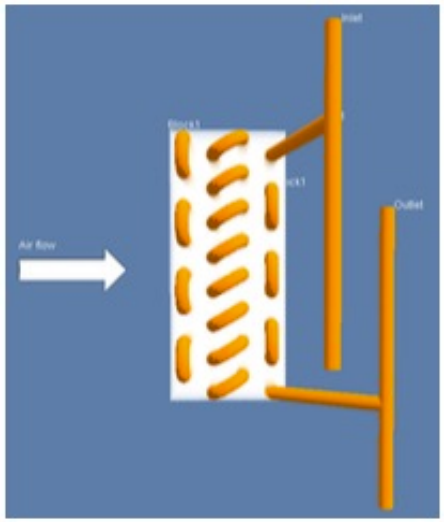
Case 1: Condenser coil for cooling cabinet

- 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.

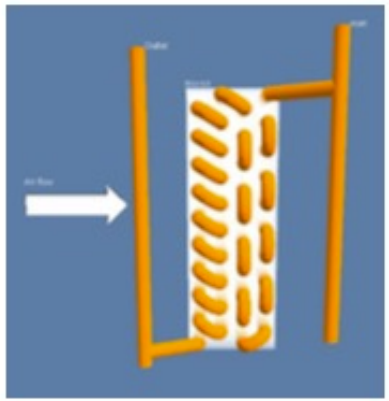
Parameters	Original	Prototype
Tube diameter (mm)	9.52	5
Tube length (mm)	278	278
HX depth (mm)	86.6	66
HX height (mm)	200	190.5
Number of columns	4	4
Tubes per column	8	10
Row spacing (mm)	21.65	16.5
Column space (mm)	25	19.05
Fin pitch (mm)	3	3

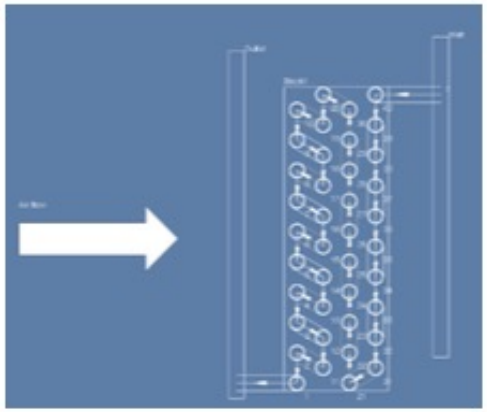
Case 1: Design objective

- 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 illustrate the charge reduction possible in switching from 9.52 mm (3/8 in.) to 5 mm diameter copper tubes.



