# Optimization of copper-tube coils for energy-efficiency and charge reduction in heat pump water heaters

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Heat Transfer Technologies

国际铜业协会 Copper Alliance

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# Introduction

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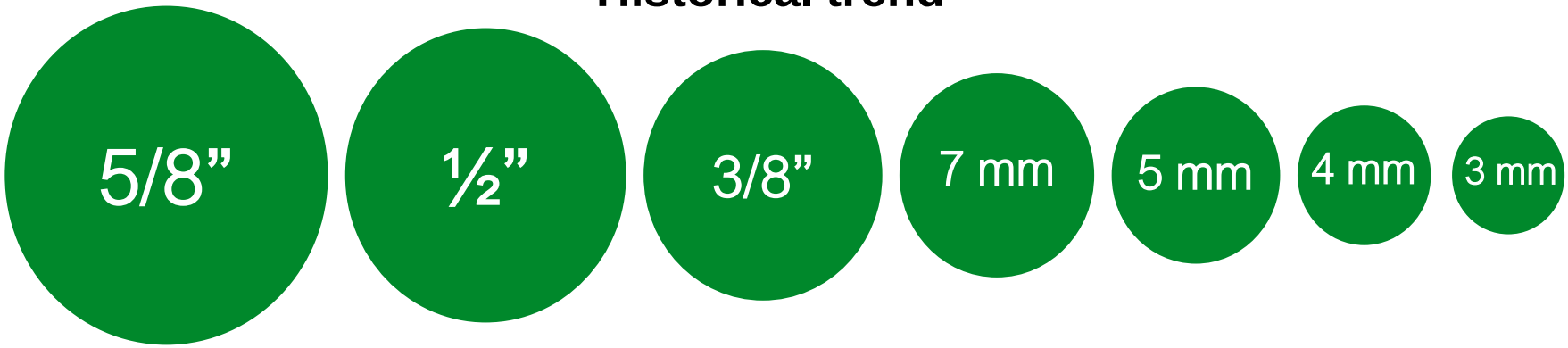
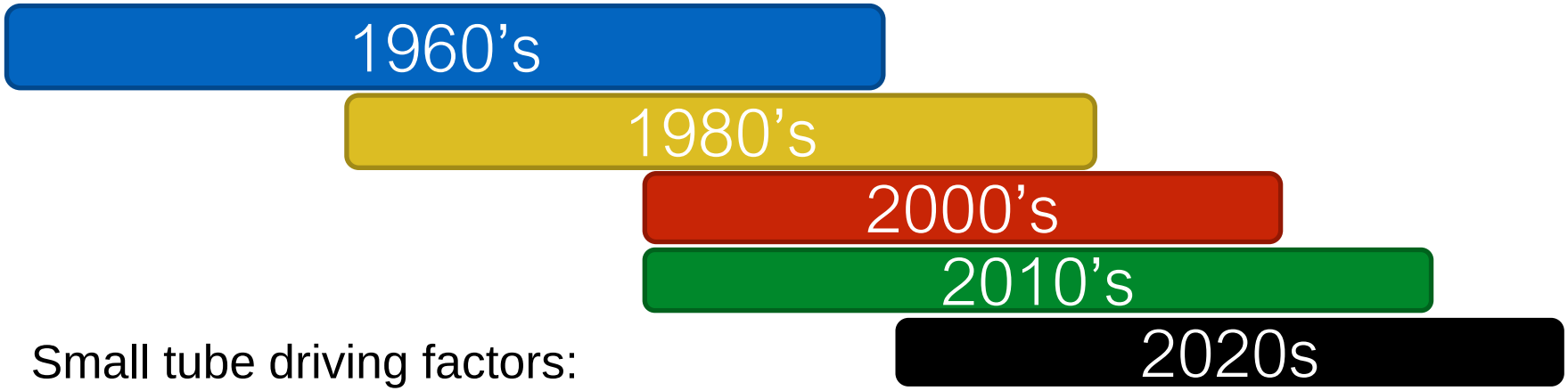
## Historical trend




Small tube driving factors:

- Higher efficiency systems
- Refrigerant changes / Charge Reduction
- Material & labor costs

# Small diameter tube advantages

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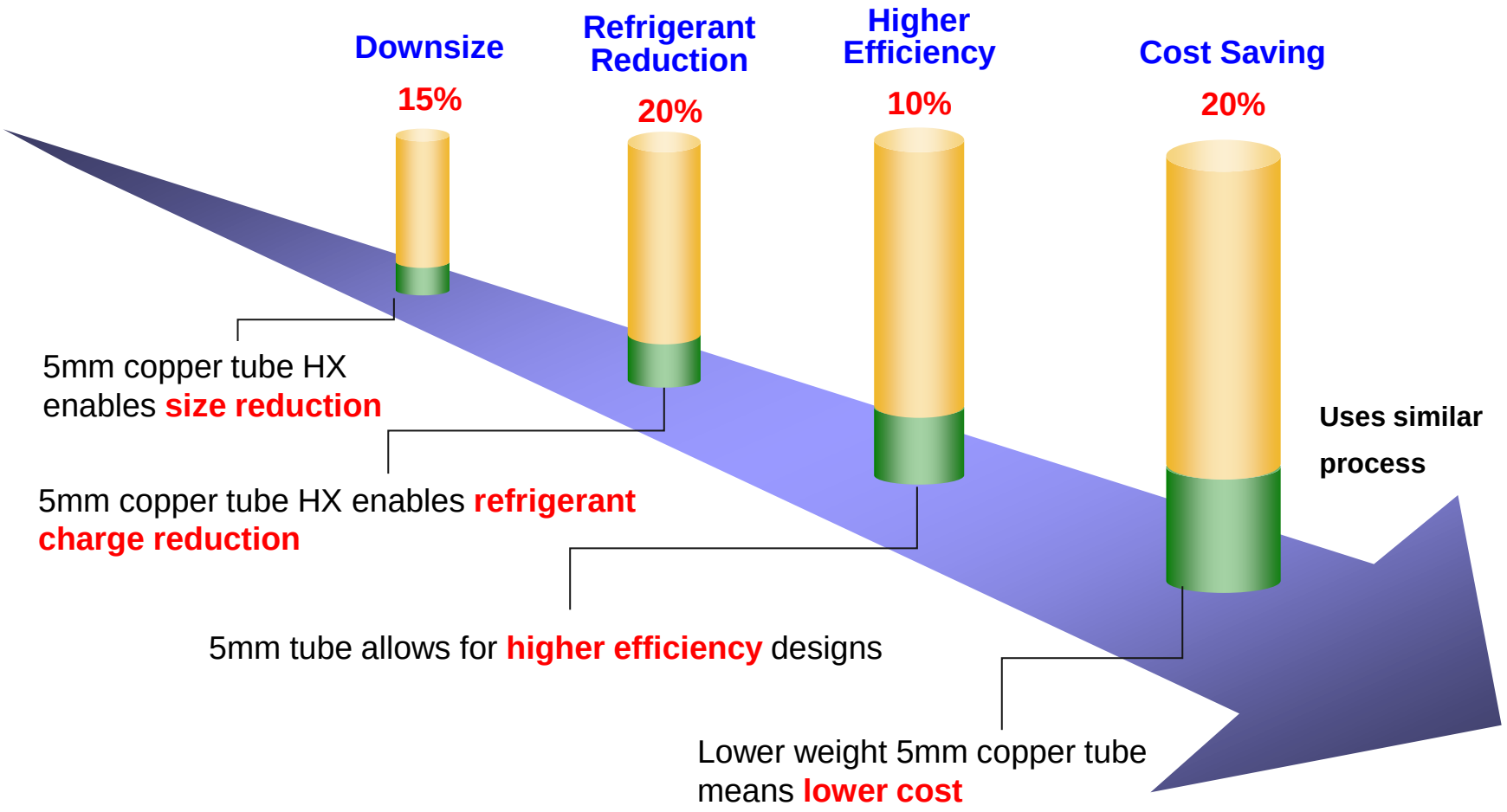

