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Thermal performance comparison between fan-coils using compact air-water HEX based on finned or metal foam surfaces

nanofancoil

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OUTLINE

- The commercial fan coil ESTRO F4
- Metal foam HEX description
- Test rig
- Thermal power exchanged with metal foam HEX
- Results in terms of HTC and fin-efficiency values obtained with metal foam
- Conclusions

Partners:

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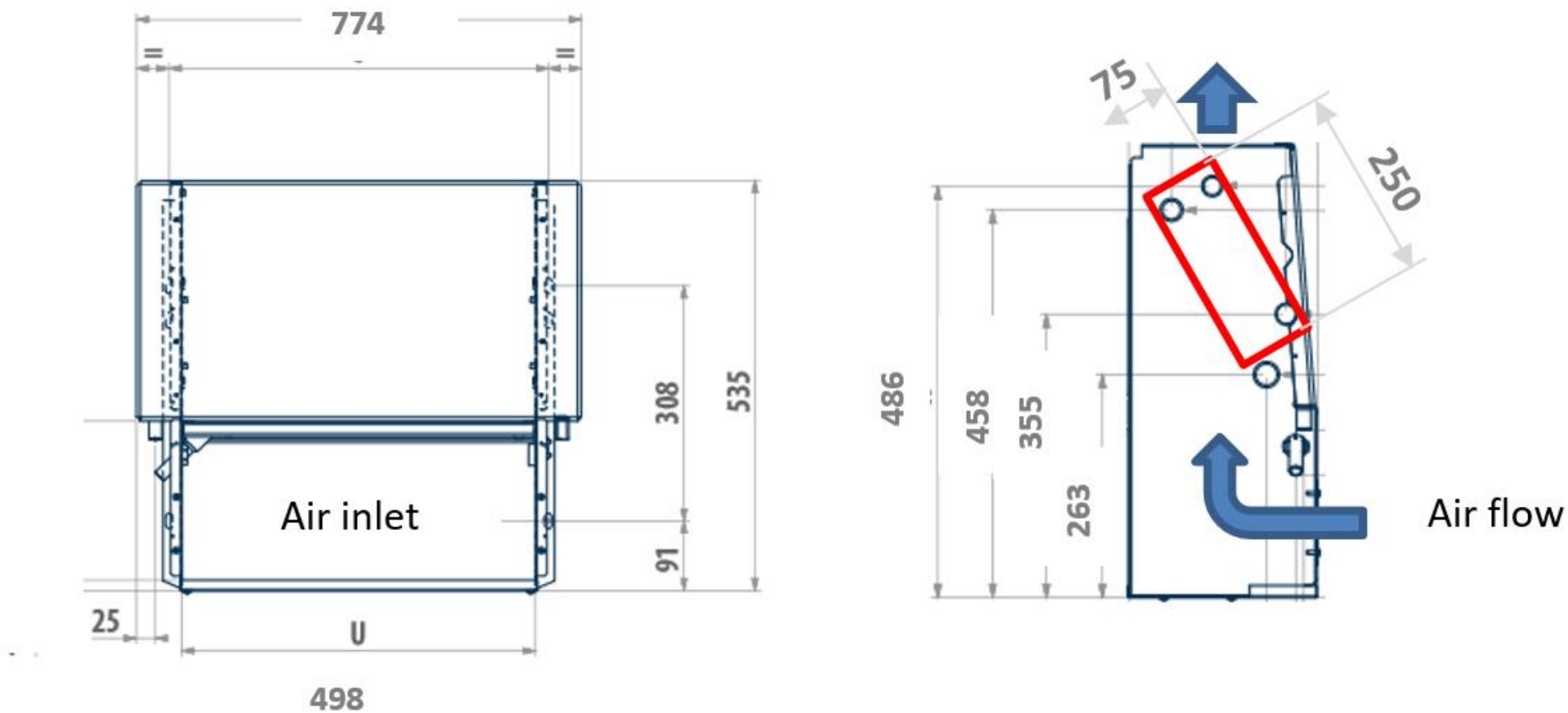
ESTRO F4



- Double-suction centrifugal fan in ABS
- 3-speed version
- HEX with copper tubes coupled to aluminium fins

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ESTRO F4 HEX

Main characteristics of the reference heat exchanger.

