Principles of evaporator coil design for air source cold climate heat pumps using smaller diameter copper tubes and low GWP refrigerants

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Introduction

Small diameter round copper tubes in HX coils can:

- Reduce refrigerant charge
- Decrease the size of cold climate heat pumps (CCHPs)
- Increase efficiency
- Quick defrost cycle

HXSim Simulation model

Table 1. Comparison of simulation results with experimental results for a typical heat exchanger

Evaporation Temperature (℃)	Dryness	Heat Transfer Test (W)	Heat Transfer Simulation (W)	Deviation (%)	Pressure Drop Test (kPa)	Pressure Drop Simulation (kPa)	Deviation (%)
5	0.1	1112	1198	7	6.26	5.02	20
10	0.2	976	1023	5	4.71	4.15	12
15	0.3	754	799	6	3.73	3.27	13
5	0.1	1131	1225	8	7.44	6.78	9
10	0.2	1008	1053	4	6.24	5.15	18
15	0.3	812	846	4	4.82	4.06	16

Variation of Tube Diameter and Microfins

Table 2. Effects of reducing tube diameter on heat exchanger design

	5 mm	7 mm	7.94 mm	9.52 mm
Fins per Inch (FPI)	14	13	16	17
Number of Tubes	228	228	164	164
Coil Depth (mm)	50.8	66	65	88
Airside Pressure Drop (Pa)	50	62	68	73
Air Velocity (m/s)	2.45	2.45	2.42	2.42
Fin Weight (kg)	13.44	16.23	19.36	19.49
Internal Volume (liter)	3.99	8.58	8.50	12.40
Refrigerant Side Pressure Drop (kPa)	4.1	4.7	4.4	3.6
Refrigerant Flow (kg/min)	3.31	3.31	3.31	3.36
Refrigerant Velocity (kg/min)	5.92	5.51	5.74	4.96
Refrigerant Charge (kg)	0.52	1.13	1.10	1.64
Output (kW)	14.4	14.35	14.35	14.4