# Small diameter Copper tube applications

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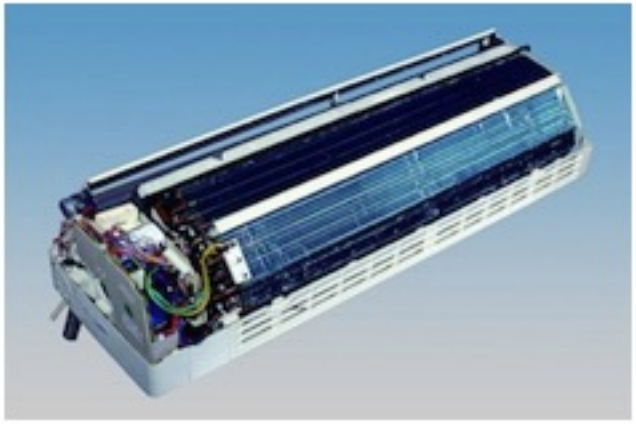
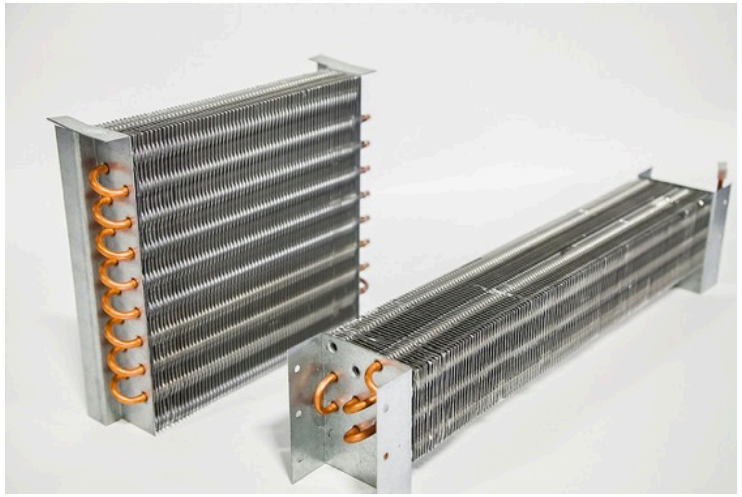
5mm OD copper tube technology used in China since 2010 for high volume AC applications



# Small diameter Copper tube HPWH

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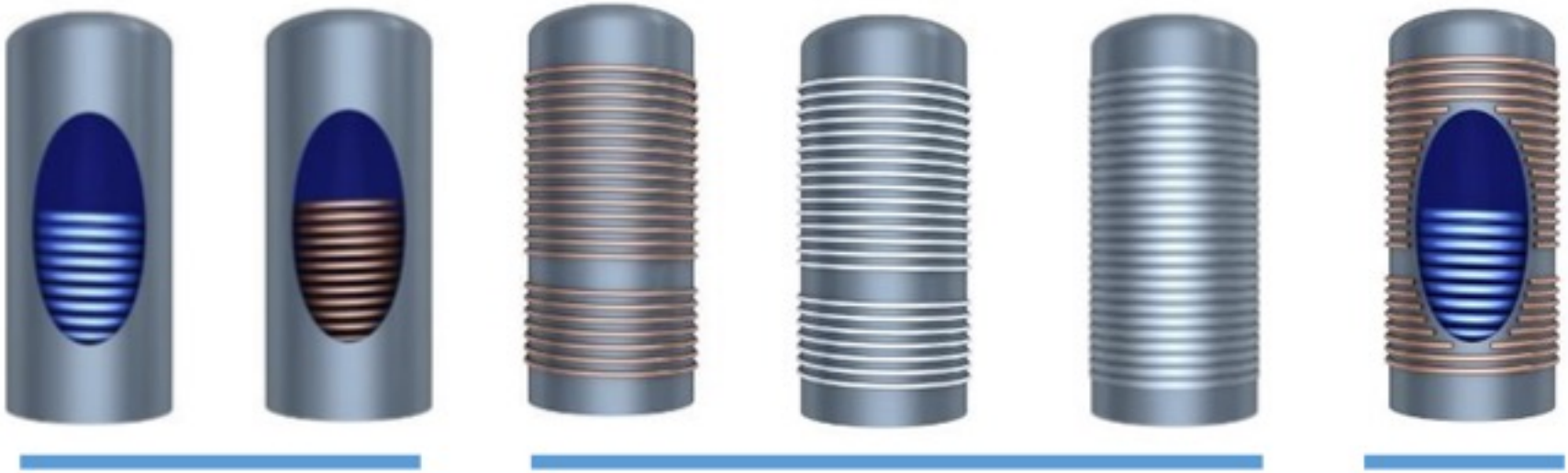

Immersion

Wrap-around

Hybrid

Optimize wrap-around designs using smaller-diameter copper tubes:

1. Location of tubes: Top, middle or bottom of tank
2. Spacing between tubes:  10mm, 15mm, 20mm
3. Copper tube diameters: 9.52mm, 7mm, 6.25mm, 5mm
4. Number of turns