	Size [mm]	N_T	D [mm]	A_b [m^2]	N_f	p_f [mm]	t_f [mm]	A_{fin} [m^2]	a_{sv} [m^2/m^3]
Ref. HEX	75x250x340	30	9.53	0.3052	198	1.6	0.12	6.579	1162

Number of tubes (3 rows) and diameter

Number of fins, pitch, thickness

Surface-to-volume ratio

Experimental test on pressure drop/air flow rate

- Air flow rate: 200 – 350 m^3/h
- Air frontal velocity: 0.5 - 2 m/s
- Maximum pressure drop: 30 Pa

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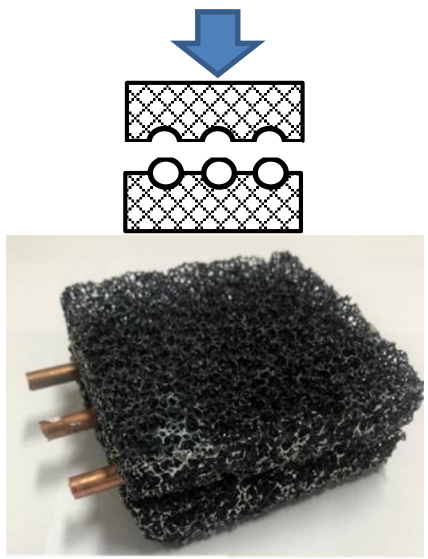
METAL FOAM

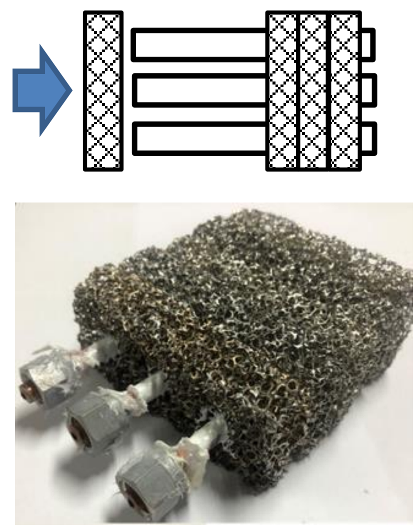
Main characteristics of the metal foam				
	Porosity φ [%] Declared/measured	PPI Declared/measured	a_{SV} $[m^2/m^3]$	d/t [mm]
AL-10-96	96/96.6	10/8-11	440	2.55/0.47

SANDWICH (S)



(a)

KEBAB (K)



(b)

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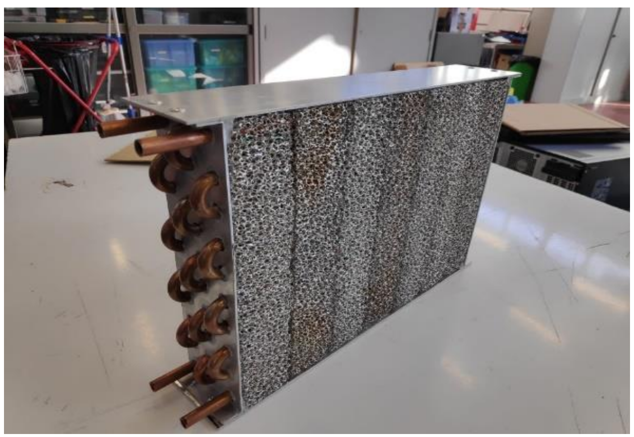
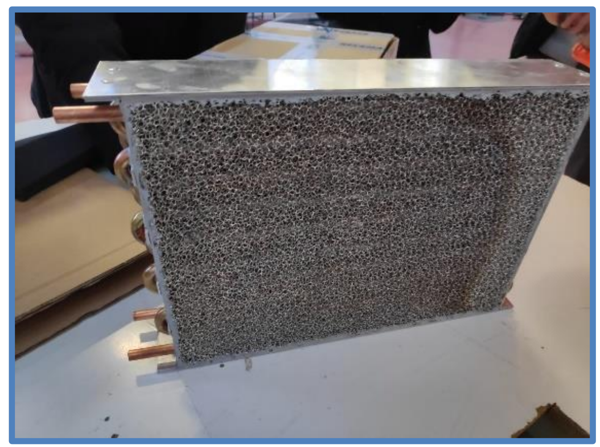
Main characteristics of the samples				
Name	H [mm]	A_f [m^2]	Foam-tubes coupling	Thermal conductive grease [W/mK]
S(AL-10-96)(p)	75	0.085	Sandwich	3.4
K(AL-10-96)(p)	75	0.085	Kebab	3.4
S(AL-10-96)(p2)	75	0.085	Sandwich	1.4 (glue)