Original design 32 Tubes 9.52 mm



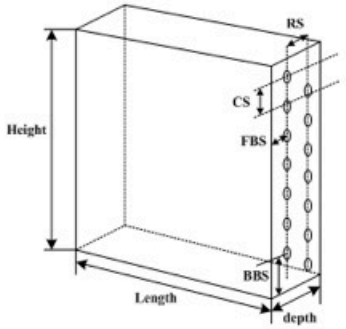


Simulation design, 40 tubes, 5 mm tubes

Heat Transfer Technologies

Case 1: Simulation results

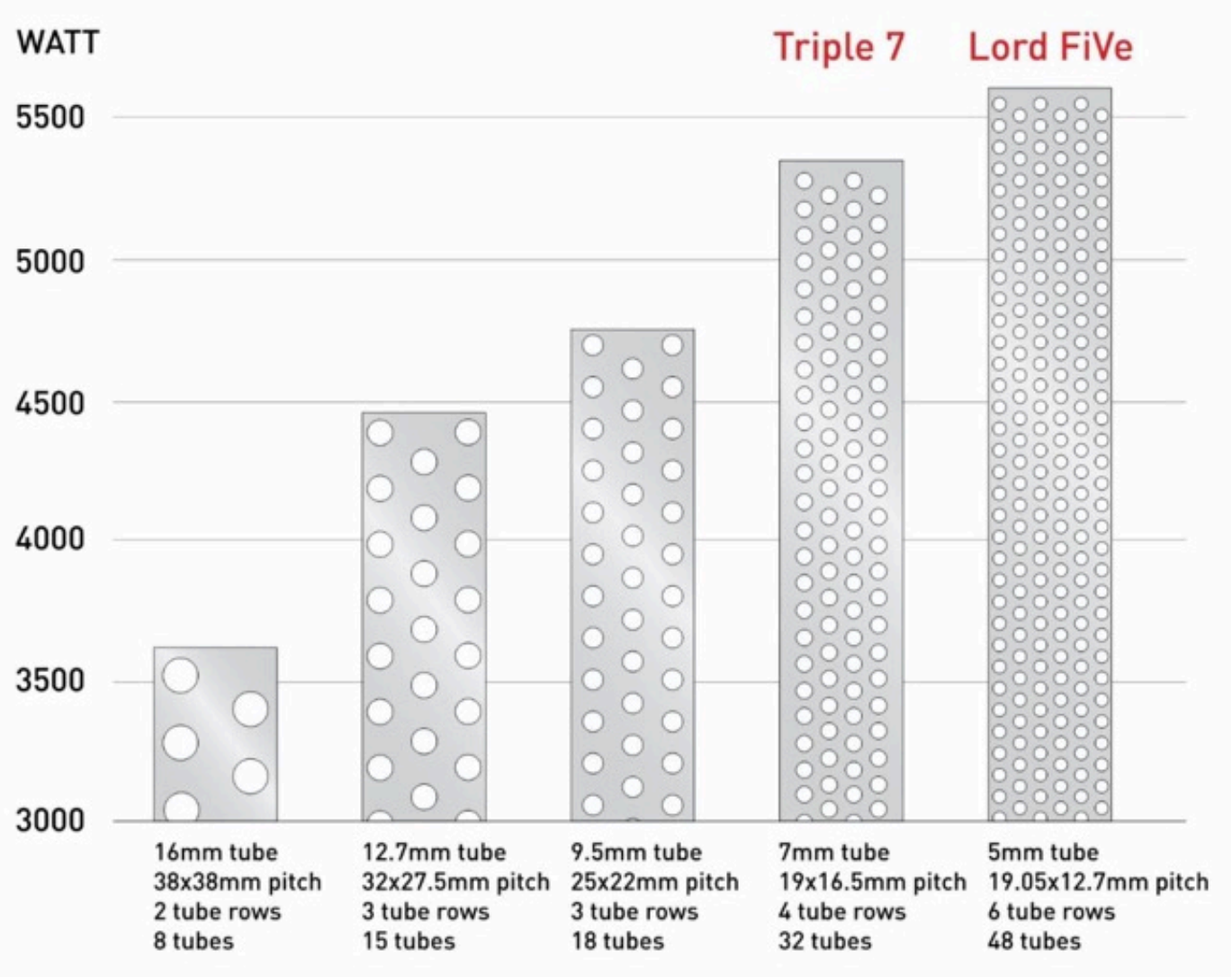
Parameters	Prototypical condenser	Condenser B-1
Thermal capacity (W)	762	814
Inlet pressure (kPa)	1385	1385
Inlet Temp. (°C)	105	105
Mass flow rate (g/s)	3.7	3.7
Pressure drop (kPa)	2.3	40
HTC of Ref. (W/m^2K)	1130	2016
Sub-cooling (°C)	1.52	6.6
Weight of Ref (g)	135	100

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	

Hence: With **5 mm tubes**, coil

- capacity is higher,
- refrigerant charge is lower and
- coil envelope is smaller.