# Small diameter Copper tube

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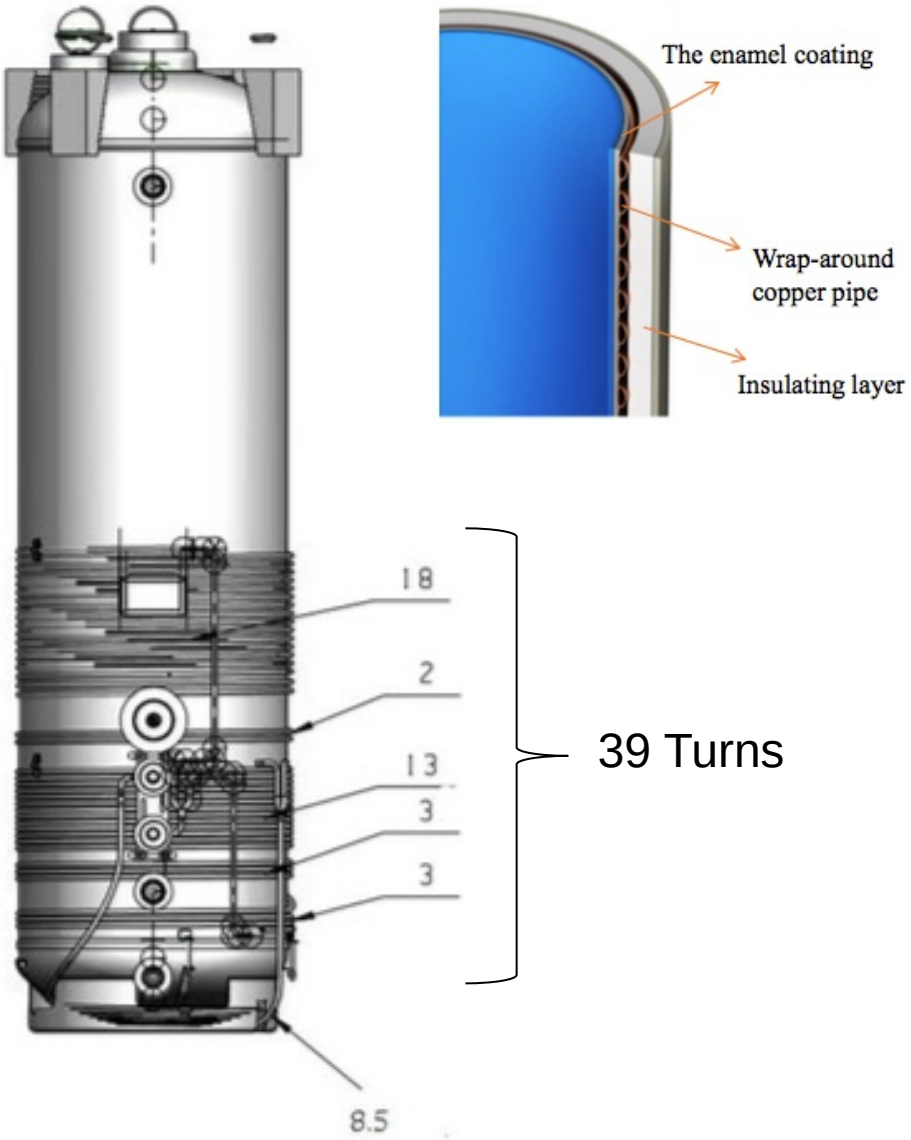
## Modeling baseline:




| Parameters | Value |
|---|---|
| Water tank capacity | 192.78 L |
| Initial water temperature | 14.77 C |
| Final water temperature | 55.33 C |
| Running time | 170.2 min |
| Power consumption | 833 W |
| Heating capacity | 3207 W |
| COP | 3.85 |
| Refrigerant | R410A |

# Small diameter Copper tube

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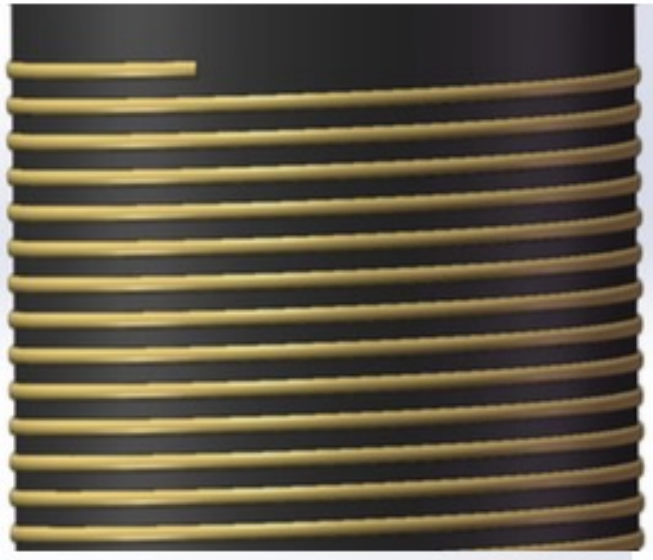
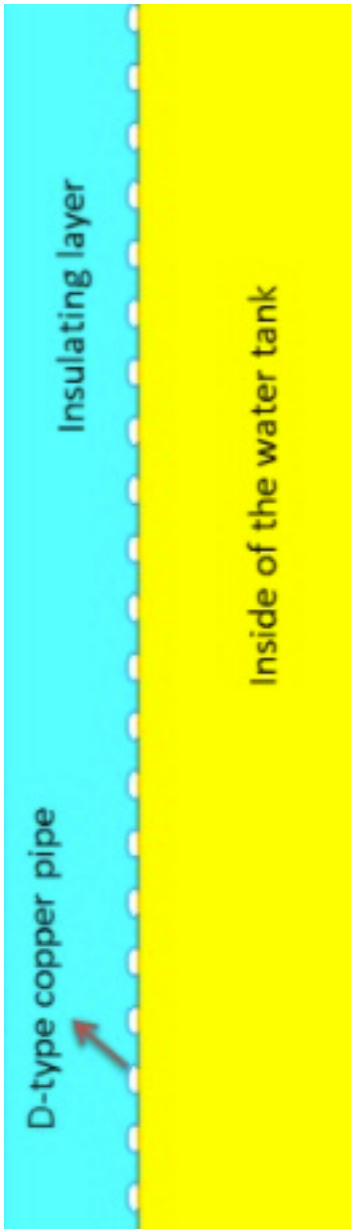
**Modeling baseline:**

Copper tube:

- D-shape
- 7mm OD
- Lateral: 39 turns
- Spacing: 10mm



- Bottom: 8.5 turns



# Small diameter Copper tube

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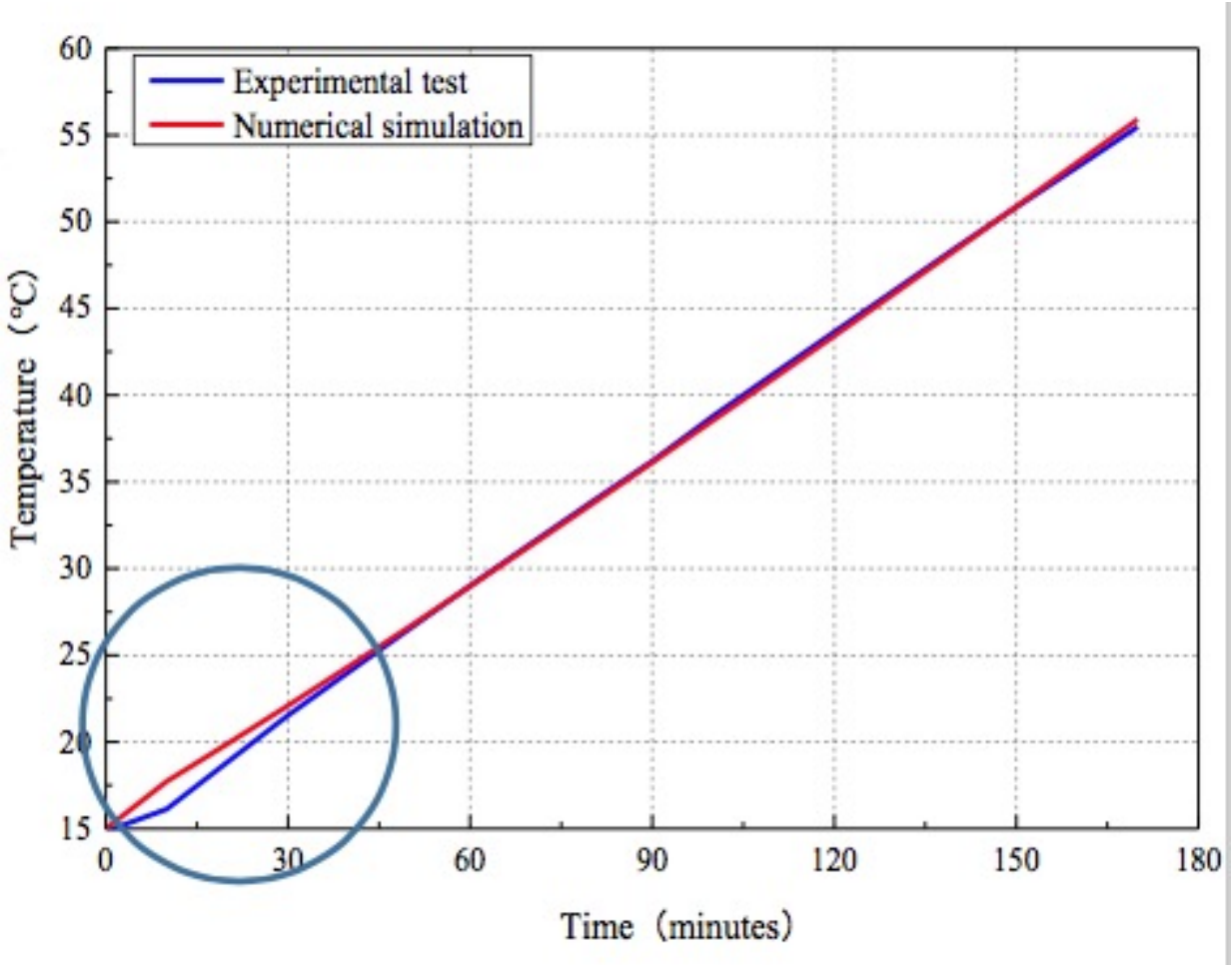
**Modeling baseline results:** Error is 1.8% up to the 45 minutes line.




**Conclusion:** Simulation equations are adequate using Solidworks, ICEM CFD and Fluent simulation software programs.

## Simulation Matrix

| | Variable parameters | Heating time (minutes) |
|---|---|---|
| **Optimize Location (7 mm, 39 Turns)** | Upper part | 203 |
| | Middle part | 176 |
| | Lower part | 167 |
| **Optimize Spacing (7 mm, 39 Turns)** | 5 mm | 179 |
| | 10 mm | 167 |
| | 15 mm | 152 |
| | 20 mm | 160 |
| **Optimize diameter 39 turns, 10 mm spacing** | ⌀5 mm | 179 |
| | ⌀7 mm | 167 |
| | ⌀9.52 mm | 155 |

## Results

| | Variable parameters | Heating time (minutes) |
|---|---|---|
| **Optimize Turns 5 mm Diameter 10 mm Spacing** | 60 turns | 165 |
| | 70 turns | 158 |
| | 80 turns | **152** |
| **Optimize Turns 7 mm Diameter 10 mm Spacing** | 31 turns | 223 |
| | 35 turns | 176 |
| | 39 turns | 167 |
| | 43 turns | 165 |

**Conclusion:**

Smaller diameter tubes with more turns results in faster heating.

# Small diameter Copper tube

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## Simulation Matrix and Results

| Fixed Parameter | Tube Diameter (mm) | Tube turns | Gross weight (kg) | Heating time (minutes) |
|---|---|---|---|---|
| 10mm Tube spacing | 9.52 | 39 | 9.06 | 155 |
| | 7 | 39 | 3.33 | 167 |
| | 5 | 39 | 1.89 | 179 |
| | 5 | 60 | 2.60 | 165 |
| | 5 | 80 | 3.28 | **152** |

**Conclusion:**

Less copper is used with 5 mm copper tube. Copper consumption is reduced by 0.73 kg for 5 mm tube with 60 turns compared to 7 mm tube with 39 turns.

# Small diameter Copper tube

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## Additional Simulation Results for 6.35 mm Tube Diameter

| Turns (#) | Spacing (mm) | Refrigerant charge (g) | COP |
|---|---|---|---|
| 35 | 20 | 900 | 3.73 |
| 35 | 20 | 850 | 3.70 |
| 35 | 15 | 900 | 3.65 |
| 35 | 15 | 850 | 3.64 |
| 35 | 10 | 850 | 3.66 |
| 43 | 15 | 1050 | **3.87** |

**Conclusion:**
COP can be increased slightly by increasing the refrigerant charge.

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## Summary of Optimization Conclusions:

Heating rate is fastest for the following:

- 5mm OD Copper coil wrapped around the lower part of the tank.
- 5mm OD Copper tube spacing from 10 mm to 15 mm.

Smaller diameter tubes transfer more heat with less materials.

- Reduced cost for the same energy efficiency.
- Improved COP with the same amount of copper, .
- As the copper tube length increases, the COP also increases.