K(AL-10-96)(p)



S(AL-10-96)(p)

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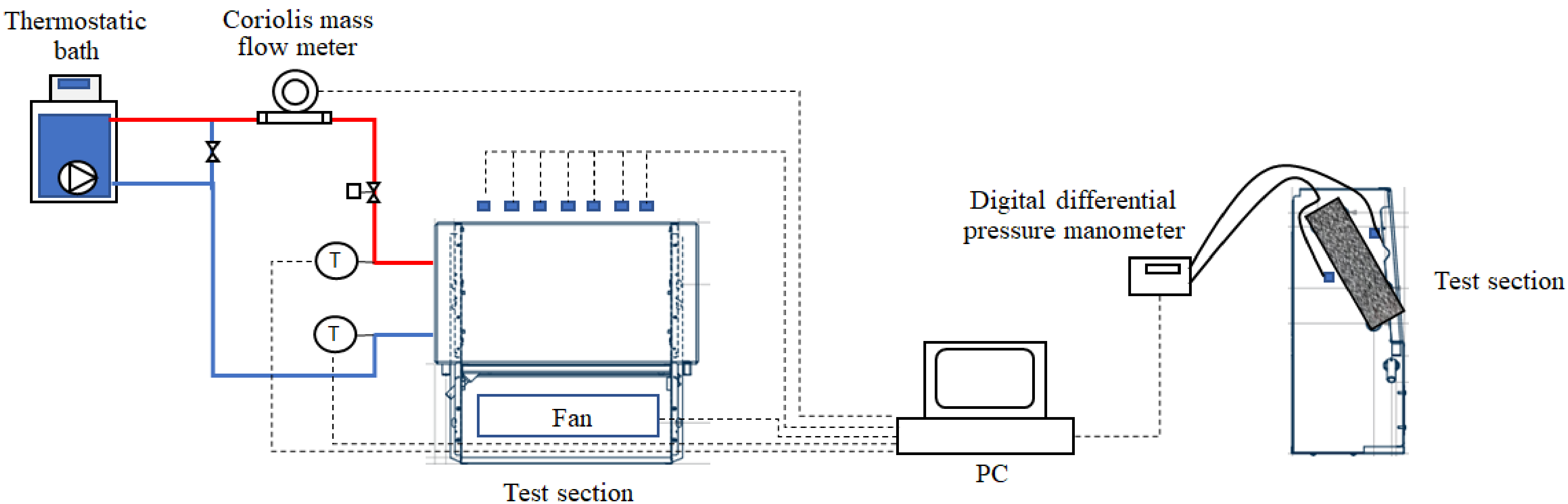
Test rig for thermal tests



Characteristics and uncertainties of the measurement instruments		
Instrument	Range	Uncertainty
TSI, VelociCalc® Plus mod. 8386A	0-50 m/s	±0.15 m/s FS
TSI, DP-Calc™ mod. 8710	0-3735 Pa	±2% FS
Coriolis mass flow meter	0-150 kg/s	±0.4% reading
Thermocouple (K-type)	0-100°C	±0.4 K

Data reduction method

Thermal power exchanged between air and water:

$$\Phi = \dot{m}_w c_{p,w} \left(T_{w,in} - T_{w,out}\right)$$

The average heat transfer coefficient:

$$HTC^* = \frac{\Phi}{A_b \Delta T_{\max}} = \frac{\Phi}{A_b \left(T_{w,in} - T_{a,in}\right)}$$

Following the fin theory one can express the thermal power as follows:

$$\Phi = HTC_0 A_b \left(1 + \eta \alpha_{SV} \left(\frac{A_f H}{A_b} - \frac{D}{4}\right)\right) \Delta T_{\max} = HTC_0 A_b \left(1 + \eta \beta\right) \Delta T_{\max}$$

where β represents the increase of the surface in contact with the air flow

with respect to A_b. In this case $\beta = 21.5$

Data reduction method

HTC_0 can be estimated by using the Zukauskas correlation:

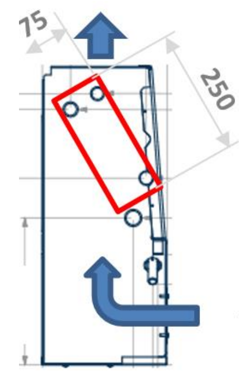
$$Nu_D = \frac{HTC_0 D}{k_a} = C_1 \,\mathrm{Re}_{D,\max}^{n} \,\mathrm{Pr}^{0.36}$$

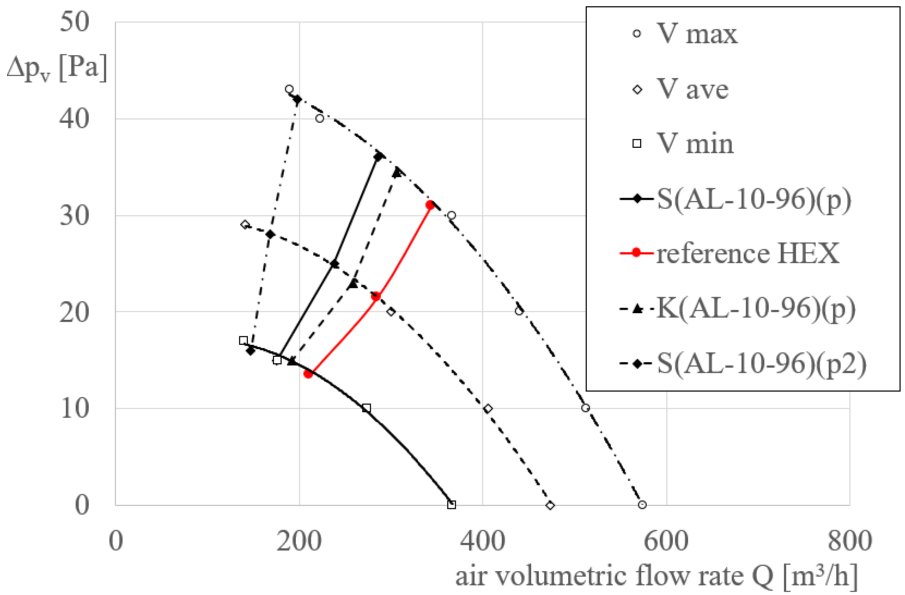
In this case, Reynolds is lower than 1000, C_1 is equal to 0.52 (three rows in-line) and *n* is assumed equal to 0.5. Reynolds is calculated by considering the maximum velocity occurring within the bank of tubes:

$$V_{\max} = \frac{A_f}{A_{f,\min}} V$$

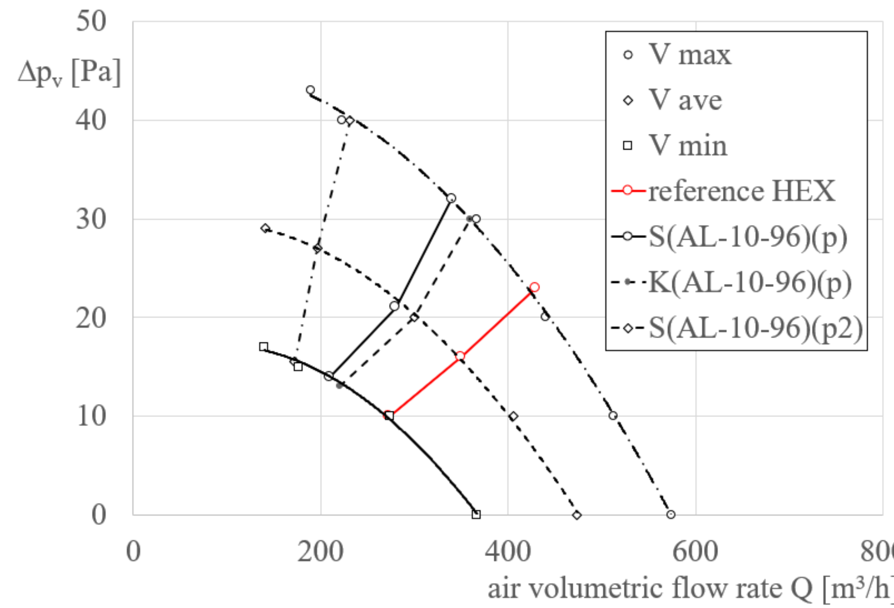
Air flow rate and pressure drop:

Effect of the HEX tilt





Tilted HEX (30°)



Perpendicular air flow

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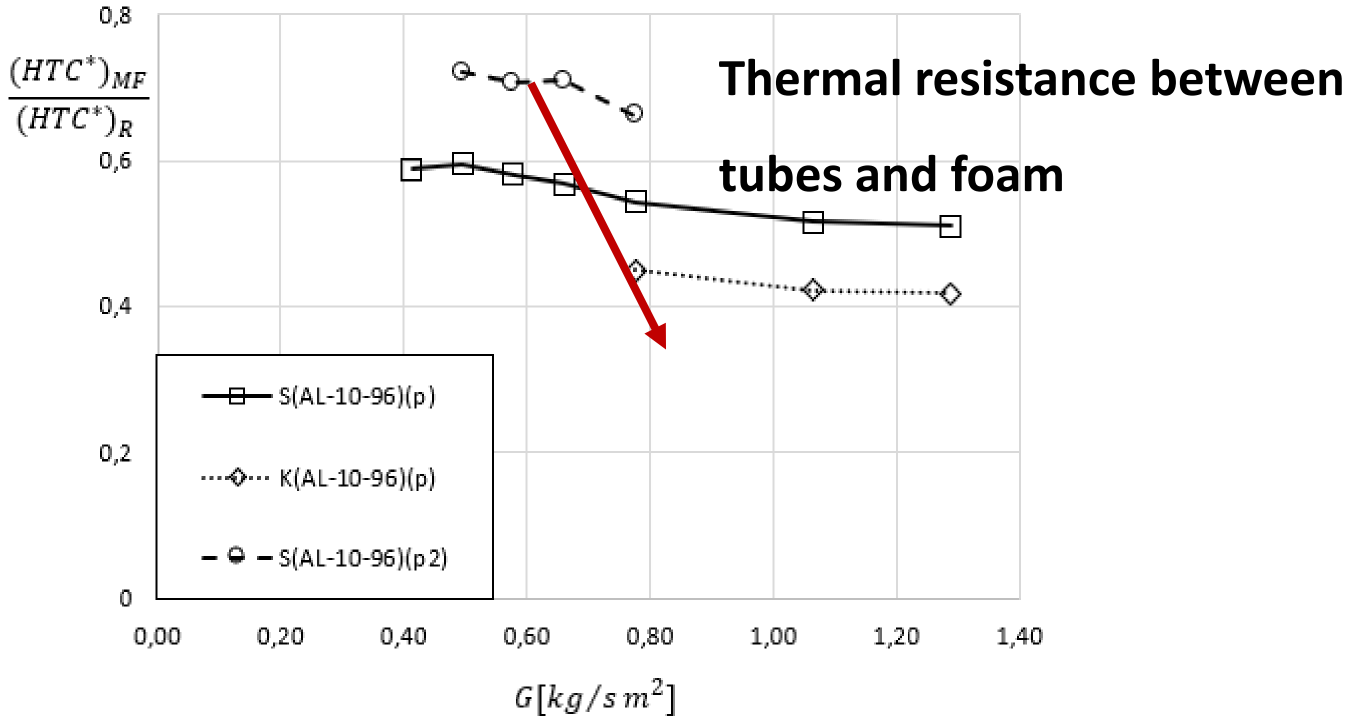
Thermal performances

Thermal power [W] exchanged in correspondence of the fan speeds (m_w=84 kg/h, $T_{w,in}$=45°C, $T_{a,in}$=22°C).							
Fan speed	Ref HEX	S(AL-10-96)(p)	Δ (%)	K(AL-10-96)(p)	Δ (%)	S(AL-10-96)(p2)	Δ (%)
rpm_{min}	1178	590	**-50.0**	501	**-57.5**	664	**-43.6**
rpm_{ave}	1313	637	**-51.5**	548	**-58.3**	695	**-47.1**
rpm_{max}	1409	672	**-52.3**	570	**-59.5**	727	**-48.4**

Metal foam HEX are not able to guarantee the same thermal performances of conventional HEX:

- Lower surface-to-volume ratio of metal foam HEX: the air-side heat transfer area is 2.8 m^2 versus 7.4 m^2 (ref HEX)
- Large contact thermal resistance (small spot-contacts)

HTC



- With metal foam the HTC is strongly reduced by the presence of the thermal resistance between tubes and foam.
- Glue with high thermal conductivity is able to reduce the thermal resistance