Case 2: Lordan 5mm tube HPWH example

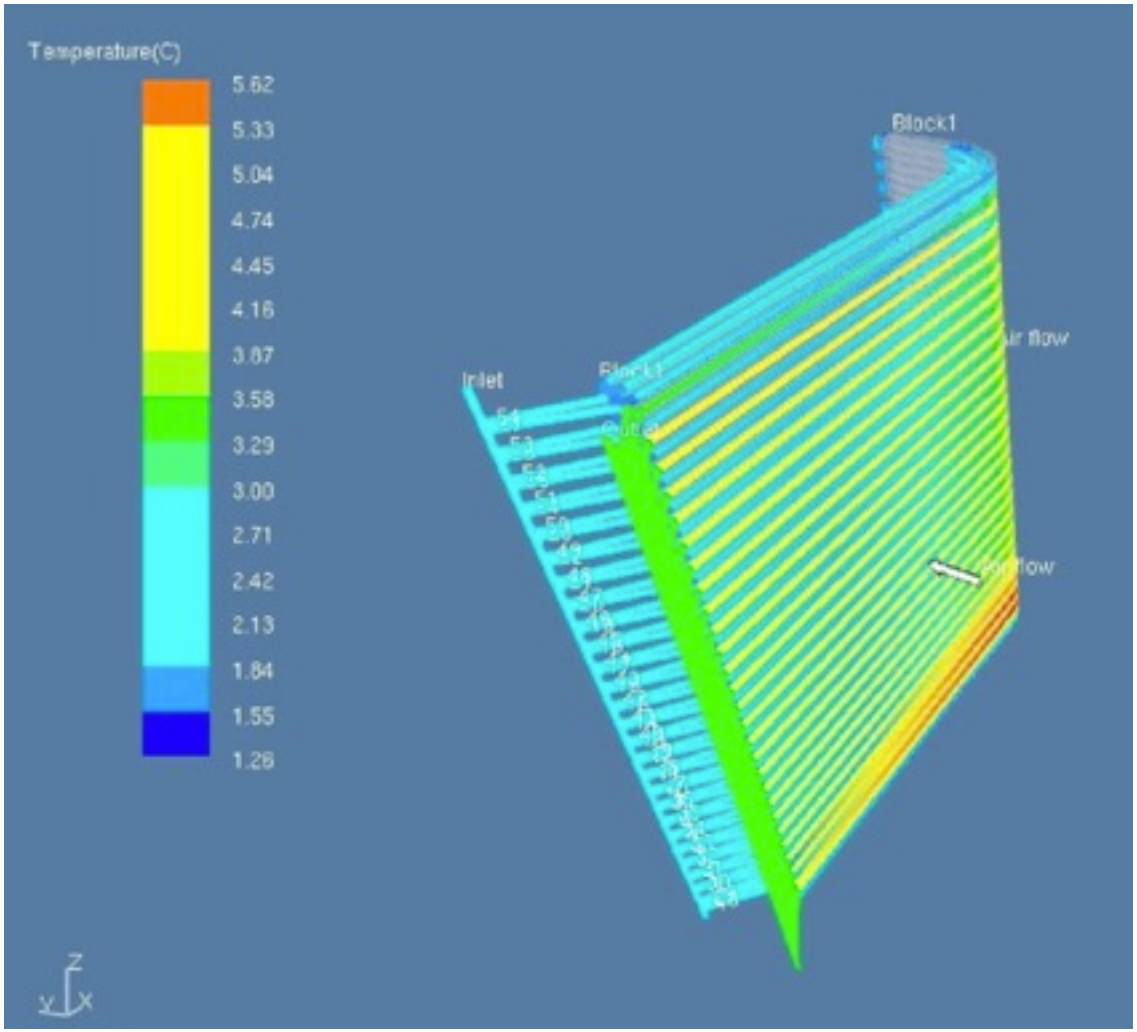


Lordan fin vs. larger tube

Case 2: Lordan 5mm tube HPWH example

Heat Transfer Technologies

Cold Climate Heat Pump Water Heater with R290



Case 2: Lordan 5mm tube HPWH example

Heat Transfer Technologies

Cold Climate Heat Pump Water Heater with R290

Case 2: Lordan 5mm tube HPWH example

Heat Transfer Technologies

Cold Climate Heat Pump Water Heater with R290

Tube OD	FPI	Num. tubes	Coil thk [mm]	Air dP [Pa]	Air vel [m/s]	Net Weight fins [kg]	Net Weight tubes [kg]	Intern vol [Liter]	Refrig dP [Kpa]	Ref flow [kg/min]	Ref Vel [m/s]	Ref charge [kg]	Output [kw]
5 mm	14	228	50.8	50	2.45	13.44	11.576	3.99	4.1	3.31	5.92	0.519	14.4
7 mm	13	228	66	62	2.45	16.225	19.355	8.58	4.7	3.31	5.51	1.131	14.35
5/16"	16	164	65	68	2.42	19.436	19.486	8.5	4.4	3.31	5.74	1.1	14.35
3/8"	17	164	88	73	2.42	28.613	23.487	12.4	3.6	3.36	4.96	1.644	14.4

Hence: With **5 mm tubes**, for the same capacity (14kW), coil

- weight is lowest
- refrigerant charge is lowest and
- envelope is smaller.