**NEXT UP: Coil Design with HXSim 3.1**
Available at no charge for qualified designers from the International Copper Association

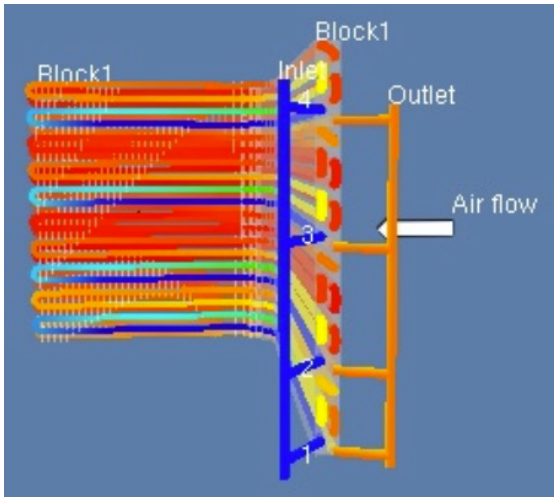
# HXSim for small diameter copper tubes

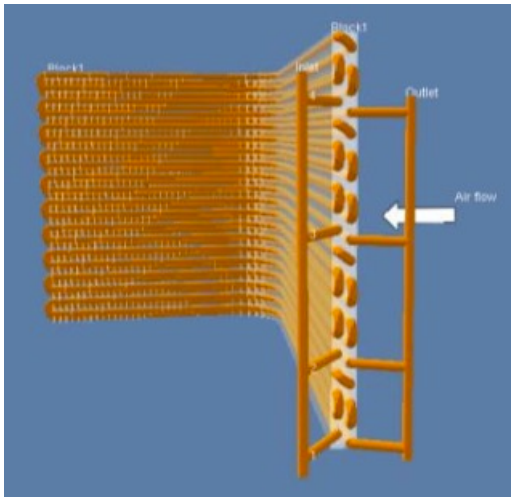
Heat Transfer Technologies

## HXSim Software

Software development supported by ICA to help manufacturers optimize designs of heat exchanger coils using smaller diameter copper tubes.

More than 200 engineers use HXSim to optimize heat exchanger designs.




Evaporator design
Blue – cold inlet

# HXSim for small diameter copper tubes

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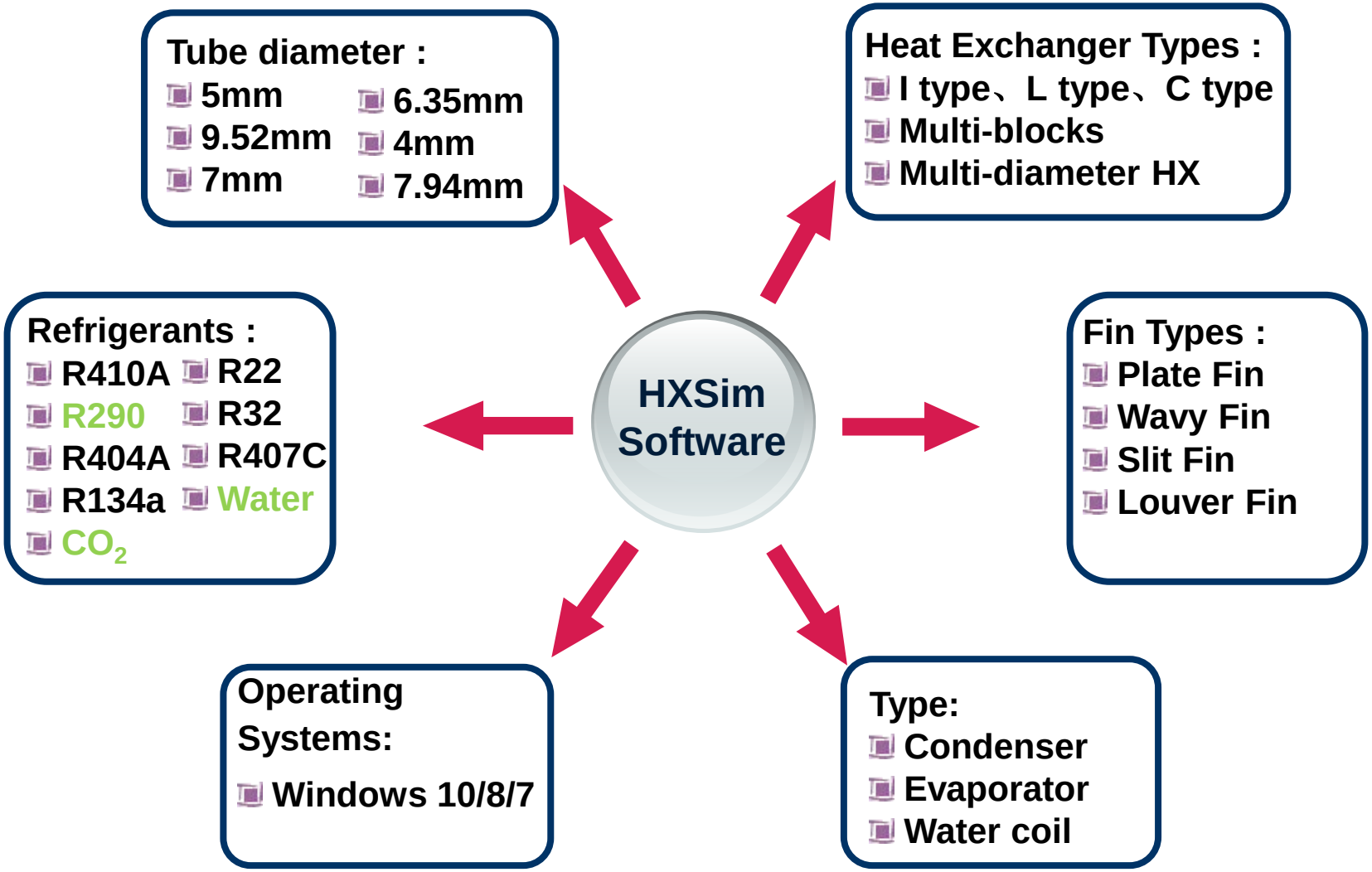
## HXSim Capabilities