Variation of Tube Diameter and Microfins

Baseline circuitry design

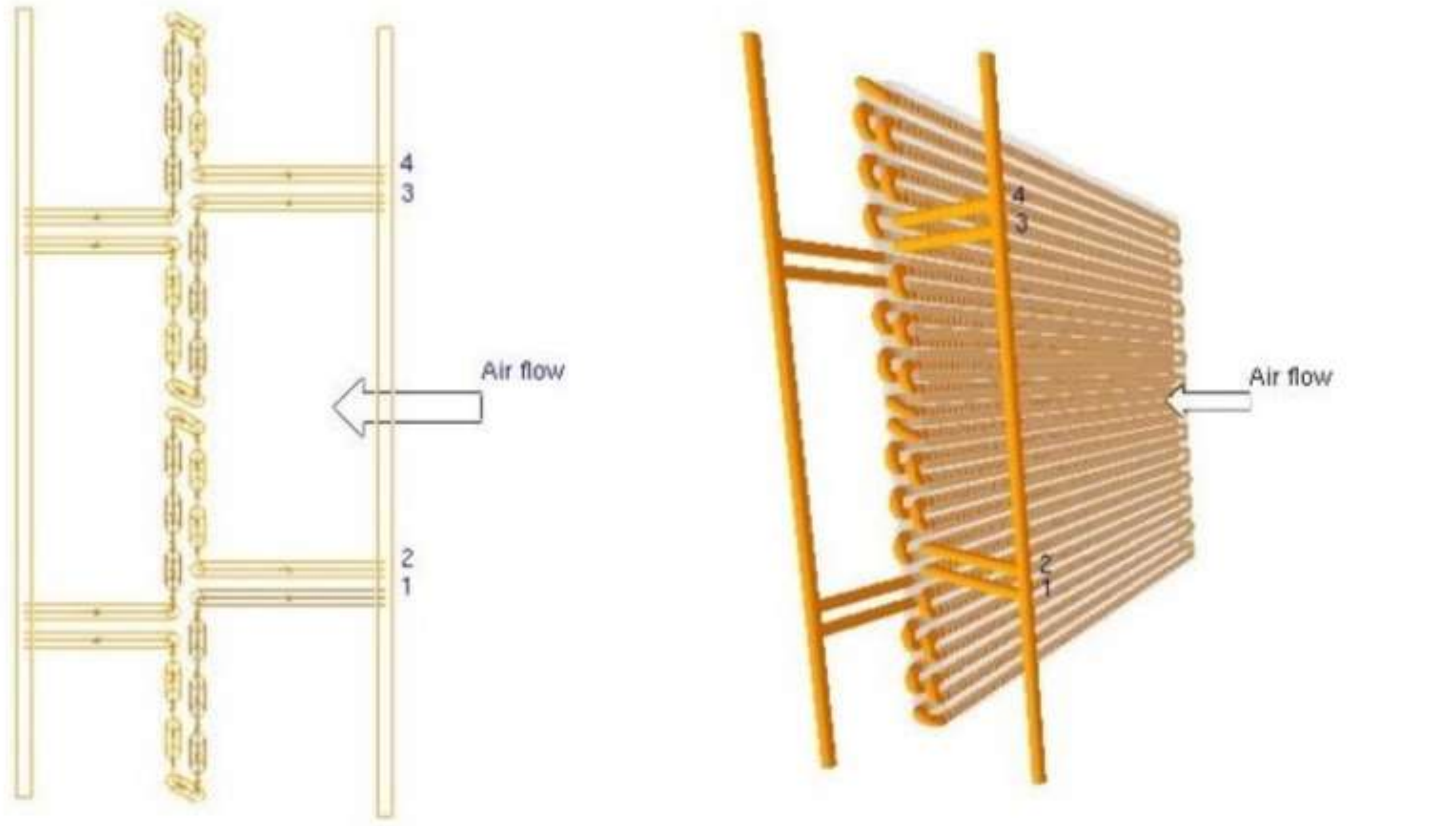


Figure 1: Two- and three-dimensional renditions of a two-row heat exchanger in HXSim.

Variation of Tube Diameter and Microfins

- These simulation results suggest that tube wall thickness has little effect on the capacity for the smooth tubes.
- Microfins have different effects for boiling (evaporation) compared to nucleation (condensation).

Table 3. Effect of inside tube enhancement on capacity

Inside Tube Enhancement (HXSim ID)	Tube Outer Diameter (mm)	Tube Wall Thickness (mm)	Microfin Height (mm)	Capacity (kW)	Airside Pressure Drop (kPa)
4	5	0.2	0.15	3.438	25.7
5	5	0.21	0.14	3.367	25.7
6	5	0.23	0.12	3.486	25.7
7	5	0.25	0.15	3.407	25.7
8	5	0.23	0	2.609	25.7
9	5	0.28	0	2.688	25.7
10	5	0.3	0	2.724	25.7

Variation of Fin Density and Fin Type

- As the fin density increases, the airside pressure drop increases and so too does the capacity.
- The results clearly show that fin density affects airside pressure drop and capacity in the same direction.
- for CCHPs where the evaporator may be subject to ice and snow, high fin density is not recommended
- The simulations were run on the same two-row, I-block coil that was used to compare microfins.

Table 4. Variation of capacity and airside pressure drop with fin density

Fin Pitch (mm)	Fin Density (FPI)	Capacity (W)	Pressure Drop (kPa)
2.0	12.7	2437	10.5
1.9	13.4	2459	11.5
1.8	14.1	2623	12.7
1.7	15.0	2752	14.0
1.6	15.9	2905	15.6
1.5	17.0	3068	17.4
1.4	18.1	3247	19.7
1.3	19.5	3288	22.4
1.2	21.2	3361	25.7
1.1	23.1	3494	29.9
1.0	25.4	3506	35.3