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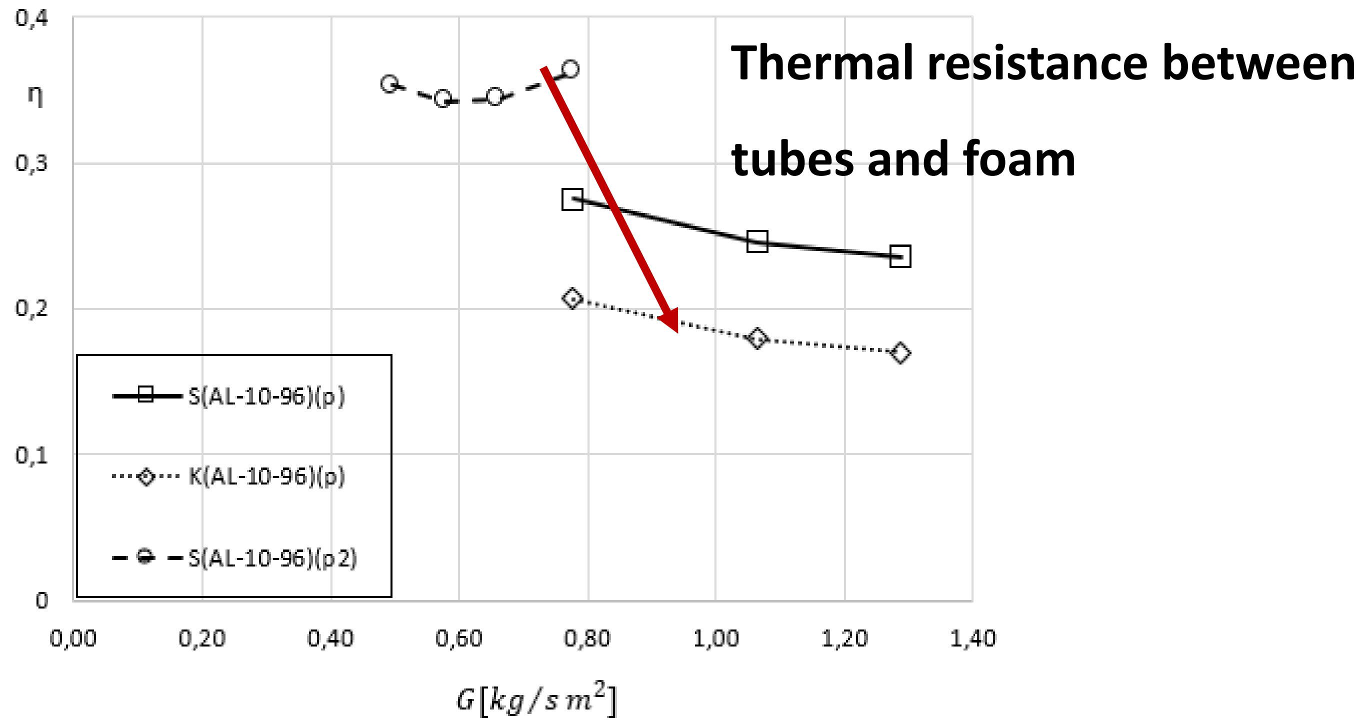
Fin-equivalent Efficiency



- The values of η are from 0.15 to 0.35 for HEXs considered in these exp runs.
- The low values of η highlight that metal foam is not correctly exploited as extended surface under the conditions considered here.

Conclusions

- **Metal foam HEX is less influenced by HEX tilt**
- **Large porosity** values are responsible of **low surface-to-volume ratio** of the foam which reduces the capability of the porous medium to transfer heat efficiently.
- **Large contact thermal resistance** between foam and tubes is responsible of the low efficiency of metal foams used as extended surfaces in air-side applications.
- The replacement of conventional air-water HEXs with metal foam can be suggested only in presence of **low air flow rates** and
  low contact thermal resistances between foam and tubes.