# HXSim software case study

Heat Transfer Technologies

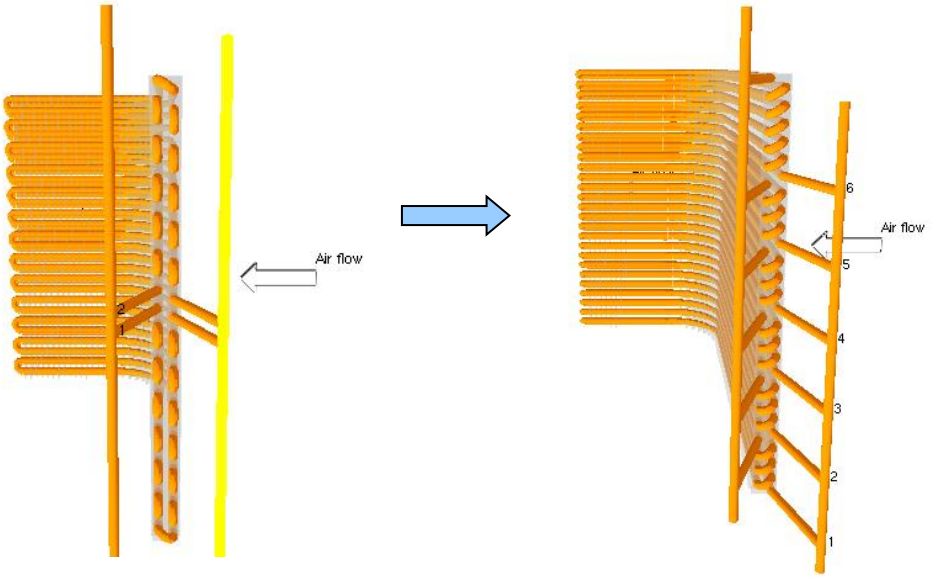
## Haier AC Example: Use HXSim to Convert 7 mm R410A condenser design to 5 mm R290 condenser design

**Original Condenser**

**7 mm OD**

**R410A**

**L-Type**




**New Design**

**5 mm OD**

**R290**

**L-Type**

Yoram Shabtay, “Heat Exchanger Simulation Tools Help to Optimize the Use of Natural Refrigerants with MicroGroove Smaller-Diameter Copper Tubes,” *2020 ATMOsphere America Virtual Conference*. Commercial Refrigeration Session, October 22, 2020.

**https://drive.google.com/file/d/1Li-gCEbm-wr7SXGUOW_3AExL8Ha0HVH4/view**

# HXSim case study summary

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## Optimization results summary:

### 7 mm R410A converted to 5 mm R290

| Tube circuitry | | Capacity [W] | Ref. Charge [g] | Ref. pd [kPa] | Ref. pd [%] | Cu [g] | Cu [%] | Ref side HTC [W/m$^2$K] |
|---|---|---|---|---|---|---|---|---|
| Original 7mm R410A condenser | 18 FPI 52 tubes | 5415 | 1030 | 24.25 | - | 1946 | - | 2243 |
| Optimized 5mm R290 condenser | 18 FPI 52 tubes | 5436 | 150 | 25.88 | +6.7% | 1484 | -23.7% | 4330 |

Tabular or graphical simulation output provides useful results including cost comparisons for tube and fin materials.

# HXSim simulation examples

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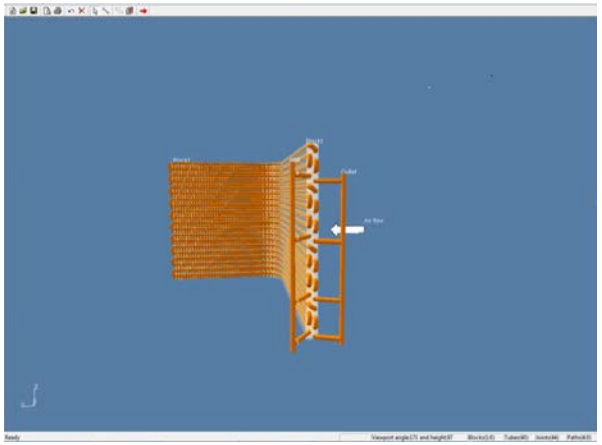
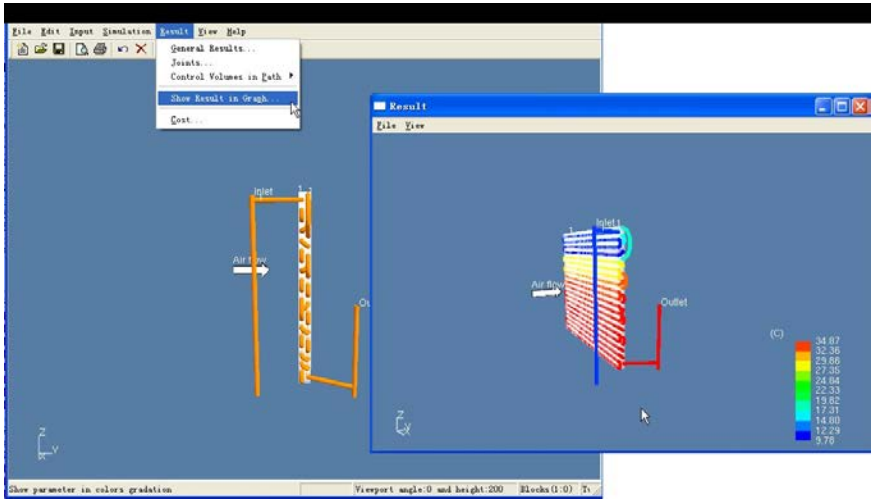
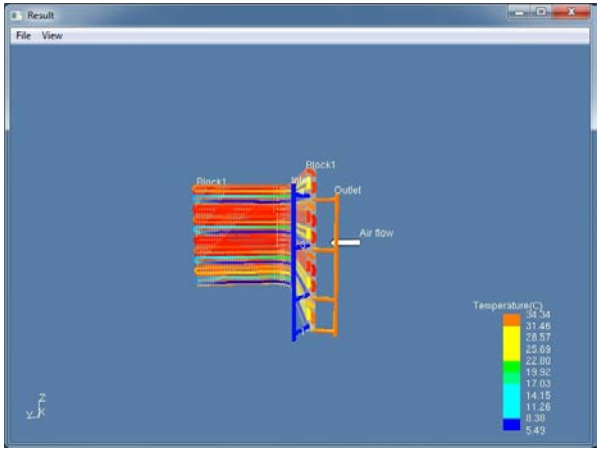
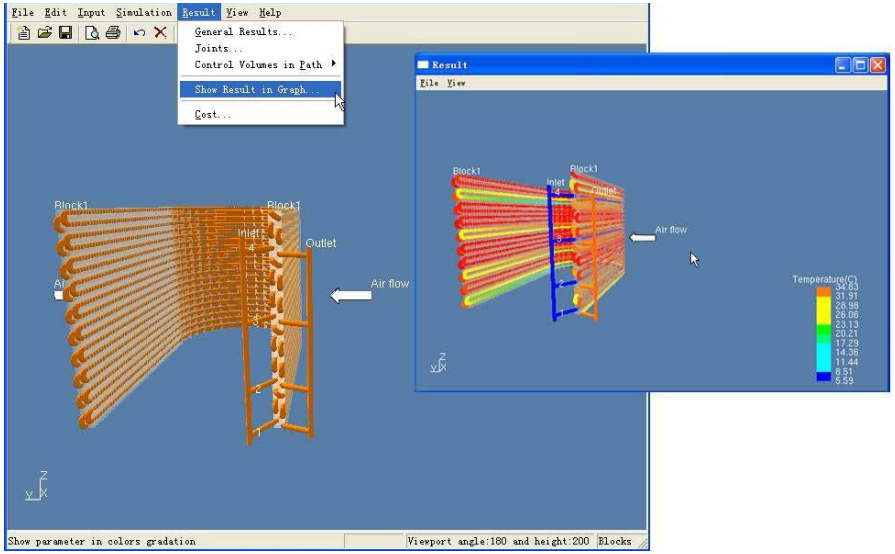