Getting Started with HXSim

Heat Transfer Technologies

Takeaways:

1. 5mm copper tubes helps reduce HX weight, refrigerant charge, weight of tube and fins, and HX envelope
2. HXSim helps design and optimize heat exchangers

HXSim Software is offered at no charge to qualified heat exchanger designers. The ICA has arranged with Shanghai Jiao Tong University to provide full working version of HXSim 3.1 *free of charge* to qualified designers.

Process:

- Download HXSim.msi from https://microgroove.net/hxsim and run it.
- Send software ID via email to yyli@craheta.org.
- Receive the registration code within 1-2 days.
- Input the registration code and finish the installation.
- Begin designs and simulations.

SJTU asks only for your name, company and email. ICA is open to partnerships and has the ability to produce prototypes in China at minimal cost.

Additional information:

Heat Transfer Technologies

https://microgroove.net
White papers, Technical material

Heat pumps:
https://microgroove.net/heat-pumps

OTS-ICA Educational Program:
https://microgroove.net/ots-ica-educational-outreach

Results:

Five different optimization studies were performed by Optimized Thermal Systems in collaboration with the International Copper Association and five different manufacturers. In each case, copper tubes with diameters of five millimeters were specified and MOGA was used to optimize the configurations of heat-exchanger-geometry parameters.

1. Heat pump condenser.

The MOGA-optimized designs were similar to the baseline microchannel coil with regard to airside pressure drop and capacity.

2. Window AC condenser.

MOGA designs increased the efficiency of the heat exchanger while reducing materials usage and refrigerant charge. MOGA designs improved the COP by as much as 15% and reduced material usage by more than 60%.

3. Refrigerator–freezer condenser.

Hydrocarbon refrigerant charge was dramatically reduced in the 5 mm designs. MOGA designs reduced the internal tube volume up to 41% along with a 57% reduction in overall coil volume compared to the baseline 6.25 mm copper tube designs. (Fig. 1)

4. PTAC condenser.

Raw material costs and airside pressure drop were reduced while maintaining performance. MOGA designs provided as much as 50% savings in raw material costs while keeping the pressure drop close to the baseline. The best design reduced the overall internal volume by 62%. (Fig. 2)

5. HPWH evaporator.

MOGA was used to show that capacity could be doubled by increasing fan power; and that 5 mm designs delivered more capacity than the 7.9 mm baseline heat exchanger for a given fan power.(Fig. 3)

A Few Words about R744

Heat Transfer Technologies

The pressure rating of an R744 gas cooler can be increased in three ways::

- Increase the wall thickness
- Use a smaller diameter tube
- Use a high strength copper alloy

Hoop stress drops in the ratio of 6 to 5 to 4 as the diameter is reduced from 6/16 to 5/16 to 4/16 inches, respectively (that is, from 9.525 mm to 7.9375 mm to 6.350 mm). Lordan makes R744 gas coolers with 5 mm tube diameters. By using a Cu-Fe alloy, Lordan can reduce tube-wall thickness from 0.7 mm to 0.4 mm.

High-strength copper alloys are also used for the refrigerant lines that run to-and-from the gas cooler. For more on this topic, see the 2019 ATMO America slideshow presentation by Yoram Shabtay: “Advantages of Small Diameter Tubes in Transcritical Refrigeration Cycles,” ATMO America Conference, Atlanta, Georgia, June 2019.

https://www.slideshare.net/ATMO/advantages-of-small-diameter-tubes-in-transcritical-refrigeration-cycles

Thank you !

Yoram SHABTAY[a], Frank GAO[b], Kerry SONG[b]

(a) Heat Transfer Technologies, LLC
Prospect Heights, Illinois 60070-1063, USA,
yoram@heattransfertechnologies.com

(b) International Copper Association
Shanghai, 200020, China,
kerry.song@copperalliance.org