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Some new result

Brazed metal foams on rectangular mini-channels

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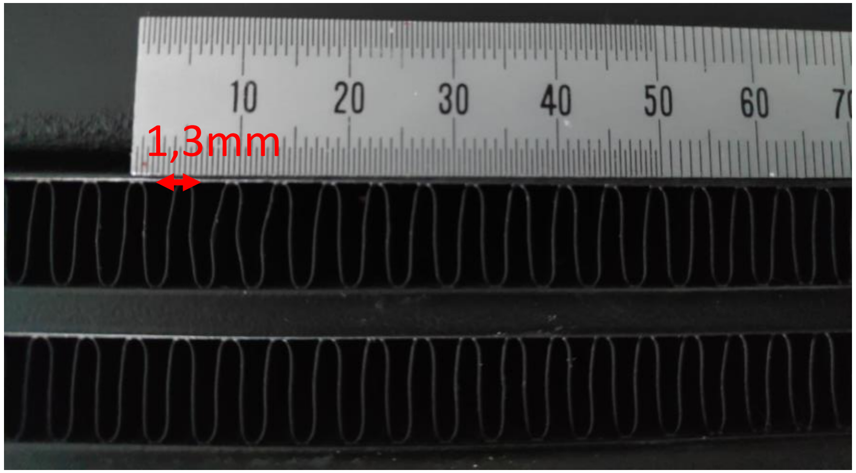
COMPARISON BETWEEN FINNED HEAT SINK AND METAL FOAM HEAT SINK

Finned heat sink

$$\frac{S}{V} = \frac{2 \cdot (800 \cdot 45)mm}{(174 \cdot 10 \cdot 45)mm} = 919\,\frac{m^2}{m^3}$$

$$\frac{Contact\ surface\ fin{-}channel}{total\ ext\ channel\ surface} = 30\%$$



Metal foam heat sink

$$\frac{S}{V} = 440\,\frac{m^2}{m^3}\ \text{(Al-10PPI-96\%)}$$

$$\frac{Contact\ surface\ fin\ -channel}{total\ ext\ channel\ surface} = 4\%$$

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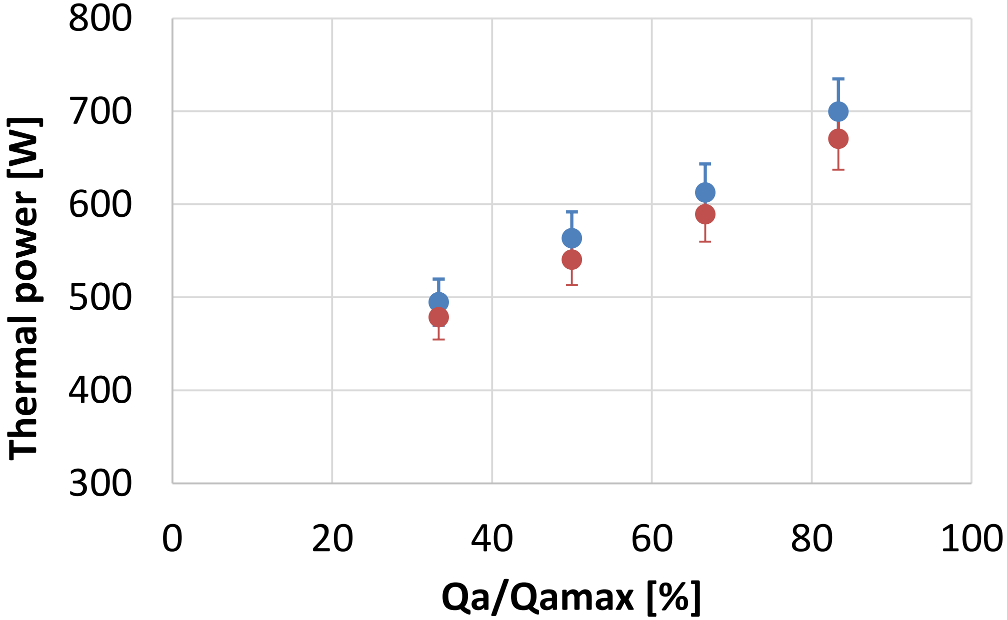
COMPARISON BETWEEN FINNED HEAT SINK AND METAL FOAM HEAT SINK

T room = 25°C

Tw,IN=45°C

$\dot{m}_w$=70 kg/h



Error bar: 5%

Qa/Qa max	Thermal power Reference finned HS	Thermal power Metal foam HS	Δ
%	W	W	%
83.3	700	671	**4.2**
66.7	613	589	**3.8**
50.0	564	541	**4.1**
33.3	495	479	**3.3**

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