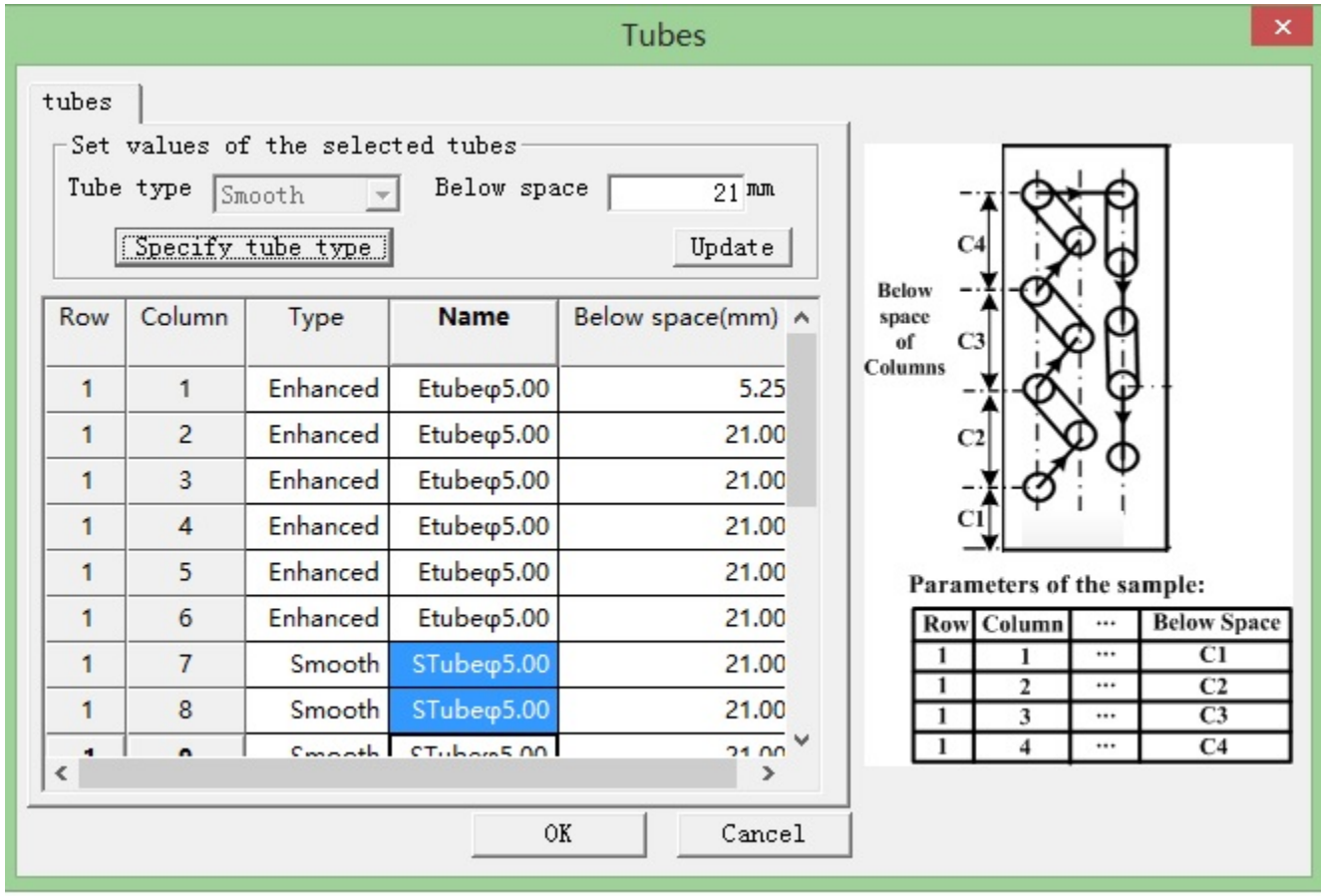




L-Type Block:
Design (*top*)
Result (*bottom*)

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

# 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

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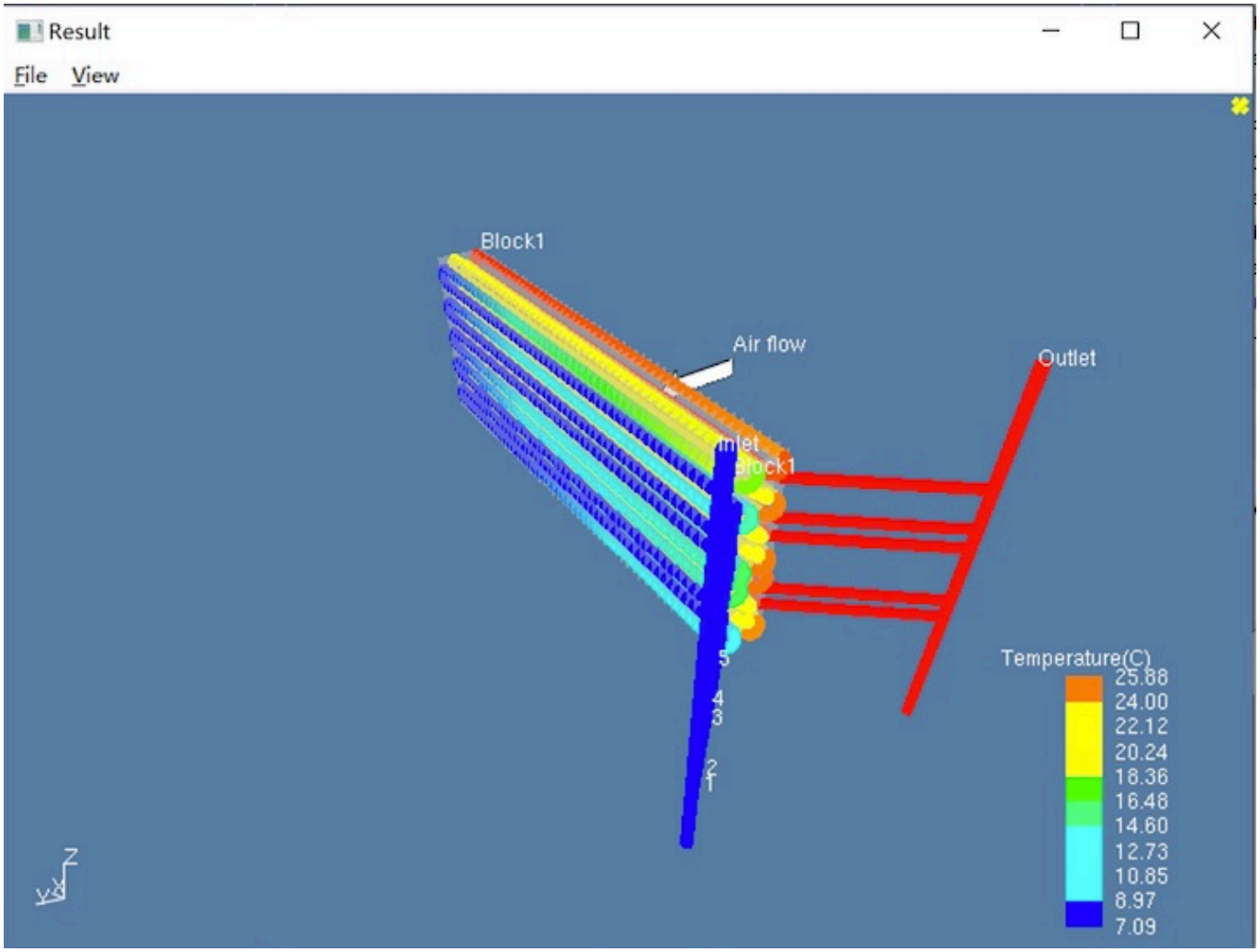
**HPWH Evaporator design example:** Blue – cold inlet