Variation of Fin Density and Fin Type:
Louver Vs Wavy Fins

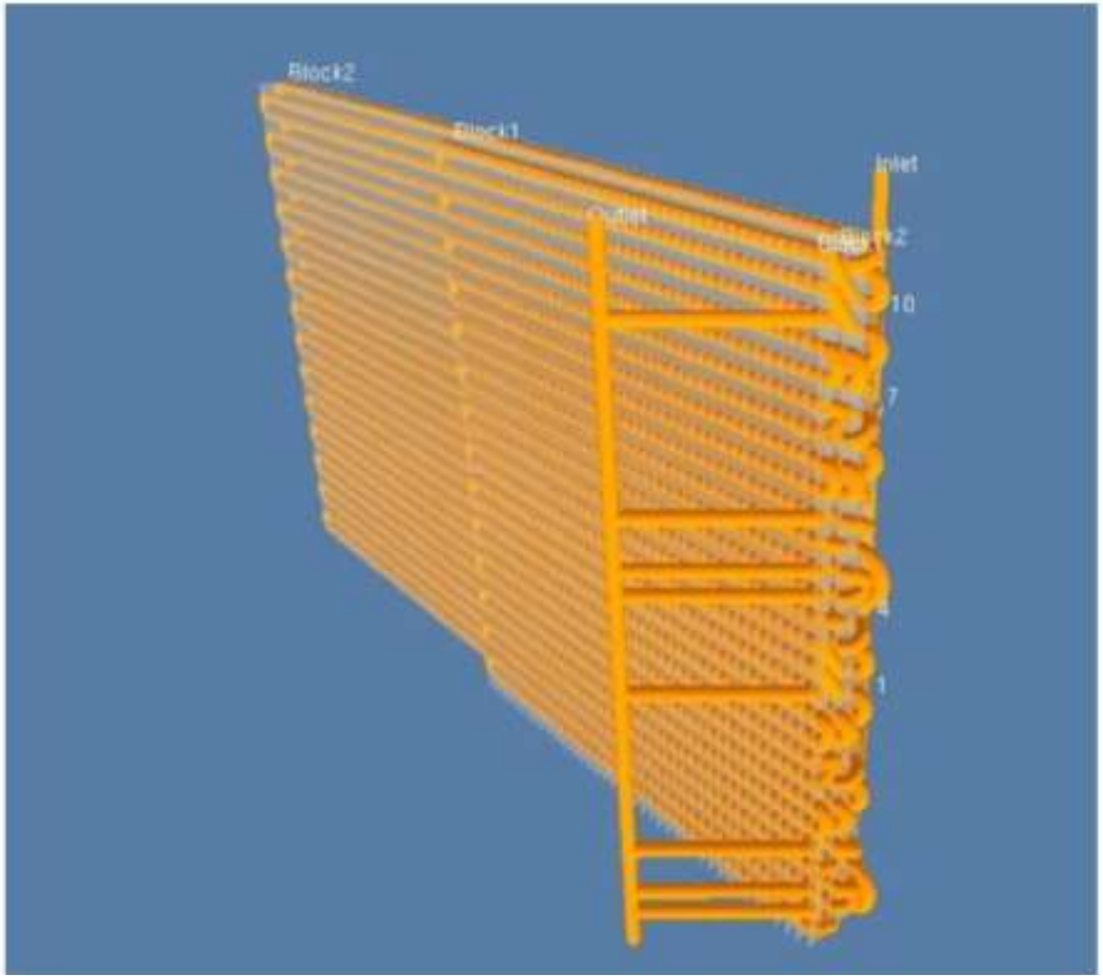
HXSim simulations were run on the same 19.05 mm x 16.5 mm hole pattern for wavy and louver fins for the same output capacity and airflow. With all else being equal, the louver fin showed a larger pressure drop compared to the wavy fin.

	Wavy Fin	Louver Fin
HX Capacity (kW)	3.36	3.53
Airside Pressure drop (Pa)	25.7	54

From the results, one would expect louver fins to be most commonly used, however Louver fins and slit fins are rarely used for CCHPs due to their quick freeze up and difficulty defrosting / condensate shedding.

Additional Half Row

- Wavy fins
- HX length 774 mm
- 28 holes per row
    - 3rd row tubes are shorter 400mm