## Conclusions:

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Small diameter copper tube offers many advantages and options.

HXSim Software is offered at no charge to qualified heat exchanger designers, courtesy of ICA
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 microgroove.net 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.

...Much more on www.microgroove.net

Thank you!

# HXSim simulation results: R410A

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| COIL SIDE | | | |
|---|---|---|---|
| Fin Type | Corrugated | Utilized Tubes | 52 |
| Fin Material | Aluminum | Non Utilized Tubes | 0 |
| Fin Spacing [mm] | 1.40 | Circuits | 2 |
| Fin Thinkness [mm] | 0.105 | Tubes Per Circuit | 26.00 |
| Tube Type | Grooved | Coil Length [mm] | 803.95 |
| Tube Material | Copper | Coil Depth [mm] | 33.00 |
| Tube Dimension [mm] | 7.00*0.23*0.10 | Coil Height [mm] | 495.30 |
| Holes | 26 | Outer Area [m2] | 17.752 |
| Rows | 2 | Inner Area [m2] | 0.886 |
| Tube Vertical Space [mm] | 19.05 | Coil Face Area [m2] | 0.41 |
| Tube Horizontal Space [mm] | 16.50 | Inner Volume [L] | 1.449 |
| Header In [mm] | 9.5 | Header Out [mm] | 9.5 |

| AIR SIDE | | REFRIGERANT SIDE | |
|---|---|---|---|
| Air Inlet DB. Temp. [¡ãC] | 35.0 | Refrigerant → | R410A |
| Relative Humidity % | 40.3 | Discharge Superheat [¡ãC] | 35.89 |
| Air Outlet DB. Temp. [¡ãC] | 44.0 | Condenser Temp.[¡ãC] | 49.11 |
| Relative Humidity % | 24.8 | Subcooling [¡ãC] | 4.99 |
| Air Flow [m3/h] | 1889.5 | Mass Flow [kg/h] | 95.0 |
| Air Mass Flow [kg/h] | 2426.9 | Pressure Drop [kPa] | 24.257 |
| Frontal Velocity [m/s] | 1.3 | Outlet Pressure [kPa] | 2966.900 |
| Air Pressure Drop [Pa] | 22.6 | Ref. Charge [kg] → | 1.03 |
| Atmospheric Pressure [kPa] | 101.3 | Ref. Side H.T.C. [W/m2*K] → | 2243.808 |
| Air Side H.T.C. [W/m2*K] | 76.780 | | |

| CAPACITY | |
|---|---|
| Total Capacity [kW] | 5.415 |

# HXSim Simulation results: R290

Heat Transfer Technologies

| COIL SIDE | | | |
|---|---|---|---|
| Fin Type | Corrugated | Utilized Tubes | 52 |
| Fin Material | Aluminum | Non Utilized Tubes | 0 |
| Fin Spacing [mm] | 1.40 | Circuits | 6 |
| Fin Thinkness [mm] | 0.105 | Tubes Per Circuit | 8.67 |
| Tube Type | Grooved | Coil Length [mm] | 803.95 |
| Tube Material | Copper | Coil Depth [mm] | 33.00 |
| Tube Dimension [mm] | 5.00*0.25*0.15 | Coil Height [mm] | 495.30 |
| Holes | 26 | Outer Area [m2] | 18.900 |
| Rows | 2 | Inner Area [m2] | 0.610 |
| Tube Vertical Space [mm] | 19.05 | Coil Face Area [m2] | 0.41 |
| Tube Horizontal Space [mm] | 16.50 | Inner Volume [L] | 0.686 |
| Header In [mm] | 9.5 | Header Out [mm] | 9.5 |

| AIR SIDE | | REFRIGERANT SIDE | |
|---|---|---|---|
| Air Inlet DB. Temp. [¡ãC] | 35.0 | Refrigerant | R290 |
| Relative Humidity % | 40.3 | Discharge Superheat [¡ãC] | 36.00 |
| Air Outlet DB. Temp. [¡ãC] | 44.1 | Condenser Temp.[¡ãC] | 49.00 |
| Relative Humidity % | 24.8 | Subcooling [¡ãC] | 3.60 |
| Air Flow [m3/h] | 1903.0 | Mass Flow [kg/h] | 51.0 |
| Air Mass Flow [kg/h] | 2444.2 | Pressure Drop [kPa] | 25.882 |
| Frontal Velocity [m/s] | 1.3 | Outlet Pressure [kPa] | 1652.609 |
| Air Pressure Drop [Pa] | 21.0 | Ref. Charge [kg] | 0.15 |
| Atmospheric Pressure [kPa] | 101.3 | Ref. Side H.T.C. [W/m2*K] | 4330.452 |
| Air Side H.T.C. [W/m2*K] | 72.750 | | |

| CAPACITY | |
|---|---|
| Total Capacity [kW] | 5.436 |