A half row was added to the I-block to create a 2.5-row heat exchanger

Additional Half Row

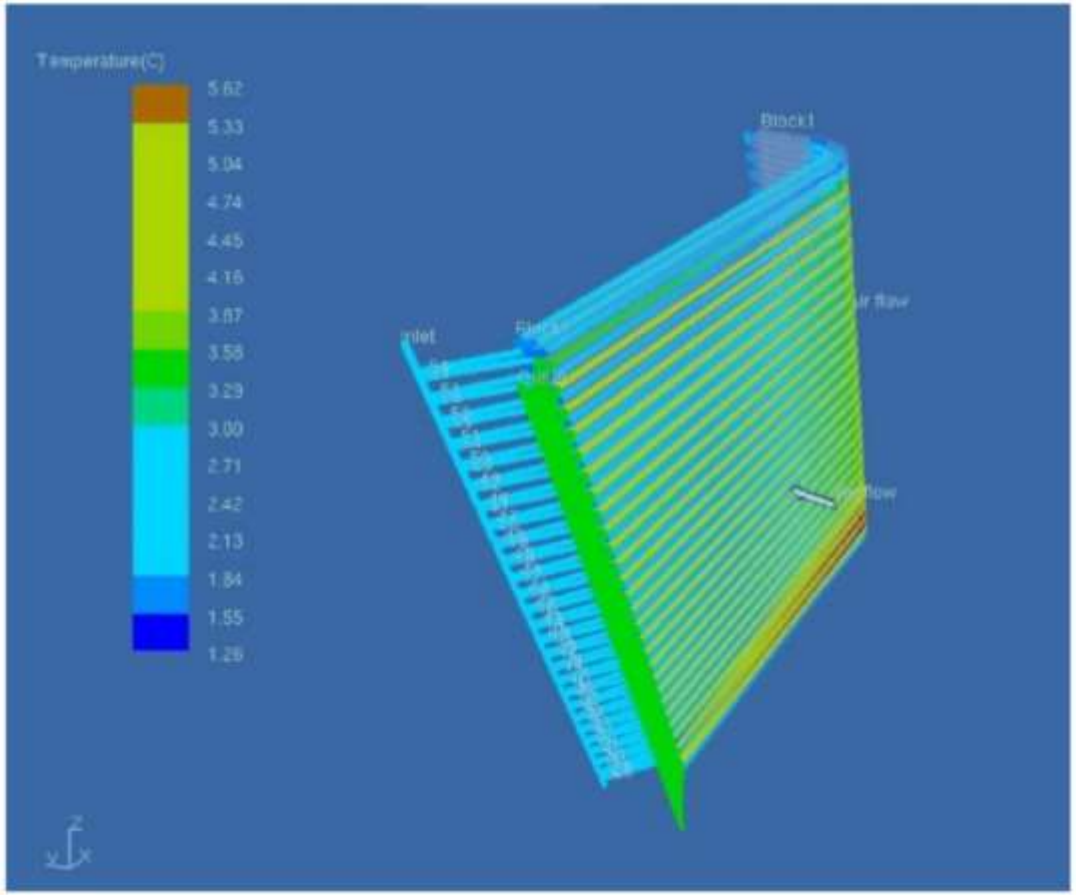
Table 5: Effects of adding half a row

	7mm Original Prototype	5mm 2 Row	5mm 2.5 Row
Heat Exchange Capacity [W]	3617	3361	3633
Refrigerant Pressure Drop [kPa]	36.6	69.0	62.9
Refrigerant Inlet Temperature [°C]	3.6	3.6	3.3
Inlet Refrigerant Dryness [kg/kg]	0.19	0.19	0.16
HX Outlet Temperature [°C]	2.7	3.5	2.9
Avg. refrigerant side htc [W/m^{2}K]	4718	7956	5907
Airside htc [W/m^{2}K]	84.5	79.4	88.2
Air flow[m^3/h]	1900	1884	1883

Test Concept

A 4 rows of 54 tubes evaporator, L-shape coil with 216 Copper tubes was simulated

Graphical results of the 4 rows evaporator temperatures, are provided by the simulation



3D simulation results with temperature map for 15 kW evaporator

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Test Concept

A test prototype of the 4-row evaporator was built

L-shape coil with 216 Copper tubes (4 rows of 54 tubes).

When tested, this coil performed as predicted by the simulation software

A larger evaporator for CCHP was then designed

Photograph of the actual evaporator on factory floor prior to brazing of the inlet and outlet distributor lines

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Variation of tube circuitry for CCHP Evaporator:

Specific for CCHP, the HX design calls for 6 rows of tubes.

Test conditions:

- 15 kW fixed capacity
- Heating water to 35°C
- Ambient air temp 7°C dry bulb 6°C wet bulb
- Evaporation temperature 2°C
- Superheat 2°K
- Air speed 2 m/s

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Table 6

Design Number	1	2	3	4	5	6
Tube Diameter (mm)	5	5	7	7	8	9.52
Rows Deep	6	6	6	6	6	6
Tubes per row	64	72	36	48	24	18
Total Tubes	384	432	216	288	144	108
Column Space (mm)	26 x	19.05 x	25 x	19.05 x	25.4 x	25.4 x
Row Space (mm)	13.8	12.7	12.5	16.5	15.87	22
Fin Density (FPI)	11	9	16	9	12	13
Fin Type	Wavy	Wavy	Wavy	Wavy	Wavy	Wavy
Simulation Results						
Pressure drop, Airside (Pa)	58	49	81	56	64	70
Pressure drop, Ref side (kPa)	4.2	2.3	2	1.3	2.9	3
Copper mass (kg)	16.32	22.8	20.99	27.3	23.74	32.71
Aluminum mass (kg)	14.92	11.66	21.36	15.88	20.35	30.55
Internal Volume (Liter)	5.66	7.67	9.23	12.1	12.1	17.6
R290 Charge	0.794	1.072	1.551	1.94	2.132	3.427
Number of circuits	32	36	18	24	24	18
Distributor tube dia (mm)	4	4	4.76 (3/16")	4.76 (3/16")	4.76 (3/16")	4.76 (3/16")
Tubes per circuit	12	12	12	12	6	6

Conclusions

Simulation software is an important tool in the design of heat exchangers

Small diameter copper tube have the following advantages in a heat exchanger:

- Lowers material weight and thus lowers cost
- Lowers refrigerant charge – suitable for R290 and others
- Lowers airside pressure drop

Research in this paper demonstrates the many advances in tube technology and simulation software that are driving breakthroughs in ASHPs and CCHPs.

HXSim simulation software can be freely obtained courtesy of the International Copper Association. See:

https://microgroove.net/hxsim

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International Copper Association
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Thank you!